



This electronic version (PDF) was scanned by the International Telecommunication Union (ITU) Library & Archives Service from an original paper document in the ITU Library & Archives collections.

La présente version électronique (PDF) a été numérisée par le Service de la bibliothèque et des archives de l'Union internationale des télécommunications (UIT) à partir d'un document papier original des collections de ce service.

Esta versión electrónica (PDF) ha sido escaneada por el Servicio de Biblioteca y Archivos de la Unión Internacional de Telecomunicaciones (UIT) a partir de un documento impreso original de las colecciones del Servicio de Biblioteca y Archivos de la UIT.

(ITU) للاتصالات الدولي الاتحاد في والمحفوظات المكتبة قسم أجراه الضوئي بالمسح تصوير نتاج (PDF) الإلكترونية النسخة هذه والمحفوظات المكتبة قسم في المتوفرة الوثائق ضمن أصلية ورقية وثيقة من نقلًا.

此电子版（PDF版本）由国际电信联盟（ITU）图书馆和档案室利用存于该处的纸质文件扫描提供。

Настоящий электронный вариант (PDF) был подготовлен в библиотечно-архивной службе Международного союза электросвязи путем сканирования исходного документа в бумажной форме из библиотечно-архивной службы МСЭ.



INTERNATIONAL TELECOMMUNICATION UNION

CCIR

INTERNATIONAL
RADIO CONSULTATIVE
COMMITTEE

RECOMMENDATIONS AND REPORTS OF THE CCIR, 1982

(ALSO QUESTIONS, STUDY PROGRAMMES,
RESOLUTIONS, OPINIONS AND DECISIONS)

XVth PLENARY ASSEMBLY
GENEVA, 1982

VOLUME IX — PART 1

FIXED SERVICE USING RADIO-RELAY SYSTEMS



Geneva, 1982



INTERNATIONAL TELECOMMUNICATION UNION

CCIR

INTERNATIONAL
RADIO CONSULTATIVE
COMMITTEE

RECOMMENDATIONS AND REPORTS OF THE CCIR, 1982

(ALSO QUESTIONS, STUDY PROGRAMMES,
RESOLUTIONS, OPINIONS AND DECISIONS)

XVth PLENARY ASSEMBLY
GENEVA, 1982

VOLUME IX — PART 1

FIXED SERVICE USING RADIO-RELAY SYSTEMS



Geneva, 1982

ISBN 92-61-01471-2

**PLAN OF VOLUMES I TO XIV
XVTH PLENARY ASSEMBLY OF THE CCIR**

(Geneva, 1982)

VOLUME I	Spectrum utilization and monitoring.
VOLUME II	Space research and radioastronomy.
VOLUME III	Fixed service at frequencies below about 30 MHz.
VOLUME IV-1	Fixed-satellite service.
VOLUME IV/IX-2	Frequency sharing and coordination between systems in the fixed-satellite service and radio-relay systems.
VOLUME V	Propagation in non-ionized media.
VOLUME VI	Propagation in ionized media.
VOLUME VII	Standard frequencies and time signals.
VOLUME VIII	Mobile services.
VOLUME IX-1	Fixed service using radio-relay systems.
VOLUME X-1	Broadcasting service (sound).
VOLUME X/XI-2	Broadcasting-satellite service (sound and television).
VOLUME XI-1	Broadcasting service (television).
VOLUME XII	Transmission of sound broadcasting and television signals over long distances (CMTT).
VOLUME XIII	Vocabulary (CMV).
VOLUME XIV-1	Information concerning the XVth Plenary Assembly: Minutes of the Plenary Sessions. Administrative texts. Structure of the CCIR. Lists of CCIR texts.
VOLUME XIV-2	Alphabetical index of technical terms appearing in Volumes I to XIII.

All references within the texts to CCIR Recommendations, Reports, Resolutions, Opinions, Decisions, Questions and Study Programmes refer to the 1982 edition, unless otherwise noted; i.e., only the basic number is shown.

DISTRIBUTION OF TEXTS OF THE XVTH PLENARY ASSEMBLY OF THE CCIR IN VOLUMES I TO XIV

Volumes I to XIV, XVth Plenary Assembly, contain all the valid texts of the CCIR and succeed those of the XIVth Plenary Assembly, Kyoto, 1978.

1. Recommendations, Reports, Resolutions, Opinions, Decisions

1.1 Numbering of these texts

Recommendations, Reports, Resolutions and Opinions are numbered according to the system in force since the Xth Plenary Assembly.

In conformity with the decisions of the XIth Plenary Assembly, when one of these texts is modified, it retains its number to which is added a dash and a figure indicating how many revisions have been made. For example: Recommendation 253 indicates the original text is still current; Recommendation 253-1 indicates that the current text has been once modified from the original. Recommendation 253-2 indicates that there have been two successive modifications of the original text, and so on. Within the text of Recommendations, Reports, Resolutions, Opinions and Decisions, however, reference is made only to the basic number (for example Recommendation 253). Such a reference should be interpreted as a reference to the latest version of the text, unless otherwise indicated.

The tables which follow show only the original numbering of the current texts, without any indication of successive modifications that may have occurred. For further information about this numbering scheme, please refer to Volume XIV-1.

1.2 Recommendations

Number	Volume	Number	Volume	Number	Volume
48, 49	X-1	374-376	VII	485, 486	VII
80	X-1	377-379	I	487-494	VIII
100	I	380-393	IX-1	496	VIII
106	III	395-405	IX-1	497	IX-1
139, 140	X-1	406	IV/IX-2	498, 499	X-1
162	III	407-412	X-1	500, 501	XI-1
182	I	414-416	X-1	502-505	XII
205	X-1	417, 418	XI-1	508	I
214-216	X-1	419	XI-1	509-511	II
218, 219	VIII	422, 423	VIII	513-517	II
239	I	428	VIII	518-520	III
240	III	430, 431	XIII	521-524	IV-1
246	III	433	I	525-530	V
257	VIII	434, 435	VI	531-534	VI
265, 266	XI-1	436	III	535-538	VII
268	IX-1	439	VIII	539-550	VIII
270	IX-1	441	VIII	552-554	VIII
275, 276	IX-1	443	I	555-557	IX-1
283	IX-1	444	IX-1	558	IV-1
290	IX-1	445	I	559-564	X-1
302	IX-1	446	IV-1	565	XI-1
305, 306	IX-1	447	X-1	566	X/XI-2
310, 311	V	450	X-1	567-572	XII
313	VI	452, 453	V	573, 574	XIII
314	II	454-456	III	575	I
326-329	I	457, 458	VII	576-578	II
331, 332	I	460	VII	579, 580	IV-1
335, 336	III	461	XIII	581	V
337	I	463	IX-1	582, 583	VII
338, 339	III	464-466	IV-1	584-591	VIII
341	V	467, 468	X-1	592-596	IX-1
342-349	III	469-472	XI-1	597-599	X-1
352-354	IV-1	473, 474	XII	600	X/XI-2
355-359	IV/IX-2	475, 476	VIII	601, 602	XI-1
362-364	II	478	VIII	603-606	XII
367	II	479	II	607, 608	XIII
368-370	V	480	III		
371-373	VI	481-484	IV-1		

IV

1.3 Reports

Number	Volume	Number	Volume	Number	Volume
19	III	363, 364	VII	581	VIII
32	X-1	368, 369	I	584, 585	VIII
93	VIII	371, 372	I	587-589	VIII
106, 107	III	374-376	IX-1	599	VIII
109	III	378-380	IX-1	607	IX-1
111	III	382	IV/IX-2	610	IX-1
122	XI-1	383-385	IV-1	612-615	IX-1
137	IX-1	386-388	IV/IX-2	616, 617	X-1
176, 177	III	390, 391	IV-1	619, 620	X-1
179	I	393	IV/IX-2	622	X-1
181	I	395, 396	II	623	XII
183	III	401	X-1	624-626	XI-1
184	I	404, 405	XI-1	628, 629	XI-1
195	III	409	XI-1	630	XI-1
196	I	411, 412	XII	631-634	X/XI-2
197	III	419, 420	I	635-637	XII
200, 201	III	422	I	639	XII
203	III	430-432	VI	642, 643	XII
204-208	IV-1	434-437	III	646-648	XII
209	IV/IX-2	439	VII	651-668	I
212	IV-1	443-445	IX-1	670, 671	I
214	IV-1	448, 449	IV/IX-2	672-685	II
215	X/XI-2	451	IV-1	687, 688	II
222	II	453-455	IV-1	690	II
224	II	456	II	692-697	II
226	II	457, 458	X-1	699, 700	II
227-229	V	461	X-1	701-705	III
236	V	463-465	X-1	706-713	IV-1
238, 239	V	468	X-1	714-724	V
249-251	VI	468	XI-1	725-729	VI
252	VI(1)	469	XI-1	730-732	VII
253-255	VI	472	X-1	735-738	VII
258-260	VI	473	X/XI-2	739-749	VIII
262, 263	VI	476-478	XI-1	751, 752	VIII
265, 266	VI	481-485	XI-1	754	VIII
267	VII	488	XII	758	VIII
270, 271	VII	491	XII	760-775	VIII
272, 273	I	493	XII	778	VIII
275-280	I	496, 497	XII	779-789	IX-1
284-289	IX-1	499-501	VIII	790-793	IV/IX-2
292, 293	X-1	509	VIII	794-800	X-1
294	XI-1	516	X-1	801-806	XI-1
299-304	X-1	518	VII	807-812	X/XI-2
306	XI-1	519-526	I	814	X/XI-2
311-313	XI-1	528	I	815-823	XII
314	XII	530	I	825-842	I
319	VIII	532-534	I	843-854	II
322	VI(1)	535, 536	II	855-865	III
324-326	I	538-541	II	866-875	IV-1
327	III	542	VIII	876, 877	IV/IX-2
329	III	543-546	II	878-885	V
336	V	548	II	886-895	VI
338	V	549-551	III	896-898	VII
340	VI(1)	552-561	IV-1	899-929	VIII
342	VI	562-565	V	930-942	IX-1
345	III	567	V	943-950	X-1
347	III	569	V	951-955	X/XI-2
349	III	571	VI	956-964	XI-1
352-357	III	574, 575	VI	965-970	XII
358	VIII	576-580	VII	971	XIII

(1) Published separately.

1.3.1 Note concerning Reports

The individual footnote "Adopted unanimously" has been dropped from each Report. Reports in this volume have been adopted unanimously except in cases where reservations have been made which will appear as individual footnotes.

1.4 Resolutions

Number	Volume	Number	Volume	Number	Volume
4	VI	39	XIV-1	71	I
14	VII	44	I	72, 73	V
15	I	61	XIV-1	74, 75	VI
20	VIII	62	I	76	X-1
23	XIII	63	VI	77	XIV-1
24	XIV-1	64	X-1	78	XIII
26, 27	XIV-1	66	XIII	79-87	XIV-1
33	XIV-1	67-70	XIV-1		

1.5 Opinions

Number	Volume	Number	Volume	Number	Volume
2	I	41	XII	64	I
11	I	42, 43	VIII	65	XIV-1
13, 14	IX-1	45, 46	VI	66	III
15, 16	X-1	49	VIII	67-69	VI
22, 23	VI	50	IX-1	70-72	VII
26-28	VII	51	X-1	73	VIII
32	I	56	IV-1	74	X-1
35	I	59	X-1	75	XI-1
38	XI-1	60	XI-1	76	XIII
40	XI-1	61-63	XIV-1	77-81	XIV-1

1.6 Decisions

Number	Volume	Number	Volume	Number	Volume
2	IV-1	28, 29	VII	47-49	VIII
3-5	V	32	VIII	50	V
6	VI	33	XI-1	51	X/XI-2
9-11	VI	36	VI	52	X-1
18	XII	39-40	X-1	53, 54	I
19	XIII	41, 42	XI-1	55	IX-1
21	VI	43, 44	X/XI-2	56	I
27	I	45	III		

1.6.1 Note concerning Decisions

Since Decisions were adopted by Study Groups, use was made of the expression “Study Group..., Considering” and the expression “Unanimously decides”, replaced by “Decides”.

2. Questions and Study Programmes

2.1 Text numbering

2.1.1 Questions

Questions are numbered in a different series for each Study Group: where applicable a dash and a figure added after the number of the Question indicate successive modifications. The number of a Question is completed by an *Arabic figure indicating the relevant Study Group*. For example:

- Question 1/10 would indicate a Question of Study Group 10 with its text in the original state;
- Question 1-1/10 would indicate a Question of Study Group 10, whose text has been once modified from the original: Question 1-2/10 would be a Question of Study Group 10, whose text has had two successive modifications.

2.1.2 *Study Programmes*

Study Programmes are numbered to indicate the Question from which they are derived if any, the number being completed by a capital letter which is used to distinguish several Study Programmes which derive from the same Question. The part of the Study Programme number which indicates the Question from which it is derived makes no mention of any possible revision of that Question, but refers to the current text of the Question as printed in this Volume.

Examples:

- Study Programme 1A/10, which would indicate that the current text is the original version of the text of the first Study Programme deriving from Question 1/10;
- Study Programme 1C/10, which would indicate that the current text is the original version of the text of the third Study Programme deriving from Question 1/10;
- Study Programme 1A-1/10, would indicate that the current text has been once modified from the original, and that it is the first Study Programme of those deriving from Question 1/10.

It should be noted that a Study Programme may be adopted without it having been derived from a Question; in such a case it is simply given a sequential number analogous to those of other Study Programmes of the Study Group, except that on reference to the list of relevant Questions it will be found that no Question exists corresponding to that number.

References to Questions and Study Programmes within the text are made to the basic number as well as for other CCIR texts.

2.2 *Arrangement of Questions and Study Programmes*

The plan shown on page II indicates the Volume in which the texts of each Study Group are to be found, and so reference to this information will enable the text of any desired Question or Study Programme to be located.

VOLUME IX

FIXED SERVICE USING RADIO-RELAY SYSTEMS

(Study Group 9)

TABLE OF CONTENTS

	Page
Plan of Volumes I to XIV, XVth Plenary Assembly of the CCIR	II
Distribution of texts of the XVth Plenary Assembly of the CCIR in Volumes I to XIV	III
Table of contents	VII
Index of texts deleted	XV
Numerical index of texts	XVII
Index of the texts published in other Volumes but containing information of interest to the fixed service using radio-relay systems	XIX
Characteristics of radio-relay systems specified in CCIR Recommendations	XXIV
Terms of reference of Study Group 9 and Introduction by the Chairman of Study Group 9	XXV

Section 9T – Terminology

Rec. 592	Vocabulary	1

Section 9A – Performance objectives and propagation effects

Rec. 390-4	Definitions of terms and references concerning hypothetical reference circuits and hypothetical reference digital paths for radio-relay systems	3
Rec. 391	Hypothetical reference circuit for radio-relay systems for telephony using frequency-division multiplex with a capacity of 12 to 60 telephone channels	5
Rec. 392	Hypothetical reference circuit for radio-relay systems for telephony using frequency-division multiplex with a capacity of more than 60 telephone channels	6
Rec. 393-4	Allowable noise power in the hypothetical reference circuit for radio-relay systems for telephony using frequency-division multiplex	8
Rec. 395-2	Noise in the radio portion of circuits to be established over real radio-relay links for FDM telephony	10
Report 288-2	Noise in circuits forming part of very long telephone connections set up over radio-relay systems for telephony using frequency-division multiplex	12
Rec. 396-1	Hypothetical reference circuit for trans-horizon radio-relay systems for telephony using frequency-division multiplex	14
Rec. 397-3	Allowable noise power in the hypothetical reference circuit of trans-horizon radio-relay systems for telephony using frequency-division multiplex	15
Rec. 593	Noise in real circuits of multi-channel trans-horizon FM radio-relay systems of less than 2500 km	16
Rec. 555	Permissible noise in the hypothetical reference circuit of radio-relay systems for television	16
Report 375-3	Noise objectives for sound-programme circuits 2500 km long provided by means of analogue radio-relay systems	18
Rec. 556	Hypothetical reference digital path for radio-relay systems for telephony; systems with a capacity above the second hierarchical level	20
Rec. 594	Allowable bit error ratios at the output of the hypothetical reference digital path for radio-relay systems for telephony	23
Report 930	Performance objectives for digital radio-relay systems	24

VIII

		Page
Report 779	Interference in digital radio-relay systems with coherent PSK modulation	27
Report 780-1	Considerations of interference between FDM-FM radio-relay systems	42
Report 931	Study of the effects of co-channel interference in the TV channels of FM radio-relay systems	50
Report 784-1	Effects of propagation on the design and operation of line-of-sight radio-relay systems	53
Report 285-5	Propagation effects on the design and operation of trans-horizon radio-relay systems	63
Rec. 557	Availability objective for a hypothetical reference circuit and a hypothetical reference digital path	72
Report 445-2	Availability and reliability of radio-relay systems	74
Report 932	Protection of radio-relay stations against lightning discharges	88

Section 9B – Radio-frequency channel arrangements and spectrum utilization

Rec. 283-4	Radio-frequency channel arrangement for analogue radio-relay systems with a capacity of 60, 120, 300 and up to 960 telephone channels or low and medium capacity digital systems of equivalent RF bandwidth operating in the 2 GHz band	99
Report 933	Radio-frequency channel arrangement for analogue radio-relay systems with a capacity up to 300 telephone-type channels or digital systems of equivalent RF bandwidth operating in the 2.3 to 2.5 GHz band	101
Rec. 382-3	Radio-frequency channel arrangements for radio-relay systems for television and telephony for 600 to 1800 telephone channels, or the equivalent, operating in the 2 and 4 GHz bands or for medium-capacity digital radio-relay systems operating in the 4 GHz band	103
Report 934	Radio-frequency channel arrangements for high and medium-high capacity digital radio-relay systems operating in the frequency bands below about 10 GHz	106
Report 935	Frequency channel arrangements based on a homogeneous pattern for digital radio-relay systems with a capacity of up to 200 Mbit/s in the 4 GHz band	115
Rec. 383-2	Radio-frequency channel arrangements, for systems having a capacity of 1800 telephone channels, or the equivalent, operating in the 6 GHz band	117
Rec. 384-3	Radio-frequency channel arrangements for analogue radio-relay systems with a capacity of 2700 telephone channels or up to 1260 telephone channels, or the equivalent, and digital radio-relay systems with a capacity of the order of 140 Mbit/s, operating in the 6 GHz band	119
Report 287-4	Analogue radio-relay systems of capacity greater than 1800 telephone channels, or their equivalent	122
Report 781-1	Radio-relay systems for telephony using single-sideband amplitude modulation (SSB-AM)	123
Rec. 385-2	Radio-frequency channel arrangements for 60, 120 and 300-channel radio-relay systems for telephony using frequency-division multiplex and operating in the 7 GHz band	128
Rec. 386-2	Radio-frequency channel arrangements for systems with a capacity of 960 telephone channels, or the equivalent, operating in the 8 GHz band	129
Rec. 387-3	Radio-frequency channel arrangements for analogue television and telephony radio-relay systems with a capacity of 600 to 1800 telephone channels, or the equivalent, or low and medium-capacity digital systems of equivalent bandwidth, operating in the 11 GHz band	132
Rec. 389-2	Preferred characteristics of auxiliary radio-relay systems operating in the 2, 4, 6 or 11 GHz bands	135

Report 782-1	Radio-frequency channel arrangements for high-capacity digital systems in the 10.7 to 11.7 GHz frequency band	138
Report 607-2	Radio-frequency channel arrangements for radio-relay systems in the ranges 10.5 to 10.68 GHz and 11.7 to 15.35 GHz	146
Rec. 497-2	Radio-frequency channel arrangements for analogue radio-relay systems for television and FDM telephony with a capacity of 960 telephone channels or the equivalent and for medium capacity digital systems operating in the 13 GHz band	149
Rec. 595	Radio-frequency channel arrangements for digital radio-relay systems in the 17.7 to 19.7 GHz frequency band	153
Report 936	Radio-relay systems in the bands between about 20 GHz and 40 GHz	156
Report 783-1	Radio-relay systems in frequency bands above about 40 GHz	158
Rec. 388	Radio-frequency channel arrangements for trans-horizon radio-relay systems . . .	165
Report 286	Radio-frequency channel arrangements for trans-horizon radio-relay systems using frequency modulation	166
Rec. 302-1	Limitation of interference from trans-horizon radio-relay systems	167
Report 378-4	Characteristics of digital radio-relay systems	169
Report 610-1	Compatibility between digital and FDM-FM radio-relay systems	174
Report 376-4	Diversity techniques for radio-relay systems	180
Report 614-2	Reference radiation patterns for radio-relay system antennas	190
Report 785-1	Frequency tolerances for radio-relay systems	194
Report 937	Spurious emissions of radio-relay systems	199

Section 9C – Interconnection characteristics (baseband and intermediate frequency)

Rec. 306	Procedure for the international connection of radio-relay systems with different characteristics	203
Rec. 268-1	Interconnection at audio frequencies of radio-relay systems for telephony	203
Rec. 380-3	Interconnection at baseband frequencies of radio-relay systems for telephony using frequency-division multiplex	204
Rec. 381-2	Conditions relating to line regulating and other pilots and to limits for the residues of signals outside the baseband in the interconnection of radio-relay and line systems for telephony	208
Rec. 270-2	Interconnection at video signal frequencies of radio-relay systems for television .	210
Rec. 463-1	Limits for the residues of signals outside the baseband of radio-relay systems for television	210
Rec. 402-2	The preferred characteristics of a single sound channel simultaneously transmitted with a television signal on an analogue radio-relay system	211
Report 289-4	The preferred characteristics for the simultaneous transmission of television and a maximum of four sound channels on analogue radio-relay systems	213
Report 786-1	Analogue radio-relay systems for simultaneous transmission of analogue and digital signals	223
Rec. 596	Interconnection of digital radio-relay systems	227
Report 938	Baseband interconnection of digital radio-relay systems	228
Rec. 275-3	Pre-emphasis characteristic for frequency modulation radio-relay systems for telephony using frequency-division multiplex	231
Rec. 404-2	Frequency deviation for analogue radio-relay systems for telephony using frequency-division multiplex	235

Rec. 405-1	Pre-emphasis characteristics for frequency modulation radio-relay systems for television	236
Rec. 276-2	Frequency deviation and the sense of modulation for analogue radio-relay systems for television	240
Rec. 403-3	Intermediate-frequency characteristics for the interconnection of analogue radio-relay systems	241
Report 788	Choice of intermediate frequencies for high-capacity digital radio-relay systems . .	242
Report 284-2	Interconnection of analogue auxiliary radio-relay systems operating in a frequency band other than that of the main system and at frequencies below about 2 GHz	245
Report 374	Interconnection of analogue auxiliary radio-relay systems operating in the same frequency band as the main radio-relay system	246
Report 939	Interconnection of trans-horizon radio links	247

Section 9D — Maintenance

Rec. 290-3	Maintenance measurements on radio-relay systems for telephony using frequency-division multiplex	251
Rec. 305	Stand-by arrangements for radio-relay systems for television and telephony	252
Rec. 401-2	Frequencies and deviations of continuity pilots for frequency modulation radio-relay systems for television and telephony	252
Rec. 444-3	Preferred characteristics for multi-line switching arrangements of analogue radio-relay systems	254
Report 137-5	Preferred characteristics for multi-line switching arrangements of analogue radio-relay systems	255
Report 443-1	Transmission interruptions due to the switching of analogue radio-relay systems . .	259
Report 787-1	Preferred methods and characteristics for the supervision and protection of digital radio-relay systems	265
Rec. 398-3	Measurements of noise in actual traffic over radio-relay systems for telephony using frequency-division multiplex	267
Rec. 399-3	Measurement of noise using a continuous uniform spectrum signal on frequency-division multiplex telephony radio-relay systems	269
Report 612-1	Measurements of equipment noise performance of analogue radio-relay systems . .	272
Report 613-2	Bit error performance measurements for digital radio-relay systems	276
Rec. 400-2	Service channels to be provided for the operation and maintenance of radio-relay systems	279
Report 444-1	Service channels for analogue radio-relay systems	280

Section 9E — Radio-relay systems for special applications

Report 379-4	Characteristics of simple radio-relay equipment operating in bands 8 and 9 for the provision of telephone trunk connections in rural areas	283
Report 380-1	Radio systems operating in bands 8 and 9 for the provision of subscriber telephone connections in rural areas	296
Report 615-1	Transportable fixed radiocommunications equipment for relief operations	303
Report 940	Point-to-multipoint systems	306

Section 9F — Frequency sharing with other services

Report 789-1	Protection of terrestrial line-of-sight radio-relay systems against interference from the broadcasting-satellite service in the band 11.7 to 12.75 GHz	313

Report 941	Protection of terrestrial line-of-sight radio-relay systems against interference from the broadcasting-satellite service (sound) in the band 1427 to 1530 MHz	315
Report 942	Frequency sharing between the fixed service and passive sensors in the band 18.6 to 18.8 GHz	320

Questions and Study Programmes, Resolutions, Opinions and Decisions

Question 1/9	Analogue radio-relay systems for telephony using frequency-division multiplex . .	321
Study Programme 1A-1/9	Analogue radio-relay systems of capacity greater than 1800 telephone channels, or the equivalent	321
Question 2-1/9	Hypothetical reference circuits and circuit noise for radio-relay systems for television and telephony	322
Study Programme 2A-1/9	Noise tolerable during very short periods of time for analogue radio-relay systems for television and telephony	322
Study Programme 2B-1/9	Noise in analogue radio-relay circuits forming part of very long telephone connections	323
Study Programme 2C/9	Noise in analogue radio-relay systems for television and telephony during periods without fading	324
Question 3-2/9	Analogue radio-relay systems for the transmission of television signals or for the simultaneous transmission of television and sound programme signals	324
Study Programme 3A-2/9	Preferred characteristics for the transmission of analogue television or sound programme signals or the simultaneous transmission of these signals	325
Question 4/9	Service channels for radio-relay systems for television and telephony	325
Study Programme 4A-1/9	Preferred characteristics for auxiliary radio-relay systems for the provision of service channels for radio-relay systems for television and telephony	326
Question 5-3/9	Availability of radio-relay systems for telephony and television	326
Study Programme 5A-3/9	Preferred characteristics for multi-line switching arrangements of analogue radio-relay systems	327
Study Programme 5B-1/9	Interruptions to traffic on line-of-sight analogue radio-relay systems for telephony	327
Study Programme 5C-2/9	Reliability and availability terminology of radio-relay systems for telephony and television	328
Question 7-3/9	Trans-horizon radio-relay systems	328
Study Programme 7B/9	Path antenna-gain in trans-horizon radio-relay systems	329
Study Programme 7C/9	Optimum frequency deviation in frequency-modulation trans-horizon radio-relay systems using frequency-division multiplex . .	330
Study Programme 7E/9	Preferred characteristics, permissible noise and signal distortion for the transmission of television signals over trans-horizon radio-relay systems	330
Study Programme 7F/9	Preferred frequency bands for tropospheric scatter radio-relay systems	331
Question 9-2/9	Radio-relay systems operating in bands 8 and 9 for the provision of telephone trunk connections in rural areas	331

XII

		Page
Study Programme 9A-1/9	Technical characteristics of simple radio-relay equipment operating in bands 8 and 9 for the provision of telephone trunk connections in rural areas	332
Study Programme 9B-2/9	Availability and performance objectives for analogue radio-relay systems operating in bands 8 and 9 for the provision of telephone trunk connections in rural areas	332
Question 10-2/9	Radio systems operating in bands 8 and 9 for the provision of subscriber telephone connections in rural areas	333
Question 12-4/9	Digital radio-relay systems	334
Study Programme 12B-1/9	Preferred characteristics of digital radio-relay systems	335
Study Programme 12C-1/9	Hypothetical reference digital paths and performance objectives for digital radio-relay systems	335
Study Programme 12E-1/9	Radio-frequency channel arrangements for digital radio-relay systems operating in frequency bands below about 12 GHz . . .	335
Study Programme 12F-1/9	Channel spacings and arrangements for digital radio-relay systems	336
Study Programme 12H-1/9	Interconnection at baseband frequencies for digital radio-relay systems	336
Study Programme 12J/9	Preferred methods and characteristics for the supervision and protection of digital radio-relay systems	337
Question 13-1/9	Diversity techniques for radio-relay systems	338
Question 16-1/9	The use of frequencies above about 12 GHz for radio-relay systems	339
Study Programme 16A-1/9	Radio-relay systems operating in frequency bands above about 40 GHz	339
Study Programme 16B/9	Radio-relay systems in frequency bands between about 20 GHz and 40 GHz	340
Question 17-1/9	Criteria for frequency sharing between radio-relay systems and space radiocommunication systems	340
Study Programme 17A-1/9	Antenna radiation diagrams of radio-relay stations for use in sharing studies	341
Study Programme 17B/9	Protection criteria between the broadcasting-satellite service and the fixed service	341
Study Programme 17C/9	Protection criteria between the broadcasting-satellite service (sound) and the fixed service, within the band 0.5 to 2 GHz . . .	342
Study Programme 17D/9	Frequency sharing between radio-relay systems and systems of the earth exploration-satellite service and the space research service	342
Question 19-1/9	Limitation of spurious emissions and frequency tolerances of radio-relay systems	343
Study Programme 19A-1/9	Limitation of spurious emissions and frequency tolerances of radio-relay systems, and the effect of spurious emissions from other sources on radio-relay systems	343
Question 20-1/9	Transportable fixed-service radiocommunication equipment for relief operations. .	344
Question 22/9	Line-up and maintenance measurements of radio-relay systems for television and telephony	344
Question 23/9	Interference among line-of-sight radio-relay systems	345
Study Programme 23A/9	Evaluation of interference among line-of-sight radio-relay systems	346

	Page
Question 25-1/9	Effects of propagation on the design and operation of radio-relay systems 346
Question 26/9	Radio-relay systems for the simultaneous transmission of analogue and digital signals 347
Study Programme 26A/9	Preferred characteristics of radio-relay systems for the simultaneous transmission of FDM telephone channels or one colour television signal and digital signals 347
Question 27/9	New techniques for spectrum sharing and band utilization for radio-relay systems 348
Study Programme 27A/9	Point-to-multipoint systems for telephony, data or video applications using new techniques for spectrum sharing and band utilization 348
Question 28/9	Maximum allowable degradation of the fixed service from services in the adjacent bands in the frequency range 1 to 20 GHz 349
Question 29/9	Possible limits for reducing transmitter power and repeater distance of radio-relay systems operating in the band 2 to 8 GHz 350
Question 30/9	Sharing criteria between the fixed, the broadcasting and the mobile service in the VHF/UHF bands 351
Question 31/9	Transmission of electric power by radio frequencies from a spacecraft 351
Question 32/9	Protection of radio-relay equipment from the effects of local lightning discharges 352
Opinion 13-1	Joint Study Group CMBD (CCITT/CCIR) on circuit noise and availability . . . 352
Opinion 14-4	Preferred frequency bands and centre frequencies for radio-relay links for international connections 353
Opinion 50	Coordination of the work of the CCIR and the IEC on measurements for the adjustment and maintenance of radio-relay systems 354
Decision 55	Effects of propagation on the design and operation of line-of-sight radio-relay systems (redrafting of Report 784) 355
Alphabetical Index of key words and terms of Vol. IX	357

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

**INDEX OF TEXTS WHICH HAVE BEEN DELETED AT THE END
OF THE STUDY PERIOD 1978-1982**

(In order to facilitate the retrieval of a given text, the page No. of Volume IX of the XIVth Plenary Assembly, Kyoto 1978, is indicated.)

Text	Title	Page No. Vol. IX (Kyoto, 1978)
Report 283	Technical characteristics to be specified to enable interconnection between any two analogue radio-relay systems for telephony using frequency-division multiplex	129
Report 377-1	Preferred characteristics, permissible noise and signal distortion for the transmission of television signals over transhorizon radio-relay systems	19
Report 446-1	Optimum frequency deviation in frequency-modulation trans-horizon radio-relay systems using frequency-division multiplex	185
Report 604-1	Summation of noise distribution in cascaded circuits as a method of subdividing noise recommendations	10
Report 608-1	General principles of radio-frequency channel arrangements for digital radio-relay systems	114
Report 609-1	Radio-frequency channel arrangements for digital radio-relay systems in the 17.7 to 19.7 GHz frequency band	92
Study Programme 12D/9	Radio-frequency channel arrangements for digital radio-relay systems, in the 17.7 – 19.7 GHz frequency band	244

Note. – No text has been deleted from Study Group 4/9.

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

NUMERICAL INDEX OF TEXTS

	Page
SECTION 9T: Terminology	1
SECTION 9A: Performance objectives and propagation effects	3
SECTION 9B: Radio-frequency channel arrangements and spectrum utilization	99
SECTION 9C: Interconnection characteristics (baseband and intermediate frequency)	203
SECTION 9D: Maintenance	251
SECTION 9E: Radio-relay systems for special applications	283
SECTION 9F: Frequency sharing with other services	313

RECOMMENDATIONS	Section	Page	RECOMMENDATIONS	Section	Page
Rec. 268-1	9C	203	Rec. 444-3	9D	254
Rec. 270-2	9C	210	Rec. 463-1	9C	210
Rec. 275-3	9C	231	Rec. 497-2	9B	149
Rec. 276-2	9C	240	Rec. 555	9A	16
Rec. 283-4	9B	99	Rec. 556	9A	20
Rec. 290-3	9D	251	Rec. 557	9A	72
Rec. 302-1	9B	167	Rec. 592	9T	1
Rec. 305	9D	252	Rec. 593	9A	16
Rec. 306	9C	203	Rec. 594	9A	23
Rec. 380-3	9C	204	Rec. 595	9B	153
Rec. 381-2	9C	208	Rec. 596	9C	227
Rec. 382-3	9B	103			
Rec. 383-2	9B	117	REPORTS		
Rec. 384-3	9B	119	Report 137-5	9D	255
Rec. 385-2	9B	128	Report 284-2	9C	245
Rec. 386-2	9B	129	Report 285-5	9A	63
Rec. 387-3	9B	132	Report 286	9B	166
Rec. 388	9B	165	Report 287-4	9B	122
Rec. 389-2	9B	135	Report 288-2	9A	12
Rec. 390-4	9A	3	Report 289-4	9C	213
Rec. 391	9A	5	Report 374	9C	246
Rec. 392	9A	6	Report 375-3	9A	18
Rec. 393-4	9A	8	Report 376-4	9B	180
Rec. 395-2	9A	10	Report 378-4	9B	169
Rec. 396-1	9A	14	Report 379-4	9E	283
Rec. 397-3	9A	15	Report 380-1	9E	296
Rec. 398-3	9D	267	Report 443-1	9D	259
Rec. 399-3	9D	269	Report 444-1	9D	280
Rec. 400-2	9D	279	Report 445-2	9A	74
Rec. 401-2	9D	252	Report 607-2	9B	146
Rec. 402-2	9C	211	Report 610-1	9B	174
Rec. 403-3	9C	241	Report 612-1	9D	272
Rec. 404-2	9C	235	Report 613-2	9D	276
Rec. 405-1	9C	236			

XVIII

REPORTS	Section	Page	REPORTS	Section	Page
Report 614-2	9B	190	Report 930	9A	24
Report 615-1	9E	303	Report 931	9A	50
Report 779	9A	27	Report 932	9A	88
Report 780-1	9A	42	Report 933	9B	101
Report 781-1	9B	123	Report 934	9B	106
Report 782-1	9B	138	Report 935	9B	115
Report 783-1	9B	158	Report 936	9B	156
Report 784-1	9A	53	Report 937	9B	199
Report 785-1	9B	194	Report 938	9C	228
Report 786-1	9C	223	Report 939	9C	247
Report 787-1	9D	265	Report 940	9E	306
Report 788	9C	242	Report 941	9F	315
Report 789-1	9F	313	Report 942	9F	320

Note. – Questions, Study Programmes, Opinions and Decisions which already appear in numerical order in the table of contents, are not reproduced in this index.

**INDEX OF THE TEXTS PUBLISHED IN OTHER VOLUMES, BUT
CONTAINING INFORMATION OF INTEREST TO THE FIXED SERVICE
USING RADIO-RELAY SYSTEMS**

Text	Title	Volume
Report 656	Efficient spectrum utilization using probabilistic methods	I
Report 657	Statistical model for the determination of band sharing criteria	I
Report 666	Systems for telecommunications using the electromagnetic spectrum above 3000 GHz	I
Report 828	Theoretical and experimental results for spectrum sharing between FDM-FM and radar systems using pulse blanking	I
Report 829	Calculation of the probability of interference	I
Report 830	Use of interference cancellers in order to increase spectrum usage	I
Report 831	Use of special screens to improve interference immunity in radio links	I
Report 528	Co-channel interference effects on multiple phase shift keyed (MPSK) system performance	I
Report 670	Worldwide minimum external noise levels, 0.1 Hz to 100 GHz	I
Report 832	Issues in packet radio communications	I
Report 181	Frequency tolerance of transmitters	I
Recommendation 329	Spurious emissions	I
Recommendation 331	Noise and sensitivity of receivers	I
Recommendation 332	Selectivity of receivers	I
Report 663	Characteristics of large millimetre and submillimetre wave reflecting antennae	I
Report 664	Review of band utilization of frequencies from about 40 to 3000 GHz	I
Report 841	Spectrum management and computer-aided techniques	I
Question 18/1	System design for maximizing the efficiency and utility of spectrum use	I
Question 44/1	System models for the evaluation of compatibility in spectrum use	I
Question 45/1	Technical criteria for frequency sharing	I
Question 58/1	Frequency sharing between various services	I
Question 61/1	Automatic identification of stations	I
Question 62/1	Lightning protection of radio equipment	I
Decision 56	Transfer of technology	I

Text	Title	Volume
Recommendation 363	Space operation systems. <i>Frequencies, bandwidths and protection criteria</i>	II
Report 396	Maintenance telemetering, tracking and telecommand for developmental and operational satellites. <i>Possibilities of frequency sharing between earth-satellite telemetering or telecommand links and terrestrial services</i>	II
Recommendation 510	Feasibility of frequency sharing between the space research service and other services in band 10. <i>Potential interference from data relay satellite systems</i>	II
Report 847	Data relay satellites. <i>Sharing with other services in bands 9 and 10</i>	II
Recommendation 364	Telecommunication links for manned and unmanned near-Earth research satellites. <i>Frequencies, bandwidths and criteria for protection from interference</i>	II
Recommendation 578	Protection criteria and sharing considerations relating to deep-space research	II
Report 684	Preliminary analysis of low-orbit satellite visibility statistics	II
Report 687	Feasibility of frequency sharing between space research (near-Earth) and fixed and mobile services in the 6 to 8 GHz spectral region	II
Report 685	Protection criteria and sharing considerations relating to deep-space research	II
Report 540	Feasibility of frequency sharing between an Earth exploration-satellite (EES) system and fixed satellite, meteorological satellite and terrestrial fixed and mobile services	II
Report 694	Sharing considerations and protection criteria relating to passive microwave sensors	II
Report 850	Frequency sharing by passive sensors with the fixed, mobile except aeronautical mobile, and fixed-satellite service in the band 18.6-18.8 GHz. <i>Minimum restrictions to other services in order to ensure satisfactory operations of passive sensors</i>	II
Report 851	Power flux-density limitation in the band 1670-1710 MHz for dissemination of meteorological information to small earth terminals	II
Report 224	Interference protection criteria for the radioastronomy service	II
Report 696	Feasibility of frequency sharing between radioastronomy and other services	II
Recommendation 517	Protection of the radioastronomy service from transmitters in adjacent bands	II
Report 697	Interference to the radioastronomy service from transmitters in other bands	II
Study Programme 15C/2	Protection of telecommunications equipment from radio-frequency radiation from space research earth stations	II
Question 18/2	Protection criteria for systems providing space operation functions	II
Question 19/2	Spurious emissions radiated from and received by stations of space services	II
Question 24/2	Characteristics of inter-satellite links	II

Text	Title	Volume
Report 869	Low-capacity earth stations and associated satellite systems in the fixed-satellite service	IV
Study Programme 2H/4	Use of frequency bands above 10 GHz in the fixed-satellite service	IV
Study Programme 2K/4	Feeder links for the space stations in the broadcasting-satellite service	IV
Question 25/4	Unwanted emissions radiated from and received by earth stations and space stations of the fixed-satellite service	IV
Question 26/4	Provision of feeder links between fixed-earth stations and space stations of various services in frequency bands allocated to the fixed-satellite service	IV
Report 719	Attenuation by atmospheric gases	V
Report 721	Attenuation by hydrometeors, in particular precipitation, and other atmospheric particles	V
Report 722	Cross-polarization due to the atmosphere	V
Report 723	Worst-month statistics	V
Report 338	Propagation data required for line-of-sight radio-relay systems	V
Recommendation 530	Propagation data required for the design of tropospheric-scatter trans-horizon radio-relay systems, terrestrial line-of-sight radio-relay systems and Earth-space telecommunication systems	V
Report 238	Propagation data required for trans-horizon radio-relay systems	V
Recommendation 452	Propagation data required for the evaluation of interference within and between the space and terrestrial services and for the calculation of coordination distances	V
Report 569	The evaluation of propagation factors in interference problems between stations on the surface of the Earth at frequencies above about 0.5 GHz	V
Report 724	Propagation data required for the evaluation of coordination distance in the frequency range 1 to 40 GHz	V
Report 885	Propagation data required for evaluating interference between stations in space and those on the surface of the Earth	V
Recommendation 590	Sharing possibilities between the radionavigation-satellite service and the fixed and mobile services in the bands 149.9-150.05 MHz and 399.9-400.05 MHz	VIII
Report 916	Sharing possibilities between the radionavigation-satellite service and the fixed and mobile services in the bands 149.9-150.05 MHz and 399.9-400.05 MHz	VIII
Report 773	A concept of coordination and protection contours for use in the coordination of mobile earth stations	VIII
Study Programme 46J/10	Compatibility between VHF sound broadcasting, television and other services using the same band or adjacent bands	X
Report 952	Technical characteristics of feeder links to broadcasting satellites. <i>Elements required for the establishment of plans of frequency assignments and orbital positions for the broadcasting-satellite service and the associated feeder links. Sharing in the feeder link bands</i>	X/XI

Text	Title	Volume
Question 1/10 and 11	Broadcasting-satellite service (sound and television). <i>Protection from interference</i>	X/XI
Study Programme 2E/10 and 11	Radiation of unwanted emissions from space stations in the broadcasting-satellite service (sound and television)	X/XI
Question 38/11	Protection of television broadcasting stations against lightning	XI
Question 39/11	Frequency sharing between the broadcasting service (television) and the fixed and mobile services below 1 GHz	XI
Opinion 38	Exchange of monochrome and colour television programmes via satellites	XI
Report 818	Automatic switching systems for television circuits	XII
Report 639	Availability of an international television circuit or chain	XII
Recommendation 570	Standard test signal for conventional loading of a television channel	XII
Report 643	Standard test signal for conventional loading of a television channel	XII
Recommendation 571	A conventional test signal simulating sound-programme signals for measuring interference in other channels	XII
Report 497	A conventional test signal simulating sound-programme signals for measuring interference in other channels	XII
Recommendation 605	Estimation of transmission performance of sound-programme circuits shorter or longer than the hypothetical reference circuit	XII
Report 821	Estimation of transmission performance of sound-programme circuits shorter or longer than the hypothetical reference circuit	XII
Report 488	Transmission of sound and vision signals by time-division multiplex or frequency-division multiplex	XII
Report 970	Characteristics of video signals. <i>Limitation of out-of-band spectral components</i>	XII
Study Programme 13E/CMTT	Noise modulation of television signals arising from carrier phase jitter. <i>Permissible levels</i>	XII
Study Programme 14A/CMTT	Digital transmission of television signals	XII
Study Programme 15G/CMTT	Noise modulation of television signals arising from carrier phase jitter. <i>Methods of measurement</i>	XII
Study Programme 18A/CMTT	Standards for the digital transmission of sound-programme signals	XII
Study Programme 19C/CMTT	Noise modulation of sound-programme signals arising from carrier jitter	XII
Question 21/CMTT	Standards for transmission of signals with multiplexing of video, sound and other types of signal used for the television service	XII
Study Programme 21D/CMTT	Characteristics of video signals	XII
Decision 18	Digital systems for the transmission of sound-programme and television signals	XII
Recommendation 971	General terminology of telecommunications. <i>Terms common to CCIR and CCITT</i>	XIII

Text	Title	Volume
Recommendation 573	Radiocommunication vocabulary	XIII
Recommendation 607	Terms and abbreviations for information quantities in telecommunications	XIII
Recommendation 431	Nomenclature of the frequency and wavelength bands used in telecommunications	XIII
Recommendation 574	Logarithmic quantities and units	XIII
Resolution 66	Terms and definitions	XIII
Decision 19	Terms and definitions	XIII

[illegible]

FIXED SERVICE USING RADIO-RELAY SYSTEMS

STUDY GROUP 9

Terms of reference:

To study questions relating to line-of-sight and trans-horizon radio-relay systems operating via terrestrial stations at frequencies above about 30 MHz.

- 1978-1982 *Chairman:* J. VERRÉE (France)
Vice-Chairman: H. WILLENBERG (Germany (Federal Republic of))
- 1982-1986 *Chairman:* J. VERRÉE (France)
Vice-Chairmen: M. MUROTANI (Japan)
H. WILLENBERG (Germany (Federal Republic of))
-

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP 9

Study Group 9 concerns itself under its terms of reference with the terrestrial fixed service using line-of-sight and trans-horizon radio-relay systems in the troposphere and excluding the ionosphere. The frequencies used are generally shared with the fixed-satellite service; conditions and forms of sharing are therefore explored in close liaison with Study Group 4, and the relevant provisions of the Radio Regulations are based on these studies.

Radio-relay systems have been employed for several decades for the equipment of telecommunication networks and lend themselves to the transmission of a wide range of signals in many frequency bands; Study Group 9 therefore cooperates with the various CCIR and CCITT Study Groups concerned. These include:

- CCIR Study Group 5, concerning the propagation data required;
- Joint Study Group on circuit noise and availability (CMBD), concerning the noise and availability characteristics of systems;
- CCITT Study Group XVIII, concerning the characteristics of digital networks;
- Joint Study Group for television and sound transmissions (CMTT), concerning the general standards for the transmission of video and sound signals over long distances.

Radio-relay links have already been standardized to a great extent; they are the subject of many Recommendations, particularly for analogue systems. A large number of problems, however, require further study in the light of technological developments and the increasing requirements of telecommunication. Among these problems, mention should be made particularly of the growth of digital techniques, the use of higher frequencies and the ever more common practice of sharing frequencies with other services following the decisions of the WARC-79. The activities of Study Group 9 have therefore been maintained at a high level during the study period 1978-82.

The interim and final meetings of Study Group 9 were held in Geneva from 20 October to 3 November 1980 and from 12 to 28 October 1981, respectively.

About 160 contributions were submitted by administrations for these meetings, and on that basis Study Group 9 prepared about 150 documents proposing new texts or the amendment or amplification of existing texts.

The work of the Study Group was divided among five Working Groups dealing with the following main items:

- performance objectives and effects of propagation on the design and operation of radio-relay systems,
- radio-frequency channel arrangements and spectrum utilization,
- interconnection characteristics (baseband and intermediate frequency),
- maintenance,
- radio-relay systems for special applications,
- frequency sharing with other services.

In addition, a standing Working Group on Terminology was set up under Resolution 66-1 and Decision 19-1 to study this subject in cooperation with the Joint Study Group for Vocabulary (CMV).

The above classification, which is very close to that adopted previously, is used for the arrangement of Study Group 9 texts in sections in Volume IX; in this Report, the most important problems covered by Study Group 9 are considered in that order.

1. Performance objectives and propagation effects

As regards analogue telephone systems, Study Group 9 concluded on the basis of the test results obtained in real systems that the adoption of an additional noise clause intermediate between § 1.1 and 1.2 of Recommendation 393 was unnecessary. This possibility is therefore omitted in the text of Recommendation 393-4; Report 604-1, which no longer serves any purpose, was cancelled. A letter to the Chairman of the CMBD (Doc. 9/394) was prepared to indicate this and also to communicate the comments of Study Group 9 concerning the standards for very long systems (5000 and 12 500 km).

New Recommendation 593 fixes the allowable noise level on real circuits set up on frequency-modulation trans-horizon radio-relay links less than 2500 km long.

The noise objectives for sound programme circuits 2500 km long provided by means of analogue radio-relay systems were updated on the basis of the most recent CMTT and CCITT texts in Report 375-3.

Report 377-1 relating to the transmission of television signals over trans-horizon radio-relay systems was regarded as out of date and was accordingly cancelled.

As regards performance objectives for digital systems, great progress was achieved with the adoption of new Recommendation 594 relating to telephony, supplemented by new Report 930 which incorporates and expands § 2 of former Report 378-3 and also discusses the problem of real digital circuits. Doc. 9/397 draws the attention of CCITT Study Group XVIII to these documents in connection with the revision of Recommendation G.821 which is now under consideration.

The problems of interference in analogue radio-relay systems were treated more fully in Report 780-1 in respect of telephone systems of different capacity and in new Report 931 with regard to frequency-modulation television systems (co-channel interference).

Maximum allowable degradation of performance in radio-relay links due to interference from services in the adjacent bands is the subject of new Question 28/9.

The effects of propagation on the design and operation of radio-relay systems are directly linked to the proposed performance objectives; these two points were therefore considered in the same Working Group and the corresponding texts were incorporated in the same section of Volume IX.

For line-of-sight radio-relay systems, Report 784-1 constitutes a text based mainly on the contributions received, particularly with regard to digital systems (co-channel operation, effects of selective fading, concept of the net margin and of "signature"). This text, however, is not regarded as fully satisfactory since on certain subjects it contains only limited information and it deals with subjects already considered in Report 338-4 compiled by Study Group 5, since the tasks of Study Group 5 and Study Group 9 are not clearly differentiated.

Study Group 9 therefore adopted Decision 55 (see Annex to Doc. 9/427), setting up Interim Working Party 9/4 to prepare, under the chairmanship of a specialist appointed by the Administration of Canada, a new version of Report 784 in cooperation with Study Group 5. Study Group 9 also submitted comments to the Chairman of Study Group 5 in Doc. 9/417(Rev. 1).

Lastly, for the study of the effects of the special propagation conditions which may be encountered in desert and jungle terrain, especially ducting, the text of Question 25-1/9 was drafted, with reference to the African continent; this text was brought to the attention of Study Group 5.

For trans-horizon radio-relay links, propagation effects are discussed in Report 285-5, which takes the new contributions into account and is the outcome of an amalgamation of former Reports 285-4 and 446-1 after deletion of the paragraphs relating to interference and interconnection, which were incorporated in other texts. Moreover, in pursuance of WARC-79 Recommendation No. 100, Study Programme 7F/9 was adopted for the determination of the preferred frequency bands for tropospheric scatter radio-relay systems.

The problem of the protection of radio-relay equipments against lightning, raised in the WARC-79 Resolution No. 64, was set for study at the interim meeting in new Question 32/9. At the final meeting, Study Group 9 drafted new Report 932 for transmission to CCITT Study Group V with a view to incorporating the contents of the Handbook "The protection of telecommunication lines and equipment against lightning discharges"; Doc. 9/366 was prepared with a view to such transmission to CCITT Study Group V and to CCIR Study Group 1. In view of the very small number of specialists on these problems, Study Group 9 does not intend to draft special texts on the subject, but rather to contribute to further work continuing the studies already undertaken by the CCITT.

2. Radio-frequency channel arrangements and spectrum utilization

The study of radio-frequency channel arrangements is now a very complex matter owing to the conditions required for the establishment of digital systems. Work is therefore focused on two possibilities: either re-use of the channel arrangements recommended for analogue systems, which allows the co-existence of analogue and digital systems on the same artery and at the nodal points; or new channel arrangements designed specifically for digital transmission and possibly not compatible with existing channel arrangements.

As regards analogue channel arrangements, most existing Recommendations and Reports were revised in the light of the new Table of Frequencies (Article 8 of the Radio Regulations (WARC-79)) and of the contributions received proposing additions, variants or compatible mixed analogue-digital utilization.

Attention is drawn particularly to the following texts:

- Recommendation 382-3 (4 GHz) which provides a new variant for 1800-channel systems with a channel arrangement conforming to that of Recommendation 497-2 and mixed utilization for bit rates of 2×34 Mbit/s or 2×45 Mbit/s per channel;
- Recommendation 383-2 (6 GHz) which also provides for a variant based on Recommendation 497-2;
- Recommendation 384-3 (6.5 GHz) which provides for mixed utilization for bit rates of the order of 140 Mbit/s per channel;
- Report 607-2 (band 10.5 to 15.35 GHz) which has been greatly amplified;
- Recommendation 497-2 (13 GHz) which now provides for digital utilization with a bit rate of 2×34 Mbit/s per channel;
- Report 781-1 (SSB amplitude modulation systems) which contains new information on the systems developed in Japan.

New Report 933 deals with the use of the band 2.3 to 2.5 GHz allocated by the WARC-79 to the fixed service, with a main channel arrangement based on 1 MHz channel separation, while the separation between adjacent channels with the same polarization is a multiple of the base spacing, the multiple being chosen in accordance with the channel capacity which may be as much as 300 telephone channels; this arrangement may be applied in particular to the systems of simple design for telephone trunk connections in rural areas considered in Report 379-4.

With regard to channel arrangements for digital transmission, the re-use of the frequency bands below about 10 GHz – hitherto employed for large-capacity analogue transmissions – for the establishment of medium- or large-capacity digital systems is a major problem considered under Study Programme 12E-1/9.

New Report 934 collects the information available on the subject and comprises five Annexes giving examples of the use of frequency bands as proposed by certain administrations.

In the case of the 4 GHz band, new Report 935 discusses the characteristics of a channel arrangement based on a homogeneous pattern for bit rates of up to 200 Mbit/s per channel; a more detailed study is required and a proposal for a new Recommendation is added in the Annex for consideration during the next study period.

Report 782-1 deals with the case of the use of the 11 GHz band for 140 Mbit/s systems and now comprises three Annexes corresponding to the main proposals submitted.

In the band 17.7 to 19.7 GHz, agreement was reached on new Recommendation 595 which considers both co-channel and interleaved arrangements. Report 609-1 and Study Programme 12D/9, which have become unnecessary, are therefore cancelled.

The use of frequency bands between about 20 and 40 GHz is the subject of new Study Programme 16B/9; the first data available on the subject are collected in new Report 936, which describes in the Annex the use of the band 17.7 to 21.2 GHz for a digital system with a bit rate of about 400 Mbit/s per channel.

For radio-relay systems operating above about 40 GHz, Report 783-1 contains new information on the length of the sections of digital systems and an example of a simple system which may be transportable.

The characteristics of digital radio-relay systems, such as coding and modulation techniques, the concepts of net margin or “signature” and possible use of automatic regulation of the transmitting power have a direct impact on the possibilities of spectrum utilization, including above all channel arrangements. Report 378-4 is devoted entirely to the study of these characteristics, while performance objectives for digital systems are now the subject of new Report 930 referred to above; accordingly, Report 608-1, the useful contents of which were incorporated elsewhere, is cancelled and Study Programme 12F-1/9 deals in its new § 4 with the problem of the overall capacity of a real digital radio-relay network. Further, a new § 7 has been added in Question 12-4/9; it relates to the use of dynamic transmitter output power control in digital radio-relay systems.

Report 376-4 provides information on the use of diversity techniques for digital radio-relay systems, allowing the disastrous effects of multipath propagation to be reduced.

Report 785-1 on frequency tolerances was improved and takes account of the decisions of the WARC-79. New Report 937 discusses spurious emissions of radio-relay systems.

Opinion 14-4, which draws the attention of administrative radio conferences to the preferred frequencies for radio-relay links, takes the most recent work of Study Group 9 into account.

Lastly, with a view to better spectrum utilization by the reduction of interference and to lower energy consumption, a shortening of repeater distances has been proposed in order to reduce the transmitter power required; new Question 29/9 was adopted on this subject for the frequency band 2 to 8 GHz.

3. Interconnection (baseband and intermediate frequency)

The texts on the interconnection of analogue radio-relay systems were amplified and updated. Report 289-4 on the simultaneous transmission of a video signal and four sound signals contains new information on the arrangements used in Japan (Annex III) and in Canada (Annex IV). Report 786-1 on the simultaneous transmission of analogue and digital signals is entirely new as regards the transmission of data above voice and above video (DAV). Report 283, regarded as out of date in view of the existing texts on the interconnection of analogue telephone systems, has been cancelled.

The baseband interconnection of digital radio-relay systems was discussed in detail. New Recommendation 596 advises interconnection at points T and T' in Fig. 1 of new Report 938. This Report reviews the various aspects of the problem such as baseband digital signal processing; the proposed definition of points of interconnection between switching and radio equipments is in fact beset by difficulties as regards both theory and practice and calls for further study. The characteristics to be studied for the baseband interconnection of digital radio-relay systems are detailed in Study Programme 12H-1/9.

Recommendation 275-3 (Analogue telephone pre-emphasis) comprises a Table I in which precise cross-over frequencies have been added.

The interconnection of trans-horizon radio links is the subject of new Report 939, which incorporates the information previously given in Report 285-4.

The texts on intermediate frequency interconnection (Recommendation 403-3 and Report 788) have not been amended.

4. Maintenance

Report 137-5 on the switching of analogue radio-relay channels contains new information on the switching criteria for television, on priority arrangements and on test access features.

Report 787-1 deals exclusively with switching devices for digital radio-relay systems, since baseband interconnection is now dealt with in new Report 938 referred to above; Report 787-1 describes particularly the arrangements required to avoid loss of synchronization in switching.

Information on bit error performance measurements for digital systems is given in Report 613-2.

Continued cooperation with the IEC on measurement methods for radio-relay equipments was approved and Opinion 50 was confirmed.

5. Radio-relay systems for special applications

It appeared from the discussions held that the simple systems intended for use in the developing countries are in reality applicable to rural areas in general, including particularly those of the developing countries. The titles and certain paragraphs of existing Questions, Study Programmes and Reports have been amended accordingly.

Report 379-4 contains new information on interference in analogue systems (Annex I) and digital systems (Annex II) and also a new Annex III relating to a point-to-multipoint radio-relay system for trunk connections in rural areas. In response to a suggestion by Interim Working Party 5/4 (Doc. 9/329) concerning the definition of slightly less strict availability and performance criteria for national (e.g. rural) applications in the developing countries in order to make substantial savings in the operation of systems and thus help these countries solve their problems, Study Group 9 adopted the text of Study Programme 9B-2/9.

The text of Report 380-1 is the outcome of a thorough revision. It now discusses simple single-channel, multiple-access equipments constituting radio concentrators and also drop/insert systems; the new Annex contains a frequency re-use plan for digital radio concentrators. The text of Question 10-1/9 was amended so as to apply to these systems.

Reports 379-4 and 380-1 should be brought to the attention of GAS 3 and the new GAS 7.

The entire problem of point-to-multipoint systems is considered in new Report 940 which comprises three Annexes describing the various applications of these systems. The studies required on this subject are defined in new Study Programme 27A/9, prepared in connection with new Question 27/9 concerning new techniques for spectrum sharing and band utilization adopted following WARC-79 Recommendation No. 65.

6. Frequency sharing with other services

6.1 One of the main consequences of the WARC-79 for Study Group 9 is the general introduction of frequency sharing between the fixed terrestrial service and the other services — both terrestrial and space — following several Conference Resolutions and Recommendations.

In view of the importance of these sharing problems and in response to the decisions of the WARC-79, Study Group 9 prepared three new Questions:

- Question 30/9: Sharing criteria between the fixed, the broadcasting and the mobile service in the VHF/UHF bands (particularly in band 87.5 to 108 MHz) (Resolutions Nos. 510 and 702);
- Question 31/9: Transmission of electric power by radio frequencies from a spacecraft (Recommendation No. 3);
- Question 27/9: New techniques for spectrum sharing and band utilization for radio-relay systems (Recommendation No. 65) referred to above;

and adopted three new Study Programmes, deriving from Question 17-1/9 (Sharing with space radiocommunication systems):

- Study Programme 17B/9: Protection criteria between the broadcasting-satellite service and the fixed service (Resolutions Nos. 31 and 34);
- Study Programme 17C/9: Protection criteria between the broadcasting-satellite service (sound) and the fixed service, within the band 0.5 to 2 GHz (Resolution No. 505);
- Study Programme 17D/9: Frequency sharing between radio-relay systems and systems of the earth exploration-satellite service and the space research service (Recommendation No. 706).

6.2 All these texts were prepared during the interim meeting and preliminary replies were given at the final meeting on the most urgent subjects.

The first of these is the protection of terrestrial services in the band 12.2 to 12.7 GHz with a view to the efficient planning of the broadcasting-satellite service in Region 2 (Resolution No. 31), for which a Regional Conference is planned in 1983. In view of the urgency, Study Group 9 established Interim Working Party 9/3 at the interim meeting by Decision 46; the Working Party operated by correspondence and concluded its work at the final meeting.

The Report of Interim Working Party 9/3, approved by Study Group 9, is submitted to the XVth Plenary Assembly in Doc. PLEN./4; further, on the proposal of Interim Working Party 9/3, Study Group 9 suggests in Doc. 9/376 (Rev.1) the addition of a new CONSIDERING in Resolution 77. Interim Working Party 9/3, having completed its task, was disbanded at the end of the final meeting and Decision 46 was cancelled.

In Report 789-1, reference is made to the conclusions of Interim Working Party 9/3.

New Report 941 constitutes a first response to Study Programme 17C/9 relating to the protection of radio-relay systems against interference from the broadcasting-satellite service (sound) in the band 1427 to 1530 MHz.

The problem of sharing between various services and passive sensors in the band 18.6 to 18.8 GHz is discussed in new Report 850 prepared by Study Group 2. Under Study Programme 17D/9, Study Group 9 has formulated certain additional observations in new Report 942 which should be treated at greater length later.

In Docs. 9/358 and 9/359, Study Group 9 communicated comments to Study Group 4 in order to help in the preparation of the Report of Interim Working Party 4/1 concerning the use of the geostationary-satellite orbit.

6.3 The problem of frequency sharing with the fixed-satellite service was studied by a Joint Study Group 4 and 9 Working Group, as in the past; there was most satisfactory cooperation between the two Study Groups in full accord with Mr. E. R. Craig, Chairman of Study Group 4. The relevant texts, adopted at joint meetings of Study Groups 4 and 9, are reproduced in a separate Volume common to the two Study Groups.

With regard to the conditions of sharing, two new texts were prepared. The first is new Report 877 on the interference criteria for digital radio-relay systems operating in the shared bands. This text, which is a counterpart to Report 793, contains in Annex I a proposal for a new Recommendation, which was, however, regarded as premature and will have to be reconsidered during the next study period with the new contributions urgently requested on the subject. The second is Report 876 on frequency sharing in bands above 40 GHz.

Texts were aligned on the decisions of the WARC-79 and new contributions were taken into account, particularly Report 209-4, which comprises a new Annex IV concerning the application of optimization techniques to interference between terrestrial and satellite systems, Recommendation 358-3, Reports 386-3 and 387-4, Recommendation 406-5 and Reports 790-1 and 791-1.

For coordination and interference calculations, account was also taken of the new contributions in Reports 388-4, 448-3 and 792-1.

The most important task was the revision of the Report on the determination of the coordination area; Report 382-4 is based on new propagation data supplied in Study Group 5 which are still partly provisional so that at this stage the Report is not proposed as a basis for amendments to the Radio Regulations. Administrations are requested to compare the results obtained by application of the new Report with those derived from the methods described in Appendix 28 to the Radio Regulations (WARC-79) and to communicate the conclusions arrived at to the CCIR.

A letter to the Chairman of Study Group 5 (Doc. 4/440-9/411(Rev.1)) draws attention to the divergencies between the propagation data used by Study Groups 4 and 9 and those proposed by Study Group 5 and asks for clarification and comments on the data to be considered.

As regards WARC-79 Resolution No. 703, it was found that no Recommendation on frequency sharing between radio-relay systems and the fixed-satellite service was liable to be used for the application of this Resolution, since all the texts in question were aligned on the regulatory provisions adopted by the WARC-79 (see Doc. 4/454-9/423, § 5).

7. Terminology

Study Group 9 transmitted to the CMV its views on the texts submitted to it and proposed the compilation of a list of the abbreviations used, particularly regarding digital transmission and new modulation techniques which are of special interest to Study Group 9.

New Recommendation 592 gives definitions for the systems studied by Study Group 9 and is presented as the first of the Study Group 9 texts.

8. Programme of work of Study Group 9 for the next study period

In the foregoing description of the work of Study Group 9, the new Questions and the new Study Programmes prepared have been mentioned in their proper place.

For the entire range of subjects under study, however, discussions brought out the main areas of activity to which Study Group 9 will have to give priority during the next study period.

These priority areas are as follows:

- the performance objectives for digital systems, for which new Recommendation 594 and new Report 930 represent only a preliminary reply which will have to be elaborated in accordance with the revision of Recommendation G.821 now under study by CCITT Study Group XVIII. In particular, consideration will have to be given to a method of subdividing the objectives, the definition of objectives for short- and medium-distance systems used only in the national part of the hypothetical reference circuit and the problem of real digital paths. Altogether, the alignment of the definitions to be used by the various Study Groups dealing with system performance objectives and availability calls for urgent study;
- the effects of propagation on the design and operation of line-of-sight radio-relay systems (Interim Working Party 9/4), particularly concerning the digital systems and the special conditions which may be encountered in the developing countries (Question 25-1/9);

- radio-frequency channel arrangements for digital systems operating in frequency bands below about 10 GHz; that fact that new Report 934 contains five Annexes describing rather different systems clearly demonstrates the complexity of this study;
- use of the frequency bands between about 20 and 40 GHz (new Study Programme 16B/9);
- more generally, the characteristics of digital radio-relay systems, particularly with regard to the problem of the overall capacity of a real network and the effects of automatic transmitter power control;
- the feasibility of reducing the distances between radio-relay repeaters (new Question 29/9);
- interconnection characteristics at baseband frequencies, the methods of channel switching, performance measurement and establishment of service channels for digital systems;
- appropriate performance and availability objectives applicable to trunk or low-capacity subscriber systems operating in rural areas (Study Programme 9B-2/9);
- the design of point-to-multipoint systems, particularly with a view to efficient spectrum utilization (new Study Programme 27A/9); the fact that new Report 940 describes three very different point-to-multipoint systems in its Annexes suggests that light may be thrown on the subject, depending on the applications desired, when sufficient new information becomes available;
- frequency sharing with other services, particularly with space radiocommunication systems (three new Questions and three new Study Programmes);
- interference criteria for digital radio-relay systems operating in bands shared with the fixed-satellite service;
- determination of the coordination area between fixed-satellite service stations and radio-relay stations, in accordance with the improved propagation data available.

Annex I recapitulates the texts of the final meeting of Study Group 9 in 1981 which establish liaison with the other Study Groups and which should be kept for the next study period.

9. Conclusion

The period 1978-82 was marked by the preparation and the meeting of the WARC-79 whose decisions will affect radiocommunications throughout the world for several years to come. Study Group 9 engaged in extensive activities to comply with these decisions (new regulatory provisions and new studies), to respond rapidly to urgent problems with a view to the Administrative Conferences scheduled and to take technical progress into account, particularly in the matter of digital radio-relay systems.

Study Group 9 prepared 5 new Recommendations, 15 new Reports, 6 new Questions and 6 new Study Programmes and cancelled 6 Reports and 1 Study Programme; it established and subsequently disbanded Interim Working Party 9/3 (Decision 46) and established Interim Working Party 9/4 (Decision 55). It consolidated its liaison with the other Study Groups and appointed correspondents to Study Groups 1, 2 and 5 of the CCIR, the CMV, the CMBD, Study Group XVIII of the CCITT and the International Electrotechnical Commission (IEC); it also confirmed the special cooperation established between Study Group 4 and Study Group 9, whose simultaneous meeting is of the greatest importance.

The arrangement of the published texts is very similar to that adopted in 1978, the main changes being due to splitting up Reports 378-3 and 285-4, which dealt with several subjects, and to the inclusion of new texts. The arrangement was chosen in order to present the texts as logically and clearly as possible, grouping together Recommendations and Reports dealing with related subjects. This presentation should greatly facilitate the use of the documentation and reference to Volume IX by those who did not attend the meetings or who are not familiar with the work of the CCIR.

The Chairman thanks all delegates to Study Group 9 and their administrations for the contributions supplied and for the diligence and the spirit of cooperation they showed.

He particularly thanks Mr. H. Willenberg (Federal Republic of Germany), Vice-Chairman of Study Group 9, for his active and efficient support at all times and the Chairmen of Working Groups:

Mr. S. Young and Mr. A. W. Muir (United Kingdom), Mr. E. R. Allan and Mr. P. E. Hervieux (Canada), Mr. J. Steel (Australia), Mr. S. Matsumoto (Japan), Mr. J. P. Houssin (France), Mr. J. Dominguez Sanz (Spain) and Mr. O. Langer, Chairman of Interim Working Party 9/3.

Special mention should be made of the Editorial Group for the final meeting consisting of Mr. D. P. Whitten (United Kingdom), Mr. L. Bourgeat (France) and Mr. J. Cruz Vias (Spain), whose task was particularly difficult owing to the arrangements made for the editing of the texts.

Special mention should also be made of Mr. H. Sonoki, Counsellor of CCIR, for his effective support and for the care with which he has prepared the documentation necessary for the efficient functioning of the Study Group.

The Chairman expresses his gratitude to all these gentlemen and to all those who contributed to the success of the meetings of Study Group 9, whose support was extremely valuable to him in the accomplishment of his duties.

ANNEX I

TEXTS OF THE FINAL MEETING OF STUDY GROUP 9 TO BE KEPT FOR THE NEXT STUDY PERIOD

Doc. 9/394:	Letter to the Chairman of CMBD.
Doc. 9/397:	Comments to CCITT Study Group XVIII concerning the performance of digital radio-relay systems.
Doc. 9/417 (Rev. 1):	Comments for the attention of the Chairman of Study Group 5.
Doc. 9/366:	Note by the Chairman of Study Group 9 to the Chairman of CCITT Study Group V.
Doc. 9/411-4/440 (Rev. 1):	Letter from the Chairmen of Study Groups 4 and 9 to the Chairman of Study Group 5.

SECTION 9T: TERMINOLOGY

Recommendation

RECOMMENDATION 592 *

VOCABULARY

(1982)

The CCIR,

UNANIMOUSLY RECOMMENDS

that the following definitions be considered for the analysis of the texts of Study Group 9:

1. Radio-relay system ; *Faisceau hertzien ; Sistema de relevadores radioeléctricos:*

Radiocommunication system in the fixed service operating at frequencies above about 30 MHz which uses tropospheric propagation and which normally includes one or more intermediate stations.

2. Trans-horizon radio-relay system ; *Faisceau hertzien transhorizon ; Sistema de relevadores radioeléctricos transhorizonte:*

Radio-relay system using *trans-horizon* tropospheric *propagation*, chiefly forward scatter.

Note. — Recommendation 310 gives a definition for *trans-horizon* (tropospheric) *propagation*.

3. Point-to-multipoint distribution ; *Distribution point à multipoint ; Distribución punto a multipunto:*

Radiocommunication technique used by the fixed service to permit the exchange of information between a central station and a given number of peripheral ones.

* This Recommendation should be brought to the attention of the CMV.

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

SECTION 9A: PERFORMANCE OBJECTIVES AND PROPAGATION EFFECTS

Recommendations and Reports

RECOMMENDATION 390-4

**DEFINITIONS OF TERMS AND REFERENCES CONCERNING
HYPOTHETICAL REFERENCE CIRCUITS AND HYPOTHETICAL REFERENCE
DIGITAL PATHS FOR RADIO-RELAY SYSTEMS**

(Question 2/9 and Study Programme 12C/9)

(1963–1970–1974–1978–1982)

The CCIR,

UNANIMOUSLY RECOMMENDS

that the following definitions be used for defining the nature and properties of hypothetical reference circuits and hypothetical reference digital paths:

1. Analogue radio-relay systems

1.1 Hypothetical reference circuit; circuit fictif de référence; circuito ficticio de referencia

A hypothetical circuit of definite length, comprising a number of intermediate and terminal equipments, this number being fairly large, but not excessive.

Note 1. — The hypothetical reference circuit is a necessary element in the study of certain characteristics of long-distance circuits (e.g. noise).

Note 2. — The length of the hypothetical reference circuit does not imply that longer real circuits cannot be used.

1.2 Hypothetical reference circuit for telephony; circuit fictif de référence (pour la téléphonie); circuito de referencia para la telefonía

A complete telephone circuit (between an audio-frequency terminal at each end), established over a hypothetical international carrier-system of definite length. It comprises a definite number of modulations and demodulations of the groups, supergroups and mastergroups, the number of these processes being reasonably large, but not the greatest number possible.

Note 1. — Various “hypothetical reference circuits for telephony” have been determined to permit coordination between the various specifications for the constituent parts of multiplex carrier telephony systems, so that the complete telephone circuits established over these systems should satisfy the CCITT standards (see § 3.2, 3.3, 3.4 and 3.7). These various hypothetical reference circuits are all conceived for the same total length (except of course hypothetical reference circuits for satellite systems) and type of operation. They are intended as a guide only in the planning of carrier systems.

Note 2. — As a result of the introduction of three pairs of channel modulations, these hypothetical reference circuits for telephony may be used to study, not only a 2500 km circuit established over a carrier system or systems, but also an international connection having the same total length, composed of three circuits, set up on different carrier systems and interconnected in two international transit centres.

1.3 Homogeneous section (for telephony); section homogène (pour la téléphonie); sección homogénea (para la telefonía)

A section without either branching or modulation of any mastergroup, supergroup, group or channel, established over the system in question, with the exception of those which are defined at the end of the section.

Note 1. — All hypothetical reference circuits are built up from homogeneous sections of equal length (six or nine sections as the case may be; the number is not specified for trans-horizon systems).

Note 2. — It is assumed that, at the end of each homogeneous section, the channels, groups, supergroups and mastergroups are interconnected among themselves in a random manner.

1.4 *Hypothetical reference circuits for other types of signal*

Using the same principles, other hypothetical reference circuits and homogeneous sections have been determined for other types of signal; television, programme circuits, etc. (see § 3.5, 3.6 and 3.7).

2. **Digital radio-relay systems**

Hypothetical reference digital path; conduit numérique fictif de référence; trayecto digital ficticio de referencia

A hypothetical digital path of definite length, comprising a number of intermediate and terminal equipments, this number being fairly large, but not excessive.

Note 1. — The hypothetical reference digital path is a necessary element in the study of certain characteristics of long-distance digital paths (e.g. errors, jitter).

Note 2. — The design objectives recommended by the CCITT for transmission equipments are commonly expressed in terms of a maximum tolerable level of impairment arising in a hypothetical reference digital path. As far as possible, a design objective so expressed takes into account all possible uses of the system, e.g. telephony, telegraphy, data, etc.

3. **References**

3.1 *General definition of a hypothetical reference circuit*

CCITT Recommendation G.212.

3.2 *Hypothetical reference circuit for telephony on cable systems and on open-wire lines*

See the references in CCITT Recommendation G.212, § 2.

3.3 *Hypothetical reference circuits for telephony on line-of-sight or near line-of-sight radio-relay systems*

- using frequency-division multiplex (with a capacity of 12 to 60 telephone channels) — CCIR Recommendation 391,
- using frequency-division multiplex (for more than 60 telephone channels) — CCIR Recommendation 392.

3.4 *Hypothetical reference circuit for telephony on trans-horizon radio-relay systems*

- using frequency-division multiplex — CCIR Recommendation 396.

3.5 *Hypothetical reference circuit for television*

CCIR Recommendation 567.

3.6 *Hypothetical reference circuit for sound programme circuits*

CCIR Recommendation 502.

3.7 *Hypothetical reference circuit for fixed-satellite service systems for telephony and/or television*

CCIR Recommendation 352.

3.8 *General definition of a hypothetical reference digital path*

CCITT Recommendation G.721.

3.9 *Definitions of a digital radio section and a digital radio path*

CCITT Recommendation G.702, Nos. 9032 and 9034.

RECOMMENDATION 391 *

**HYPOTHETICAL REFERENCE CIRCUIT FOR RADIO-RELAY SYSTEMS
FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX
WITH A CAPACITY OF 12 TO 60 TELEPHONE CHANNELS**

(Question 2/9)

(1956-1959-1963)

The CCIR,

CONSIDERING

- (a) that it is desired to establish hypothetical reference circuits for radio-relay systems, to afford guidance to the designers of equipment and systems for use in international telecommunication networks;
- (b) that hypothetical reference circuits for radio-relay systems should, as far as possible, be in agreement with the hypothetical reference circuits specified by the CCITT for cable systems,

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for frequency-division multiplex radio-relay systems, with a capacity of 12 to 60 telephone channels per radio-frequency channel, should be 2500 km long;
2. that this circuit should include, for each direction of transmission:
 - 3 sets of channel modulators,
 - 6 sets of group modulators,
 - 6 sets of supergroup modulators,
 it being understood that a "set of modulators" comprises a modulator and a demodulator;
3. that this circuit should include, respectively, six sets of radio modulators and demodulators, for each direction of transmission, and that these should divide the circuit into six homogeneous sections of equal length.

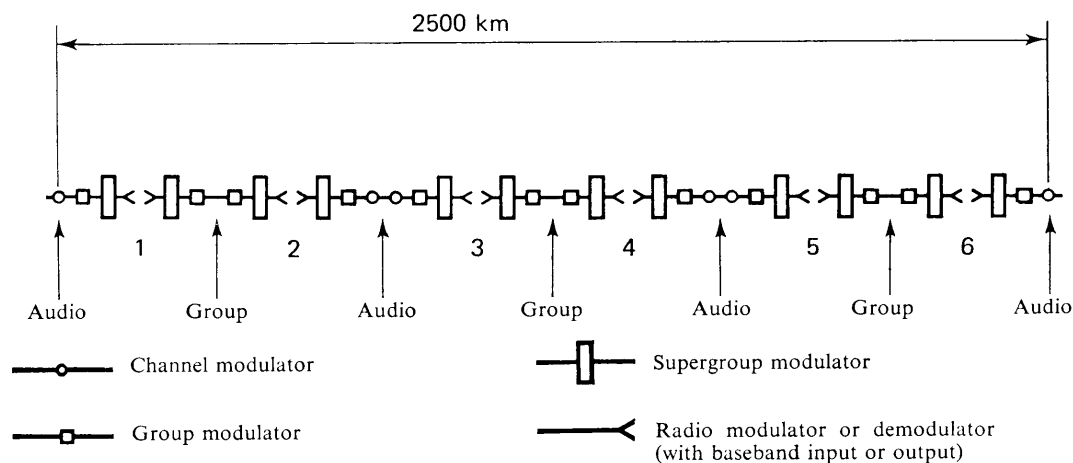


FIGURE 1

*Hypothetical reference circuit for radio-relay systems using frequency-division multiplex
with capacities of 12 to 60 telephone channels per radio-frequency channel*

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

RECOMMENDATION 392 *

**HYPOTHETICAL REFERENCE CIRCUIT FOR RADIO-RELAY SYSTEMS
FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX
WITH A CAPACITY OF MORE THAN 60 TELEPHONE CHANNELS**

(Question 2/9)

(1956–1959–1963)

The CCIR,

CONSIDERING

- (a) that it is desired to establish hypothetical reference circuits for radio-relay systems, to afford guidance to the designers of equipment and systems for use in international telecommunication networks;
- (b) that hypothetical reference circuits for radio-relay systems should, as far as possible, be in agreement with the hypothetical reference circuits specified by the CCITT for cable systems,

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for frequency-division multiplex radio-relay systems, with a capacity of more than 60 telephone channels per radio-frequency channel, should be 2500 km long;
2. that this circuit should include, for each direction of transmission:
 - 3 sets of channel modulators,
 - 6 sets of group modulators,
 - 9 sets of supergroup modulators,it being understood that a “set of modulators” comprises a modulator and a demodulator;
3. that this circuit should include nine sets of radio modulators and demodulators respectively, for each direction of transmission, and that these should divide the circuit into nine homogeneous sections of equal length.

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

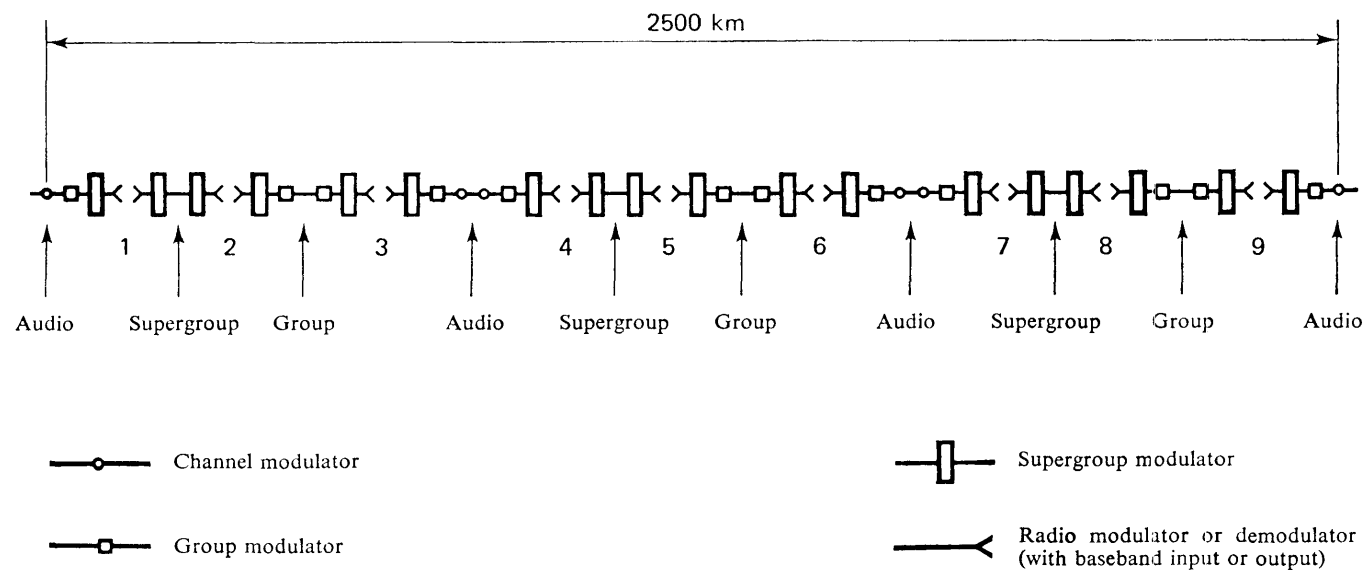


FIGURE 1

Hypothetical reference circuit for radio-relay systems using frequency-division multiplex with a capacity of more than 60 telephone channels per radio-frequency channel

RECOMMENDATION 393-4 *

**ALLOWABLE NOISE POWER IN THE HYPOTHETICAL REFERENCE
CIRCUIT FOR RADIO-RELAY SYSTEMS FOR TELEPHONY USING
FREQUENCY-DIVISION MULTIPLEX**

(Question 2/9)

(1956-1959-1963-1966-1974-1978-1982)

The CCIR,

CONSIDERING

- (a) that the hypothetical reference circuit is intended as a guide to designers and constructors of actual systems;
- (b) that the total noise power in a radio-relay system is dependent on the one hand upon a number of factors concerned with equipment design, and on the other hand upon the path attenuation and the variation of path attenuation with time, which are in turn dependent upon factors such as the spacing of stations and the nature of the intervening terrain;
- (c) that the total noise power in the hypothetical reference circuit should not be such as would appreciably affect conversation in a substantial number of telephone calls or the transmission of telephone signalling;
- (d) that while a conventional load has been adopted for the multiplex signal (see Note 9), no conventional values have been adopted for propagation characteristics in any frequency range or in any climate;
- (e) that it is desirable to prepare, for radio-relay systems, clauses which define a noise performance considered equivalent to that of cable systems;
- (f) that during normal operation, periods of high noise will occur which will cause short interruptions, these interruptions being mostly caused by adverse propagation conditions (see Note 12),

UNANIMOUSLY RECOMMENDS

1. that the noise power at a point of zero relative level in any telephone channel on a 2500 km hypothetical reference circuit for frequency-division multiplex radio-relay systems should not exceed the values given below, which have been chosen to take account of adverse propagation conditions:
 - 1.1 7500 pW0p, psophometrically weighted (Note 14) one-minute mean power (Note 15) for more than 20% of any month;
 - 1.2 47 500 pW0p, psophometrically weighted (Note 14) one-minute mean power (Note 15) for more than 0.1% of any month;
 - 1.3 1 000 000 pW0, unweighted (with an integrating time of 5 ms) for more than 0.01% of any month;
2. that in a part of the hypothetical reference circuit consisting of one or more of the homogeneous sections defined in Recommendation 392, the one-minute mean noise power not exceeded for 20% of the month shall be considered to be proportional to the number of sections involved;
3. that in parts of a hypothetical reference circuit consisting of one or more of the equal homogeneous sections defined in Recommendations 391 and 392, the small percentage of a month in which the one-minute mean power may exceed 47 500 pW0p and in which the noise power (with an integrating time of 5 ms) may exceed 1 000 000 pW0, should be regarded as proportional to the number of homogeneous sections involved;

* — The Recommendation relates only to "line-of-sight" radio-relay systems. Trans-horizon radio-relay systems are dealt with in Recommendation 397.

— This Recommendation should be brought to the attention of the CCITT/CCIR Joint Study Group CMBD.

4. that the following Notes should be regarded as part of the Recommendation:

Note 1. — Noise in the frequency-division multiplex equipments is excluded from the foregoing. On a 2500 km hypothetical reference circuit, the CCITT allows 2500 pW0p mean value for this noise.

Note 2. — This Recommendation relates to the hypothetical reference circuit and the indicated figures are design objectives and it is not intended that they will be quoted in specifications for equipment or used for acceptance tests. Recommendations relating to real circuits are contained in Recommendation 395.

Note 3. — The noise performance of radio-relay systems designed to the *objectives* of this Recommendation is considered equivalent to that of cable systems having noise averaging 3 pW/km over *long* circuits (noise in the frequency-division multiplex equipment is excluded).

Note 4. — It is assumed that noise surges and clicks from power supply systems and from switching apparatus are reduced to negligible proportions and will not be taken into account when calculating the noise power.

Note 5. — For the calculation of noise in hypothetical reference circuits the characteristics preferred by the CCIR and to be found in their Recommendations, should be used where appropriate; where more than one value is recommended, the designer should indicate the value chosen.

Note 6. — The requirements of the Recommendation are unlikely to be met unless the line-of-sight radio-relay system has adequate clearance over intervening terrain.

Note 7. — Designers should indicate their assumptions regarding the lengths of repeater sections, the nominal attenuation between transmitter outputs and receiver inputs, intermodulation noise in feeders and the radio path, possible interference between the radio channels of the system under consideration, precautions taken against fading (in particular, the use or not of diversity reception and protection channels) and the distribution curve of fading over short periods of time. Designers are expected to fit their noise distribution curves to fall below the figures specified in § 1.1 and 1.2.

Note 8. — It is assumed that, at junctions between the homogeneous sections of a hypothetical reference circuit, the telephone channels, groups, supergroups and mastergroups are interconnected at random; and that the noise coming from the homogeneous sections of the hypothetical reference circuit is power-additive.

Note 9. — It is assumed that, during the busy hour, the multiplex signal can be represented by a uniform-spectrum signal, the mean power absolute level of which, at a point of zero relative level is equal to $(-15 + 10 \log_{10} N)$ dBm for 240 channels or more, and $(-1 + 4 \log_{10} N)$ dBm for numbers of channels between 12 and 240 (this value is provisional for systems with a capacity of less than 60 channels), N being the total number of channels for which the radio-relay system is to be designed.

Note 10. — The requirement indicated by § 1.3 is related to the need to transmit signalling for telephony satisfactorily. It covers also the performance requirement for frequency-modulation VF telegraphy at 50 bauds over telephone channels. For amplitude-modulation VF telegraphy at 50 bauds, the CCITT has stated performance requirement in its Recommendation G.442.

Note 11. — Recommendation 357 fixes the maximum permissible value of interference caused by systems in the fixed-satellite service to a telephone channel of a radio-relay system. The values indicated in Recommendation 357 (or smaller values calculated taking account of the parameters of the radio-relay system) should, in principle, be included in the general objectives with regard to noise (see CCITT Recommendation G.222, Vol. III, Fascicle III.2). In certain cases, however, additional noise may cause the limits fixed in the general objectives to be slightly exceeded. This should not cause serious concern, provided that the provisions of CCITT Recommendation G.222, § 2.6 are met.

Note 12. — Adverse propagation conditions can result in a decrease of the wanted signal and/or an increase in the level of interfering signals.

Note 13. — This Recommendation applies only when the system is considered to be available in accordance with the non-availability criteria defined in Recommendation 557 and includes periods of high noise exceeding 1 000 000 pW0 unweighted which persist for periods of less than 10 consecutive seconds. Periods of high noise which persist for 10 consecutive seconds duration or longer are taken into account by Recommendation 557.

Note 14. — The level of uniform-spectrum noise power in a 3.1 kHz band must be reduced by 2.5 dB to obtain the psophometrically weighted noise power.

Note 15. — The one-minute mean power was chosen by CCITT Study Group XII which is responsible for all studies concerned with the quality of telephone transmission (CCITT *Red Book*, 1957 and Recommendation G.222, Vol. III, Fascicle III.2).

RECOMMENDATION 395-2 *

**NOISE IN THE RADIO PORTION OF CIRCUITS TO BE ESTABLISHED
OVER REAL RADIO-RELAY LINKS FOR FDM TELEPHONY ****

(Question 2/9)

(1959-1963-1966-1978)

The CCIR,

CONSIDERING

- (a) that provisional maximum values for the noise in hypothetical reference circuits are given in Recommendation 393 as a guide to designers of equipment;
- (b) that real circuits sometimes differ in composition from the hypothetical reference circuit (Recommendation 392) (see Fig. 1);
- (c) that the hypothetical reference circuit shows a single 2500 km telephone circuit and that circuits carried over real links will share many of the component baseband sections with other telephone circuits of lesser length. While the performance requirements of these shorter circuits could safely be relaxed to ease the planning of links, the longer international circuits must not be allowed to suffer the full cumulative effect of any relaxations which are permissible for the shorter circuits;
- (d) that, in some circumstances, a planned real link may comprise a larger number of baseband points than is envisaged in the hypothetical reference circuit;
- (e) that equipment, which has been designed to satisfy the design objectives (Recommendation 393) for the hypothetical reference circuit (Recommendation 392), cannot be expected to give the same standard of performance when used in a circuit established over real links, the actual composition of which differs from that of the hypothetical reference circuit or its homogeneous section;
- (f) that, therefore, it is necessary to give planning objectives for noise as a guide in the planning of links forming part of international circuits;
- (g) that noise contributions arise from several sources; some of these contributions depend on the number of baseband equipments and others on the law of addition for intermodulation noise in a long chain of repeaters or in permanently connected group links (defined in CCITT Recommendation G.211), and that these contributions differ in different parts of the baseband-frequency spectrum,

UNANIMOUSLY RECOMMENDS

1. that, in circuits established over real links which do not differ appreciably from the hypothetical reference circuit, the psophometrically weighted *** noise power at a point of zero relative level in the telephone channels of frequency-division multiplex radio-relay systems of length L , where L is between 280 and 2500 km, should not exceed:

1.1 $3 L$ pW one-minute mean power for more than 20% of any month;

1.2 47 500 pW one-minute mean power for more than $(L/2500) \times 0.1\%$ of any month; it is recognized that the performance achieved for very short periods of time is very difficult to measure precisely and that in a circuit carried over a real link, it may, after installation, differ from the planning objective;

* This Recommendation applies only to line-of-sight radio-relay systems suitable for use in the international telephone network.

** The term "circuit" is understood to refer to a circuit as defined in No. 02.06 of the ITU *List of Essential Telecommunication Terms*, Second Impression, Geneva, 1961, Part I. The calculations are performed between the points R' and R (see Recommendation 380) of each radio section which enters into the circuit under consideration.

*** The level of uniform-spectrum noise power in a 3.1 kHz band must be reduced by 2.5 dB to obtain the psophometrically weighted noise power.

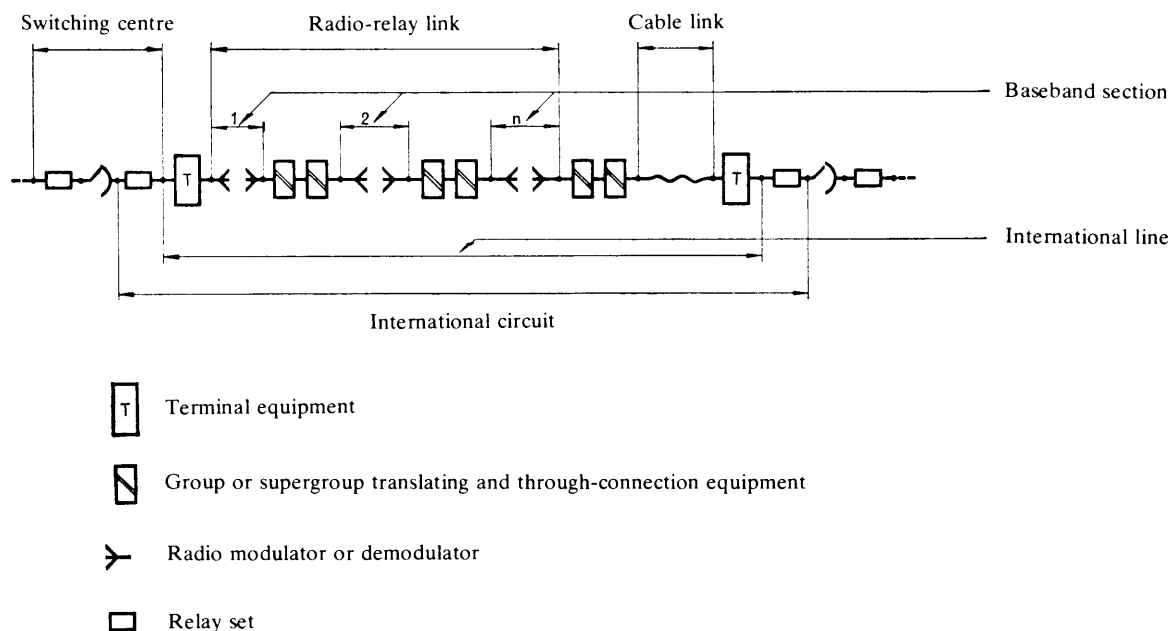


FIGURE 1 – Constitution of an international circuit comprising real links on radio-relay and cable systems

(The Figure is intended to illustrate the terms used in this Recommendation)

2. that circuits to be established over real links, the composition of which, for planning reasons, differs substantially from the hypothetical reference circuit, should be planned in such a way that the psophometrically weighted noise power at a point of zero relative level in a telephone channel of length L , where L is between 50 and 2500 km, carried in one or more baseband sections of frequency-division multiplex radio links, should not exceed:

2.1 for $50 \text{ km} \leq L \leq 840 \text{ km}$:

2.1.1 $3 L \text{ pW} + 200 \text{ pW}$ one-minute mean power for more than 20% of any month,

2.1.2 $47\,500 \text{ pW}$ one-minute mean power for more than $(280/2500) \times 0.1\%$ of any month when L is less than 280 km, or more than $(L/2500) \times 0.1\%$ of any month when L is greater than 280 km;

2.2 for $840 \text{ km} < L \leq 1670 \text{ km}$:

2.2.1 $3 L \text{ pW} + 400 \text{ pW}$ one-minute mean power for more than 20% of any month,

2.2.2 $47\,500 \text{ pW}$ one-minute mean power for more than $(L/2500) \times 0.1\%$ of any month;

2.3 for $1670 \text{ km} < L \leq 2500 \text{ km}$:

2.3.1 $3 L \text{ pW} + 600 \text{ pW}$ one-minute mean power for more than 20% of any month,

2.3.2 $47\,500 \text{ pW}$ one-minute mean power for more than $(L/2500) \times 0.1\%$ of any month;

3. that the following Notes should be regarded as part of the Recommendation:

Note 1. – Noise in the frequency-division multiplex equipment is excluded. On a 2500 km hypothetical reference circuit the CCITT allows 2500 pW mean value for this noise in any hour.

Note 2. – It is assumed that noise surges and clicks from power supply systems and from switching apparatus are reduced to negligible proportions and will not be taken into account when calculating the noise power:

Note 3. — It is permissible to assume that noise coming from individual baseband sections is power-additive, but only if the baseband spectra of adjacent baseband sections are substantially different.

Note 4. — It will be assumed that, during the busy hour, the multiplex signal can be represented by a uniform-spectrum signal, the mean power absolute level of which at a point of zero relative level, is equal to $(-15 + 10 \log_{10} N)$ dBm for 240 channels or more, and $(-1 + 4 \log_{10} N)$ dBm for numbers of channels between 12 and 240 (this value is provisional for systems the capacity of which is less than 60 channels), N being the number of channels for which the radio-relay system is designed.

REPORT 288-2

NOISE IN CIRCUITS FORMING PART OF VERY LONG TELEPHONE CONNECTIONS SET UP OVER RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

(Study Programme 2B/9)

(1966–1970)

1. Introduction

This Report is a provisional reply to Study Programme 2B/9.

The provision of low-noise channels over large capacity systems, designed in accordance with Recommendation 393, has been considered in the light of information contributed to Study Group 9 and summarized by CMBD.

This reply assumes that the required low-noise channels should have a noise power, excluding the noise from frequency-division multiplex equipment, not worse than one-third of the noise power allowed in Recommendation 393.

The methods of provision correspond respectively to Study Programme 2B/9, § 1 and 2:

- selection of low-noise channels;
- adaptation of a system to provide low-noise channels.

2. Selection of low-noise channels from large capacity systems designed in accordance with Recommendation 393

Traffic and other practical considerations indicate that channel selection should be considered worthwhile only if at least 10% of the nominal capacity of a system can be made available as low-noise channels.

In the light of the limited documentation available up till now, the indications are that this requirement would not be met in general, but that certain systems might be capable of doing so.

3. Adaptation of large capacity systems designed in accordance with Recommendation 393 to provide low-noise channels

Adaptation entails removal of channels from service and/or removing or modifying pre-emphasis characteristics to increase the effective sending level of the low-noise channels.

In a number of radio-relay systems, test results indicate that in the extreme case where the maximum number of low-noise channels is to be derived, some 50 to 70% of the original capacity of the system would be sacrificed. In another case, where only 10% of the capacity of a radio-relay system is required as low-noise channels, up to 50% of the original channel capacity would have to be sacrificed. In the latter case, the usable portion of the original capacity of the system would consist of the 10% low-noise channels and 40% or more as channels giving up to 3 pW/km performance. In between these extreme cases (i.e., when the maximum number of low-noise channels is needed and when 10% of low-noise channels would suffice) intermediate conditions could be realized.

The process of adaptation appears, in the light of present information, to be rather costly from the point of view of baseband utilization.

Note. — The required performance for low-noise circuits is not necessarily obtained merely by reducing the amount of baseband equipment used on these circuits.

The above summary applies when the low-noise circuits are required to contribute not more than one-third of the noise power allowed for equipment designed in accordance with Recommendation 393.

Study Group 9 considered CCITT Recommendation G.143 and has drawn the conclusion that it would be sufficient if a low-noise circuit were to produce not more than one-half of the noise power allowed in Recommendation 393, corresponding to not more than 1.5 pW/km (averaged over a long distance). These figures are exclusive of the noise caused by frequency-division multiplex equipment.

For the noise in the multiplex equipment, CMBD has estimated 5000 to 7000 pW for the international part of the connection which is about 20 000 km long. The multiplex noise therefore would average 0.25 to 0.35 pW/km over long circuits.

The noise performance required in Recommendation G.143 is 1 to 2 pW/km, including that in the multiplex equipment and the figure of 1.5 pW/km plus the multiplex noise would result in 1.75 to 1.85 pW/km, which is well within the requirements of Recommendation G.143.

If this calculation is found acceptable to CMBD, it would appear that the conclusions in the above, regarding the number of normal channels which need to be sacrificed to produce low-noise channels, should be reconsidered in terms of the 1.5 pW/km requirement rather than the 1 pW/km requirement.

4. Other ways of obtaining low-noise channels

In the following it will be assumed that a noise contribution, from a radio-relay system, of 1.5 pW/km is an acceptable objective for low-noise circuits and that this objective could be attained.

CMBD has suggested that a new hypothetical reference circuit, as well as new design objectives, could be envisaged for systems planned to give only low-noise channels.

Study Group 9 has considered the desirability of introducing a further hypothetical reference circuit for low-noise circuits and found that many administrations would like to avoid the creation of a further hypothetical reference circuit.

The reasons are as follows:

- 4.1 The performance requirement for low-noise channels differs by only 3 dB from the requirement of Recommendation 393 and it seems quite possible to define noise performance adequately without introducing a new hypothetical reference circuit.
- 4.2 If a new hypothetical reference circuit were introduced, it would lead to design of new types of equipment which would, in general, not be compatible with equipment designed to the existing hypothetical reference circuit.
- 4.3 It is very desirable to use the smallest possible number of types of equipment in the majority of radio stations.
- 4.4 It is highly desirable that low-noise systems and normal systems on a route should be capable of sharing protection and reserve circuits. This is readily attained if both systems use equipment designed in accordance with Recommendation 393.

In the above, compatibility implies that the two grades of circuit performance are obtainable by the use of the same station sites and antennas and that mutual interference between different radio-frequency channels in the station is not made worse, when equipment providing low-noise performance circuits is introduced. These considerations have led to a strong desire to use the same type of radio-frequency equipment for both grades of service. The low-noise grade of service may then be obtained by using equipment designed in accordance with Recommendation 393 at all stations with, however, minor modifications at stations where the baseband signal is available.

These modifications would comprise:

- reduction in the quantity of circuits and in the baseband frequency range;
- readjustment of the frequency deviation per channel (Recommendation 404) to a new value to be defined later;
- provision of new pre- and de-emphasis networks appropriate to the new maximum baseband frequency (Recommendation 275).

5. Conclusions and further studies

Study Group 9 is of the opinion that, when many low-noise telephone channels are required on a route, they could be provided by using equipment designed in accordance with Recommendation 393, but operated differently. At the same time, the study should be pursued of radio-relay systems specially designed for the purpose of providing circuits ("low-noise circuits") all of which meet a noise objective 3 dB better than the one at present recommended.

Adequate values must be determined for each of the clauses in Recommendation 393.

The further study is particularly related to § 3 and 4 of Study Programme 2B/9.

Information is required on the consequences of low-noise requirements on the design of systems, in particular because of constraints arising from sharing of certain frequency bands between radio-relay systems and satellite communication systems. Broadband systems of moderate and of high capacity are of primary interest. This Report should be brought to the notice of CMBD.

RECOMMENDATION 396-1

HYPOTHETICAL REFERENCE CIRCUIT FOR TRANS-HORIZON RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

(Question 7/9)

(1963-1966)

The CCIR,

CONSIDERING

- (a) that trans-horizon radio-relay systems may form part of an international connection;
- (b) that the characteristics of trans-horizon systems do not allow the application of existing hypothetical reference circuits for line-of-sight radio-relay systems;
- (c) that trans-horizon systems are generally limited to 120 telephone channels not utilizing supergroup through-connection;
- (d) that the specific characteristics of trans-horizon systems are usually individually optimized,

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for trans-horizon radio-relay systems should be 2500 km long;
2. that the hypothetical reference circuit for trans-horizon radio-relay systems should not be divided into homogeneous sections of fixed length because these systems, as distinct from line-of-sight systems, are usually composed of long radio sections, the length of which depends on local conditions and may vary considerably (e.g. between 100 and 400 km);
3. that, if a radio section under study is L km long, the hypothetical reference circuit should be composed of $2500/L$ sections of this type in tandem, the value $2500/L$ being taken to the nearest whole number;
4. that the hypothetical reference circuit should include:
 - 3 sets of channel modulators,
 - 6 sets of group modulators,
 - 6 sets of supergroup modulators,

for each direction of transmission, the term "set of modulators" being taken to comprise a modulator and a demodulator.

RECOMMENDATION 397-3

**ALLOWABLE NOISE POWER IN THE HYPOTHETICAL REFERENCE CIRCUIT
OF TRANS-HORIZON RADIO-RELAY SYSTEMS FOR TELEPHONY
USING FREQUENCY-DIVISION MULTIPLEX**

(Question 7/9)

(1963-1966-1970-1978)

The CCIR,

CONSIDERING

- (a) that a hypothetical reference circuit for trans-horizon radio-relay systems is established in Recommendation 396, as a guide to the designers of systems in use in international telecommunication networks;
- (b) that wherever practicable, trans-horizon radio-relay systems should meet the same performance regarding noise as recommended for line-of-sight systems in Recommendation 393;
- (c) that, nevertheless, the achievement of this desirable objective would sometimes result in a very high, even prohibitive cost or a power that is impractically high, or such that is likely to result in harmful interference;
- (d) that this might well retard desirable extensions of the telephone network,

UNANIMOUSLY RECOMMENDS

1. that, from the point of view of performance, trans-horizon radio-relay systems be divided into two classes;
2. that, when a trans-horizon system is intended to operate between two points for which other transmission systems could be used without excessive difficulty, e.g. line-of-sight radio-relay, underground cable, etc., the hypothetical reference circuit should be established in accordance with Recommendation 396. The noise power at the end of this hypothetical reference circuit will be calculated by statistical combination of the noise power in each of its radio sections. The statistical distribution curve of the one-minute mean psophometric power, during the most unfavourable month, should then pass below the points defined in Recommendation 393, § 1.1 and 1.2;
3. that, if a trans-horizon system is to be used between points, for which other transmission systems cannot be used without excessive difficulty, and if the condition laid down in Recommendation 393 cannot be met without excessive difficulty, the following conditions will apply, once the statistical noise power distribution at the end of the hypothetical reference circuit has been calculated by the method set out in § 2:
 - 3.1 the mean psophometric power during one minute must not exceed 25 000 pW0p for more than 20% of any month;
 - 3.2 the mean psophometric power during one minute must not exceed 63 000 pW0p for more than 0.5% of any month;
4. that for the two classes of system defined above, the unweighted noise power (with an integration time of 5 ms) must meet Recommendation 393, § 1.3, but with the percentage of the most unfavourable month changed to 0.05%, for the systems referred to in § 3 of the present Recommendation.

Note 1. — All the values given above include the intermodulation noise in the radio part of the system. On the other hand, noise within the frequency-division multiplex equipment is excluded. On a hypothetical reference circuit 2500 km long, the CCITT authorizes a mean value of 2500 pW0p for this latter noise.

Note 2. — The method of statistical combination referred to in § 2 is described in detail in the paper "Thermal noise in multi-section radio links" by B. B. Jacobsen, IEE Monograph No. 262 R (1957).

Note 3. — The method of calculation of mean noise power in a telephone channel from the distribution of the received signal amplitude in each receiver is given in "Puissance moyenne de bruit dans les faisceaux hertziens transhorizon à modulation de fréquence" by L. Boithias and J. Battesti, *Annales des télécommunications* (May-June, 1963).

Note 4. — Systems which comply only with the terms of § 3 and 4, will be excluded from the main international and intercontinental routes; consequently in a world-wide connection, a maximum of one or two circuits of medium length will be encountered, which comply only with the terms of § 4 with a percentage of 0.05%; as far as telephone signalling is concerned, this state of affairs is acceptable. Under these conditions, the transmission of voice-frequency telegraphy is also satisfactory (see the reply by Study Group CMBD (CCITT/CCIR) to Question 1/C, annexed to Docs. IX/240 and IX/164, 1963-1966).

RECOMMENDATION 593

**NOISE IN REAL CIRCUITS OF MULTI-CHANNEL
TRANS-HORIZON FM RADIO-RELAY SYSTEMS OF LESS THAN 2500 km**

(Question 7/9)

(1982)

The CCIR,

CONSIDERING

- (a) that provisional maximum values for noise power in the hypothetical reference circuit of trans-horizon systems are given in Recommendation 397 as a guide to the designers of equipment;
- (b) that in many cases the real circuits differ in both composition and length from the hypothetical reference circuit described in Recommendation 396;
- (c) that recommendations governing noise in real trans-horizon radio-relay systems should be issued for guidance in the engineering of radio links,

UNANIMOUSLY RECOMMENDS

1. that in the case described in Recommendation 397, § 3, the statistical distribution of noise at a point of zero relative level in the telephone channel of a real communication system of length L km (less than 2500 km), the composition of which does not substantially differ from that of the hypothetical reference circuit, should be defined as follows:

- 1.1 the psophometric mean-minute noise power should not exceed $10 L$ pW for more than 20% of the time in any month;
- 1.2 the psophometric mean-minute noise power should not exceed 63,000 pW for more than $(0.5 L/2500)\%$ of the time in any month;

2. that the following Notes should be considered as part of the Recommendation:

Note 1. — Noise in the frequency-division multiplex equipments is excluded from the foregoing. On a 2500 km hypothetical reference circuit, the CCITT allows 2500 pW_{0p} mean value for this noise.

Note 2. — It is assumed that noise surges and clicks from power supply systems and from switching apparatus are reduced to negligible proportions and will not be taken into account when calculating the noise power.

Note 3. — It is assumed that, at junctions between the homogeneous sections of a hypothetical reference circuit, the telephone channels, groups, supergroups and mastergroups are interconnected at random; and that the noise coming from the homogeneous sections of the hypothetical reference circuit is power-additive.

Note 4. — It is assumed that, during the busy hour, the multiplex signal can be represented by a uniform-spectrum signal, the mean power absolute level of which, at a point of zero relative level is equal to $(-1 + 4 \log N)$ dBm for numbers of channels between 12 and 240 (this value is provisional for systems with a capacity of less than 60 channels), N being the total number of channels for which the radio-relay system is to be designed.

RECOMMENDATION 555

**PERMISSIBLE NOISE IN THE HYPOTHETICAL REFERENCE CIRCUIT
OF RADIO-RELAY SYSTEMS FOR TELEVISION ***

(Questions 2/9 and 3/9)

(1978)

The CCIR,

CONSIDERING

- (a) that the hypothetical reference circuit defined in Recommendation 567 is intended as a guide to designers and constructors of actual systems;

* The Recommendation relates only to "line-of-sight" radio-relay systems. For a definition of the characteristics of television systems see Report 624.

- (b) that the total noise power in a radio-relay system is dependent on the one hand upon a number of factors concerned with equipment design, and on the other hand upon the path attenuation and the variation of path attenuation with time, which are in turn dependent upon factors such as the spacing of stations and the nature of the intervening terrain;
- (c) that the total noise power in the hypothetical reference circuit should not be such as would appreciably affect the transmission of television signals;
- (d) that the minimum signal-to-noise ratios which should be achieved are stated in § 3.2.1 of Part D of Recommendation 567; however, certain difficulties arise in the use of a noise objective relating to 1% of a month and it is therefore desirable to express the noise objective in terms of other percentages of a month;
- (e) that, on radio-relay systems, it may be necessary to accept slightly lower signal-to-noise ratios for very small percentages of time;
- (f) that, on radio-relay systems, it is possible to provide a better signal-to-noise ratio for the majority of the time than is required by Recommendation 567;
- (g) that the relative distribution with time of noise in radio-relay systems for television or frequency-division multiplex telephony, will be similar and it is appropriate therefore to employ similar methods for specifying the noise performance;
- (h) that a simple method is required for defining the noise contributions of the different sections of the hypothetical reference circuit;
- (j) that to take account of the daily and seasonal variations in radio propagation conditions the period of time considered should be long, e.g. a month;
- (k) that in Recommendation 567, the use of instruments with an effective time constant or integrating time of 1 s, is recommended and administrations are asked to make measurements with instruments having this time constant,

UNANIMOUSLY RECOMMENDS

1. that in the 2500 km hypothetical reference circuit for the transmission of television, the ratio expressed in decibels, of the nominal amplitude of the luminance signal to the r.m.s. amplitude of the weighted noise, measured under the conditions given in Parts B and C of Recommendation 567, should not fall below the following values,

1.1 57 dB for more than 20% of a month; 1.2 45 dB for more than 0.1% of a month;	}	these values are provisional;

2. that, in a part of a hypothetical reference circuit consisting of one or two of the three identical homogeneous sections defined by Recommendation 567, Part A, the mean noise power which should not be exceeded for more than 20% of a month shall be considered to be proportional to the number of homogeneous sections involved (see Note 3);

3. that, in a part of a hypothetical reference circuit consisting of one or two of the three identical homogeneous sections defined by Recommendation 567, Part A, the small percentages of a month, during which the signal-to-noise ratio may fall below the values indicated in § 1.2 of RECOMMENDS 1, shall be regarded as proportional to the number of homogeneous sections involved (see Note 4).

Note 1. — The requirements of the Recommendation are unlikely to be met unless the line-of-sight radio-relay system has adequate clearance over intervening terrain.

Note 2. — Based on the information supplied by CMBD obtained from measurements, with a time constant of one minute, of the total noise (thermal noise and cross-talk) of telephone circuits, it is likely that signal-to-thermal noise ratio for 20% of one month and the signal-to-thermal noise ratio for 0.1% of one month will differ by about 12 dB at the most; the signal-to-thermal noise ratio obtained during at least 99% of one month, mentioned by the television specialists, is likely to be lower by about 4 dB than the signal-to-noise ratio for 20% of a month; this explains the difference between the values 57 dB and 45 dB, see § 1.1 and 1.2 of RECOMMENDS 1, these values being such, that the signal-to-noise ratio obtained during at least 99% of a month will be 53 dB, as the television specialists desire.

As mentioned in RECOMMENDS 1, these values are provisional and will, if necessary, be reviewed in the light of the tests made with a time constant of 1 s.

Note 3. — The law of proportionality given in RECOMMENDS 2, is based on the assumption that noise due to fading can be neglected for all but 20% of a month. Therefore, the value of 57 dB given in § 1.1 of RECOMMENDS 1 can be regarded as the objective for the signal-to-weighted noise ratio in the absence of fading.

Note 4. — The law of proportionality given in RECOMMENDS 3, is based on the assumption that individual fades which are of such magnitude that they occur for only very small percentages of time, and originate in different sections of a complete circuit, do not occur simultaneously. This assumption may not always be completely justifiable, but the error is small, and the approximation is regarded as acceptable.

Note 5. — This Recommendation relates to the hypothetical reference circuit. The figures given are design objectives, and it is not intended that they should be quoted in specifications of equipment or used for acceptance tests.

REPORT 375-3

NOISE OBJECTIVES FOR SOUND-PROGRAMME CIRCUITS 2500 km LONG PROVIDED BY MEANS OF ANALOGUE RADIO-RELAY SYSTEMS

(Question 3/9)

(1966-1974-1978-1982)

1. Introduction

Study Programme 2C/IX (1966) and its Annex were accepted for study by Special Joint Study Group C (now Study Group CMBD) under its Question 10/C in 1965.

Special Joint Study Group C undertook the necessary coordination with CCITT Study Group XV and also the responsibility for any liaison required with broadcasting organizations.

The question was studied at the 1966 meeting of the Special Joint Study Group C with a view to providing a reply for transmission to CCIR Study Group 9 and the following paragraphs are based on this reply. The noise clauses, given in § 3 and 4 below, are acceptable to CCIR Study Group 9 and could be the subject of a future CCIR Recommendation.

The explanatory clause, given in § 2, has been included to clarify the noise clauses.

All the values given below are to be understood to refer to a 2500 km hypothetical reference circuit (h.r.c.) for sound-programmes, as defined in Recommendation 502. For real circuits with a constitution differing from that of the h.r.c., rules for subdividing the noise requirements are given in Recommendation 605.

Further information will emerge in due course as progress is made with Study Programme 17D/CMTT.

2. Assumptions and terminology

The expression dBq0ps is used to indicate noise levels in a programme circuit, which are psophometrically weighted according to Recommendation 468 and measured in decibels relative to 0.775 V at a point of zero relative level in that circuit. From the measured weighted noise level the signal-to-noise ratio can be derived if the maximum programme level is considered. This value is defined by the peak voltage of a sinusoidal signal having an r.m.s. value of 2.2 V (across an impedance of 600 ohms) at a point of zero relative level, i.e. a signal having an absolute level of 9 dBm in accordance with CCITT Recommendations J.14/N.15. A noise level of e.g. -42 dBq0ps thus corresponds to a signal-to-weighted noise ratio of 51 dB.

In measuring, or when calculating programme circuit noise, the transmission system should be suitably loaded.

2.1 When the programme circuit is carried on a radio-relay system for telephony, the telephone channel frequency band should be loaded conventionally (see Recommendation 393).

2.2 When the programme circuit is carried on a radio-relay system for television, the television channel should be loaded with the standard test signal for conventional loading, as defined in Recommendation 570.

(Special test signals used for the television channel may cause substantial disturbance in an associated programme channel. This might in some circumstances occur at times when the programme channel is in service.)

The problem of television test signals comes within the scope of CCIR Study Group 11 and of the CMTT.

2.3 When more than one programme circuit is carried on a radio-relay system for telephony or television the programme circuits not under test should be loaded with the conventional test signal simulating sound-programme signals as defined in Recommendation 571.

3. Noise in programme circuits set up over radio-relay systems intended for telephony

When programme circuits are set up on radio-relay links in place of telephone channels which conform to the general noise objectives (Recommendation 393), the weighted noise level can be expected to vary with time.

The following values for a hypothetical reference circuit of 2500 km can be deduced from Recommendation 393 by making certain assumptions (see Note):

TABLE I

Types of sound-programme circuits			One-minute mean value of weighed noise level			
Bandwidth (kHz)	Recommendation	Objectives of weighted noise levels (dBq0ps)	For not more than 20% of a month		For not more than 0.1% of a month	
			without compandor (dBq0ps)	with compandor (dBq0ps)	without compandor (dBq0ps)	with compandor (dBq0ps)
7	503 ⁽¹⁾	– 44	– 34.6	– 46.6	– 27.6	– 39.6
10	504 ⁽¹⁾	– 39	– 36.4	—	– 29.4	—
15	505 ⁽¹⁾	– 42	– 36.2	– 48.2	– 29.2	– 41.2

(¹) Corresponding CCITT Recommendations are J.23, J.22 and J.21.

Note that the noise power is expressed as the mean over one minute and that the noise power in Table I is a consequence of the design of systems to provide telephone channels meeting the clauses in Recommendation 393.

Table I shows that the noise objectives cannot be met without an additional noise reduction method. Considering that CCITT Recommendations J.31 and J.34 specify equipment with pre-/de-emphasis and companding facilities for 15 and 7 kHz sound-programme circuits only, these types of equipment should preferably be used in radio-relay systems for telephony. This can be done without any risk of overloading.

Programme transmission channels, based on low-noise telephone channels (1.5 pW/km) rather than on normal performance channels, will be studied by CMBD (low-noise channels form the subject of Report 288).

Note. — The translation of the weighted noise level in a telephone channel to the weighted noise level in a programme channel depends on the following factors:

TABLE II

Type of programme circuit	7 kHz	10 kHz	15 kHz
Conversion of telephone weighted noise to unweighted noise in 3.1 kHz bandwidth (dB)	+ 2.5	+ 2.5	+ 2.5
Correction for actual bandwidth (dB)	+ 3.5	+ 5.1	+ 6.8
Improvement due to the use of pre-emphasis (Recommendation J.17) (dB)	– 4	– 5.3 ⁽¹⁾	– 6.7 ⁽¹⁾
Weighting effect for de-emphasized white noise (dB)	+ 3.9	+ 4.8	+ 4.7
Correction for r.m.s. to quasi-peak measurement (dB)	+ 5	+ 5	+ 5
Allowance for loss between programme zero level and telephone zero level at sending end (dB)	+ 4.5	+ 1.5	+ 1.5
Total effect without compandor	+ 15.4	+ 13.6	+ 13.8
Improvement due to the use of compandor (Recommendations J.31/J.34) including an additional 5 dB reduction of zero level at sending end (dB)	– 12		– 12
Total effect with compandor (dB)	+ 3.4		+ 1.8

(¹) Taken from Report 496 and corrected by 1.5 dB.

The total effect figure must be added to the weighted noise level in one telephone channel to find the weighted noise level in the programme channel.

When the one minute mean noise levels in a telephone channel are -50 dBm0p and -43 dBm0p respectively the corresponding noise levels in a programme circuit transmitted by the same carrier frequency would be as shown in Table I. (These figures include noise of the multiplex equipment.)

4. Programme circuit set up on a sub-carrier of a radio-relay link for television

The noise objectives defined below are those of Recommendation 504 for 10 kHz programme circuits (20% of a month only) and of Recommendation 505 for 15 kHz programme circuits. The 1% and 0.1% values of a month for 10 kHz circuits are established with the same differences against the value for 20% of a month as with 15 kHz circuits.

These objectives apply for programme circuits such as those defined in Recommendation 402 and Report 289.

TABLE III — *Noise objectives for a 2500 km programme circuit set up by means of a sub-carrier*

Type of programme circuit (kHz)	Weighted noise level in a programme circuit (dBq0ps) exceeded for the percentage of any month shown (one-second measurement)		
	20%	1%	0.1%
10	-39	-35	-27
15	-42	-38	-30

Note that in Table III the noise levels are given in terms of one second average. This and the differences between the three percentages conform with Recommendation 555.

RECOMMENDATION 556

**HYPOTHETICAL REFERENCE DIGITAL PATH FOR RADIO-RELAY SYSTEMS
FOR TELEPHONY*; SYSTEMS WITH A CAPACITY ABOVE
THE SECOND HIERARCHICAL LEVEL**

(Study Programme 12C/9)

(1978)

The CCIR,

CONSIDERING

- (a) that it is desirable to define a hypothetical reference digital path for digital radio-relay systems, to afford guidance to the designers of equipment and systems for use in international telecommunication networks;
- (b) that the hypothetical reference digital path for digital radio-relay systems should, as far as possible, be in agreement with the 2500 km hypothetical reference digital paths as specified by the CCITT;
- (c) that the capacity of digital radio-relay systems should be that of a CCITT recommended hierarchical level or an integral multiple of it,

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference digital path for digital radio-relay systems with a capacity above the second hierarchical level, should be 2500 km long (see Note 1);
2. that this digital path should include, for each direction of transmission, nine sets of digital multiplexing equipment at the CCITT recommended hierarchical levels, it being understood that a set of digital multiplexing equipment comprises a number of associated multiplexers and demultiplexers;
3. that this digital path should include nine consecutive identical digital radio sections of equal length (see Note 2);
4. that this hypothetical reference digital path should be as represented in Fig. 1.

Note 1. — In conformity with considering (c) this hypothetical reference digital path also applies to systems with a capacity which is an integral multiple of the second or higher hierarchical level.

Note 2. — A digital radio section consists of two consecutive radio terminal equipments and their interconnecting transmission medium which together provide the whole of the means of transmitting and receiving between two consecutive digital distribution frames (or equivalents), a digital signal of specified rate (see CCITT Recommendation G.702). The characteristics of some radio-relay systems (for instance code conversion, insertion of justification bits, parity bits and service bits) may cause the bit rate within the digital radio section to be different from the CCITT recommended hierarchical level or an integral multiple of it.

* In the 64 kbit/s path (as defined by the CCITT), signals other than telephony may be accommodated.

For information see Recommendation 594 and Report 930.

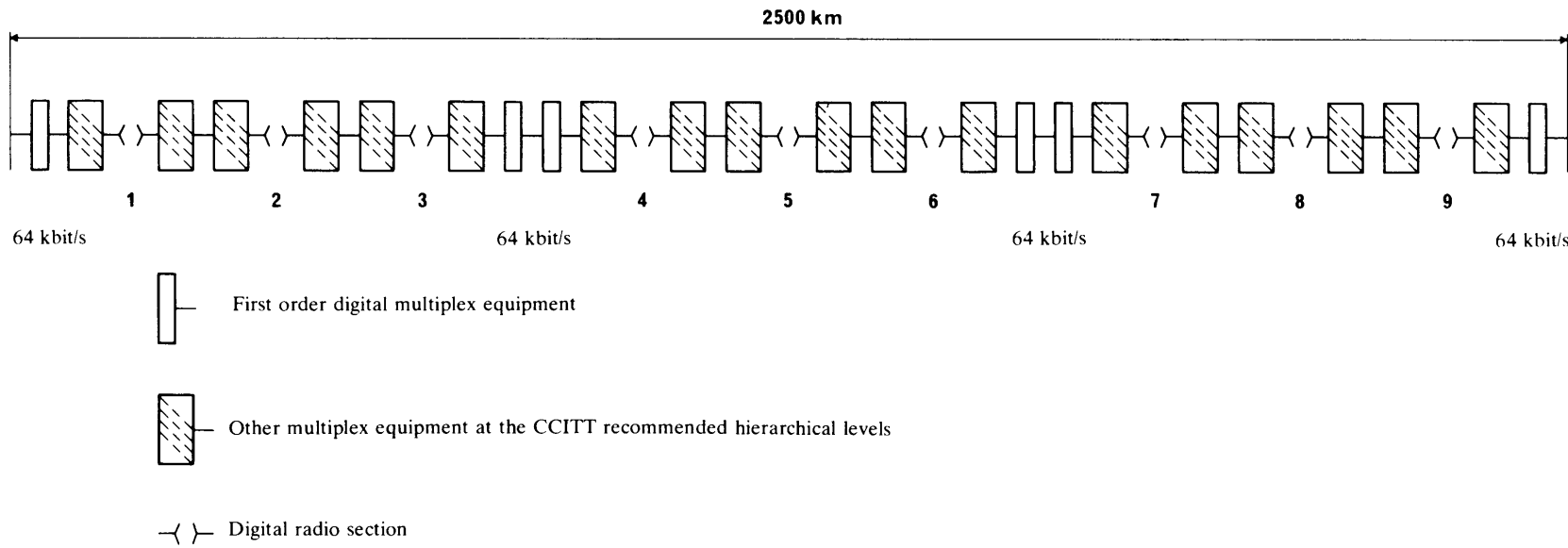


FIGURE 1 – Hypothetical reference digital path for radio-relay systems with a capacity above the second hierarchical level

RECOMMENDATION 594

**ALLOWABLE BIT ERROR RATIOS AT THE OUTPUT
OF THE HYPOTHETICAL REFERENCE DIGITAL PATH
FOR RADIO-RELAY SYSTEMS FOR TELEPHONY ***

(Question 12/9)

(1982)

The CCIR,

CONSIDERING

- (a) that the performance objectives of digital radio-relay systems should be defined;
- (b) that the definition of the allowable bit-error performance of the hypothetical reference digital path is necessary for the design and construction of radio-relay systems;
- (c) that propagation and other effects suggest that the bit-error performance should be stated statistically as a percentage of time;
- (d) that a bit-error measurement requires a certain duration of time which depends on the magnitude of the error ratio;
- (e) that the effect of error burst phenomena and jitter may need to be taken into account;
- (f) that during normal operation, periods of high bit error ratio will occur which will cause short interruptions, these interruptions being mostly caused by adverse propagation conditions (see Note 11),

UNANIMOUSLY RECOMMENDS

1. that the bit error ratio for the 64 kbit/s hypothetical reference digital path defined in Recommendation 556 should not exceed the following provisional values given below, which take account of fading, interference, and all other sources of degradation of the performance:

- 1.1 1×10^{-7} for more than 1% of any month; integration time under study (see Note 12).
- 1.2 1×10^{-3} for more than 0.05% of any month; integration time 1 second.

Note 1. — The limits proposed are based on the best knowledge currently available but are subject to review in the future in the light of further studies. For the time being the limits should be considered as being provisional.

Note 2. — This Recommendation has not taken into account the consequences of burst phenomena, and a system designed for the above objectives may give rise to multiple call dropout. Possible methods of overcoming this problem are a subject for study by the CCITT.

Note 3. — The output bit stream from a digital radio-relay system suffers from jitter. No Recommendation on the limits of jitter can be made at this time. The subject requires further study and is also being considered by the CCITT.

Note 4. — The aforementioned error ratios are assumed to be caused by random events and not from predictable sources that can cause large error bursts. For example, schedules switching for maintenance which may cause transient error bursts should not be counted in the objectives. However, error burst which could arise during switching to a protection channel should be counted.

Note 5. — This Recommendation relates to the hypothetical reference digital path. The values given are for use by the system designer, and it is not intended that they should be quoted in specifications of equipment or used for acceptance tests.

Note 6. — Contributions from multiplex equipment are not included.

Note 7. — The Recommendation applies only when the system is considered to be available in accordance with Recommendation 557 and includes periods of high bit error ratio exceeding 10^{-3} which persist for periods of less than 10 consecutive seconds. Periods of high bit error ratio which persist for 10 consecutive seconds duration or longer are taken into account by Recommendation 557.

Note 8. — The limits given in RECOMMENDS 1.2 are based upon the 10 second non-availability criteria given in Recommendation 557, and therefore will not necessarily include all forms of degradations in performance due to adverse propagation. Degradations due to adverse propagation which persist for 10 seconds or longer will be limited by the requirements of Recommendation 557.

* In the 64 kbit/s path (as defined by the CCITT) signals other than telephony may be accommodated. In particular, the move towards an Integrated Services Digital Network (ISDN) may require the introduction of an error-free second (EFS) performance objective. This is discussed further in Report 930.

Note 9. — A Recommendation for the error performance of an international digital connection forming part of an Integrated Services Digital Network is given by the CCITT in Recommendation G.821.

Note 10. — RECOMMENDS 1.1 is defined on the basis of CCITT Recommendation G.821, on the assumption that the 25 000 km hypothetical reference connection may contain up to 10 hypothetical reference digital paths as defined in Recommendation 556.

Note 11. — Adverse propagation conditions can result in a decrease of the wanted signal and/or an increase in the level of interfering signals.

Note 12. — Measurements of BER are normally made at a much higher bit rate than 64 kbit/s; for example at the bit rate of the radio-relay system. The integration time required to achieve the same confidence level will be dependent upon the capacity of the system (see Report 613). The seconds during which BER exceeds 10^{-3} must not be taken into account in this integration time. For the present, a value in the region of one minute has been proposed.

REPORT 930

PERFORMANCE OBJECTIVES FOR DIGITAL RADIO-RELAY SYSTEMS

(Question 12/9)

(1982)

1. Introduction

This Report considers factors which need to be taken into account in determining performance requirements for digital radio-relay systems.

A recommendation, for the allowable bit error ratio performance of the hypothetical reference digital path defined in Recommendation 556, is given in Recommendation 594.

2. Performance requirements

The performance of the 2500 km hypothetical reference digital path (see Recommendation 556) or any shorter digital section which may be defined, could be expressed in terms of two error ratios, two error-free-second (EFS) objectives and an objective based upon error burst criteria. The higher error ratio, the short-term EFS or the error burst objective would in many systems be the most significant and would determine repeater spacing. The lower error-ratio objective would serve to control performance for the majority of the time. All objectives should apply only when the system is considered to be available. The methods of measurement may be of significance in defining the performance of a digital radio-relay system. Report 613 discusses this subject.

The 2500 km hypothetical reference digital path (HRDP) given in Recommendation 556 may form part of a longer international digital connection (see CCITT Recommendation G.104, Fig. 1b). CCITT Recommendation G.821, which defines performance requirements for a hypothetical reference connection forming part of an integrated service digital network (ISDN) needs to be taken into account in determining the performance requirements for digital radio systems.

2.1 Low error ratio value

The CCITT has proposed an error-ratio design objective of 1 in 10^{10} per km for the transmission system in a 25 000 km hypothetical reference digital connection. For a 2500 km digital radio-relay path this gives an error ratio objective of 2.5×10^{-7} (this figure excludes the contributions due to the multiplexing equipment). In digital radio-relay systems, this error ratio will, according to present design criteria, be achieved for at least 99% of the time. Therefore a low value of error ratio of about 10^{-7} would seem appropriate for a 2500 km hypothetical reference digital path.

2.2 High error ratio value

The proportion of time for which the high error ratio may be exceeded has a very great influence on the design of a system. A requirement that the higher error-ratio may not be exceeded for more than 0.01% of any month for a 2500 km circuit would have severe repercussions on the economics of a practical system. On the other hand, a requirement that this error ratio should not be exceeded for more than 0.1% of any month would result in a more economic system but one which may not compare favourably with existing FDM-FM radio-relay systems.

2.3 *Long-term error-free-second (EFS) objective*

The bit error ratio (BER) parameter does not give an accurate estimate of the data circuit performance except when the error distribution is known. The more desirable alternative block error-ratio criterion unfortunately requires a knowledge of data block size and data rate which vary from user to user. The EFS based objectives are one way in which the above limitations can be resolved. The CCITT has proposed that for data transmission a 95% EFS objective should be attained on the local exchange — local exchange portion of a 25 000 km hypothetical reference connection. A value of 99.5% EFS for the 2500 km hypothetical reference digital path would seem appropriate.

In general there is no simple relationship between bit error ratio performance and the long-term EFS performance during periods of multipath fading. In particular the long-term EFS performance for radio systems during multipath fading is a function of the rate of fading; this contrasts with the bit-error probability performance which is independent of the rate of fading. Computer simulation studies have indicated that there is only a slight dependence of EFS performance on the transmitted bit rate during periods of multipath fading.

2.4 *Short-term EFS objective*

In addition to the long-term EFS objective of § 2.3, it may be worthwhile to consider the need for a short-term EFS objective. Its purpose would be to ensure adequate performance over an acceptable percentage of typical data connections.

2.5 *Performance objectives for real digital paths*

Recommendation 594 gives performance objectives for the hypothetical reference digital path (HRDP) as defined in Recommendation 556. Real paths will differ both in length and composition from the HRDP, and it is therefore desirable to provide planning objectives for the allowable bit error ratios of such paths, particularly those which are shorter in length than the HRDP. At present there is no agreement on the method to be used to derive the performance objectives.

In general for real paths there are two problems:

- (a) to find a method of apportioning the objectives given in Recommendation 594 for systems which are intended to be connected in tandem in order to form paths similar to the HRDP;
- (b) to take into account CCITT Recommendation G.821 in determining objectives for short and medium haul systems utilized only in the national part of the hypothetical reference connection (see Fig. 1 of CCITT Recommendation G.104).

In addressing the first of these problems (item (a)), there are a number of assumptions upon which there is general agreement.

Since the performance of digital radio-relay systems is dependent upon fading, it is generally agreed that the behaviour of any section of the HRDP will be statistically independent. If this is assumed, then mathematically the HRDP performance could be determined by the convolution of the probability density functions of all sections. This process is however not a practical one, since the probability density function is not known in sufficient detail.

Guidelines to be used for the apportionment of the performance criteria of Recommendation 594 over a section must therefore first be clearly established. This subject requires further study.

An important issue to take into account is the assumed characteristics of the bit error ratio distribution for the HRDP; particularly that which is controlled by RECOMMENDS 1.1 of Recommendation 594. If it is assumed that the HRDP has a background bit error ratio of 1×10^{-7} , then it must be concluded that the background bit error ratio of any shorter section should be better than 1×10^{-7} . However, if the background bit error ratio of the HRDP is considerably better than 1×10^{-7} , then it may be satisfactory to define the performance of a shorter section by apportioning the small percentage of time that the BER of 1×10^{-7} can be exceeded. Two administrations have so far submitted proposals concerning this problem [CCIR, 1978-82a and b].

It has generally been agreed that the percentage of time of RECOMMENDS 1.2 of Recommendation 594 can be apportioned linearly with distance down to a length of 280 km.

Administrations are invited to submit additional information on the two problems outlined in (a) and (b) above.

2.6 Possible error burst objective

With many commonly used digital demultiplex equipments the occurrence of error burst on large-capacity digital radio-relay systems will cause undesirable effects in the telephony network, such as multiple call dropout. Consideration may therefore have to be given to placing a limit on these error bursts. Area (1) of Fig. 1 illustrates a possible limit which would serve to control the incidence of multiple call dropout, and is based upon proposals from the United Kingdom.

Such an objective, which might incur inordinate economic penalties for digital radio-relay systems, is critically dependent upon the performance of demultiplex and signalling equipment. This would appear to be a matter for resolution with CCITT Study Group XVIII.

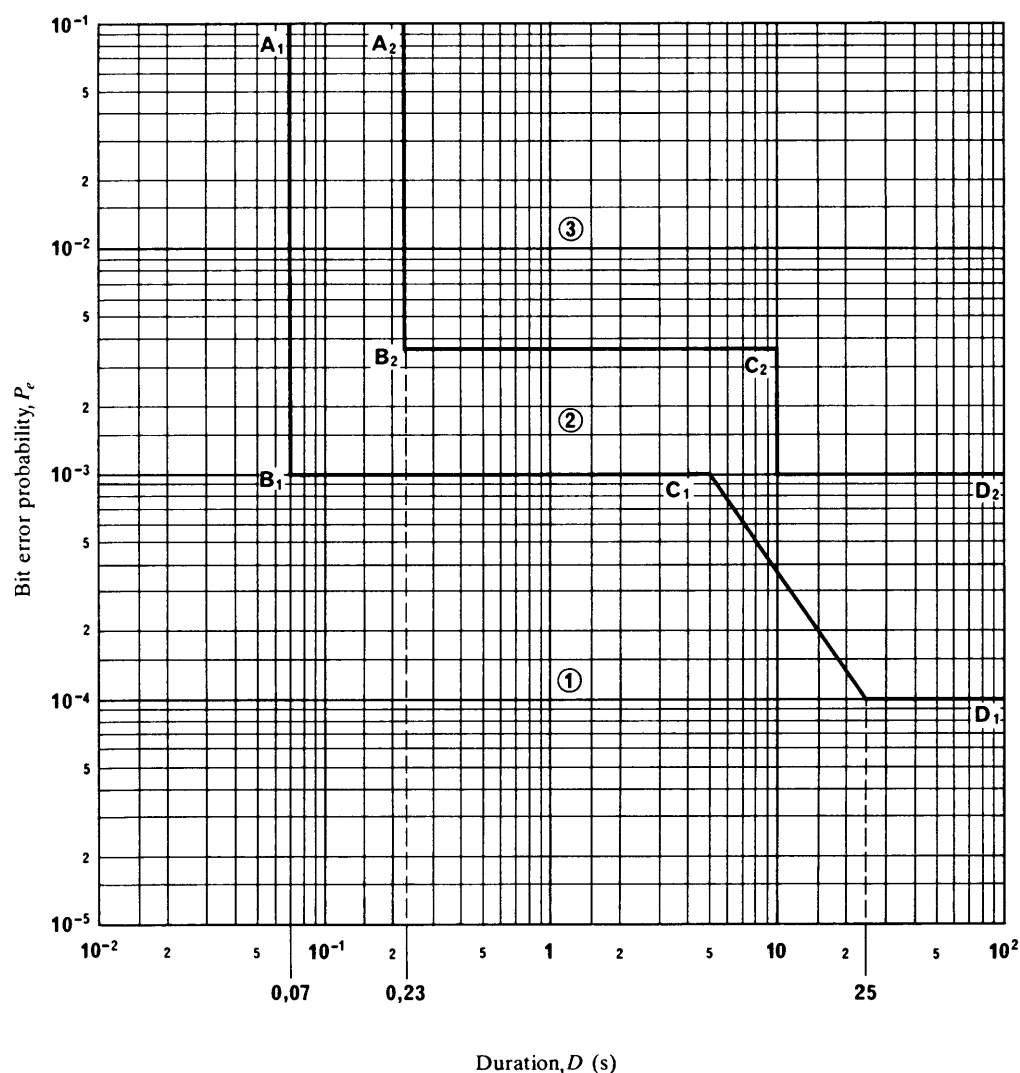


FIGURE 1 – Possible error burst objective

Area ①: error bursts confined within this area will have a negligible probability of causing multiple call dropout.

Area ②: error bursts extending into this area will have an increased probability of causing multiple call dropout and would probably be unacceptable.

Area ③: error bursts extending into this area are likely to have an unacceptably high probability of causing multiple call dropout.

$\left. \begin{matrix} A_1 & B_1 & C_1 \\ A_2 & B_2 & C_2 \end{matrix} \right\}$ boundaries related to signaling performance criteria.
 $\left. \begin{matrix} C_1 & D_1 \\ C_2 & D_2 \end{matrix} \right\}$ boundaries related to subjective performance criteria.

2.7 Other factors

Timing jitter has an influence on digital performance, particularly on long paths, and requires further investigation. Some results have been reported [Yamamoto *et al.*, 1973]:

It should be noted that the addition or loss of a bit, due for instance to switching without prior alignment to ensure coincidence or to a spurious impulse affecting the timing, may desynchronize the downstream transmission chain and cannot be considered an isolated error. This phenomenon affects system performance and should be studied further.

REFERENCES

YAMAMOTO, H. MORITA, K. and NAKAMURA, Y. [11-13 June, 1973] Experimental considerations on 20 GHz high-speed digital radio relay system. IEEE International Conference on Communications (ICC '73), Seattle, Wa., USA, Conf. Record, Vol. II, Session 28: New developments in radio relay systems, 28-37 – 28-42.

CCIR Documents

[1978-82]: a. 9/269 (France); b. 9/304 (Germany (Federal Republic of)).

BIBLIOGRAPHY

COUTTS, R. P. [4 March, 1980] Data transmission performance over terrestrial radio-relay systems. Proc. IEEE International Zurich Seminar on Digital Communications, 4-6 March, Zurich, Switzerland, B7.1-B7.5.

REPORT 779 *

INTERFERENCE IN DIGITAL RADIO-RELAY SYSTEMS WITH COHERENT PSK MODULATION

(Question 23/9 and Study Programmes 23A/9 and 12F/9)

(1978)

1. Introduction

This Report deals with the subject of RF interferences into digital radio-relay systems using PSK modulation, including those operating above 12 GHz, in which fading due to precipitation is a predominant factor. The results in this Report deal only with 2-PSK and 4-PSK modulation systems.

On a long distance system in the presence of fading attenuation, Report 930 indicates that the design of a digital radio-relay system is controlled by the need not to exceed a given error ratio (in the approximate range 10^{-3} to 10^{-6}) for a small percentage of the time. A usual assumption is that the origin of such errors depends only on the critical performance of one or a few hops. The correct apportioning of the system error ratio between regenerative sections is not dealt with in this Report. It is worth noting that the order of magnitude of the highest acceptable error ratio in one regenerative hop is very near the above-mentioned system limit.

This Report deals only with digital radio-relay systems having regenerative repeaters. Systems with non-regenerative repeaters will give rise to different interference effects which are not discussed here.

Errors in a digital receiver are caused by peaks in Gaussian noise occasionally causing the decision circuit to mistake one level for another. Under non-fading conditions (when the signal is typically 30 to 50 dB higher in value), the error ratio would then be very small and limited only by practical constraints in the design of decision circuits. Interference sources are peak-limited, in the sense that the statistical amplitude distribution is truncated, and in general of insufficient level (even in total) to cause the decision circuits to make mistakes (i.e. interference peaks, unlike noise peaks, do not close the eye pattern). Interference as such does not therefore cause errors. However, it does enhance the ability of the thermal noise to cause errors by occasionally causing a partial reduction in the eye pattern opening.

* This Report combines Reports 605 and 606.

The exact worsening of the error ratio in the presence of interference can be computed when the statistical amplitude distribution of the received interfering signal has been evaluated. Such calculations are presented in [Castellani and Sant'Agostino, 1971]. Alternatively an upper bound error ratio can be calculated, given the peak-to-r.m.s. ratio of the interference as in [Rosenbaum and Glave, 1974]. This bound is shown to be tight and therefore the method does not give an unduly pessimistic result. A discussion of methods for calculating the bit error ratio can also be found in Report 388.

The present Report covers the following topics:

- the effects of the transmission channel distortions (inter-symbol interference). The choice of the filtering characteristics at the transmitting and at the receiving ends is very important in determining the sensitivity of the digital receiver to RF interferences;
- the sources of RF interferences in a long-haul connection. Some subdivisions of such interferences into groups having similar characteristics are presented;
- the effects of co-channel or adjacent channel interferences on coherent PSK transmissions. Some simple criteria to establish an allowance for such degradations are also discussed;
- the apportioning of the performance degradation amongst the main groups of interference sources.

2. Inter-symbol interference

Inter-symbol interference or distortion occurs when the signal at the sampling time is in part affected by the residues from previous and following symbols. Inter-symbol interference is mainly due to distortion of the transmitted wave-form introduced by band-limiting filters in the transmission channel. In a digital transmission system the bandwidth is deliberately limited to that required for transmitting only the information contained in the signal. In general this bandwidth is much less than that required to transmit the waveform of the signal and therefore a distortion of the waveform is inevitable. The objective when designing the transmission channel is to minimize the inter-symbol interference, as described above, within the constraints imposed by considerations of channel spacing and adjacent channel interference.

The effect of such a distortion (inter-symbol interference or ISI) is to increase the error ratio with respect to the ideal performances. Using the normalized carrier-to-noise ratio W defined in Report 378 the performance of a modulation method is defined by the value of W corresponding to a given error ratio (for example 10^{-6}).

The effect of varying the receiver filter bandwidth in a binary or quaternary coherent PSK system is shown in Fig. 1. As the lower values of W for a given error ratio (10^{-6}) correspond to lower values of error ratio for a given signal-to-noise ratio, it appears that the minimum of the curves represents the optimal choice of receiver bandwidth.

As a compromise between excessive noise power (right-hand side of Fig. 1) and excessive waveform distortion (left-hand side of Fig. 1) an optimum value for β appears to be in the range 1 to 1.1.

The normalized parameter β is defined as follows:

$$\beta = B_{eq}/S \quad (1)$$

with,

B_{eq} : equivalent noise bandwidth of the receiver;

S : symbol rate = B for binary PSK and $B/2$ for quaternary PSK

B : bit rate before modulation.

In the absence of ISI the 10^{-6} error ratio is achieved with $W = 10.5$, so the minimum degradation produced by the filters considered in Fig. 1 comes out to be in the range 0.8 to 1.3 dB.

The effect of the inter-symbol interference can also be inspected by means of the well known oscilloscope eye pattern. If the error ratio of the worst pulse pattern (inner eye margin) is dominant over those of the other pulse patterns, an upper bound to the performance degradation is given by $-20 \log E/\beta$, where E is the eye aperture, and is defined as:

$$E = \frac{\text{The minimum demodulated signal amplitude at a decision time} \\ \text{when a random digital signal is transmitted}}{\text{The demodulated signal amplitude when the carrier is unmodulated}}$$

where all the quantities are measured in the absence of noise or interference external to the channel. The degradation evaluated by this formula may typically be 0.5 to 1 dB in excess of the value obtained by calculating the error ratio.

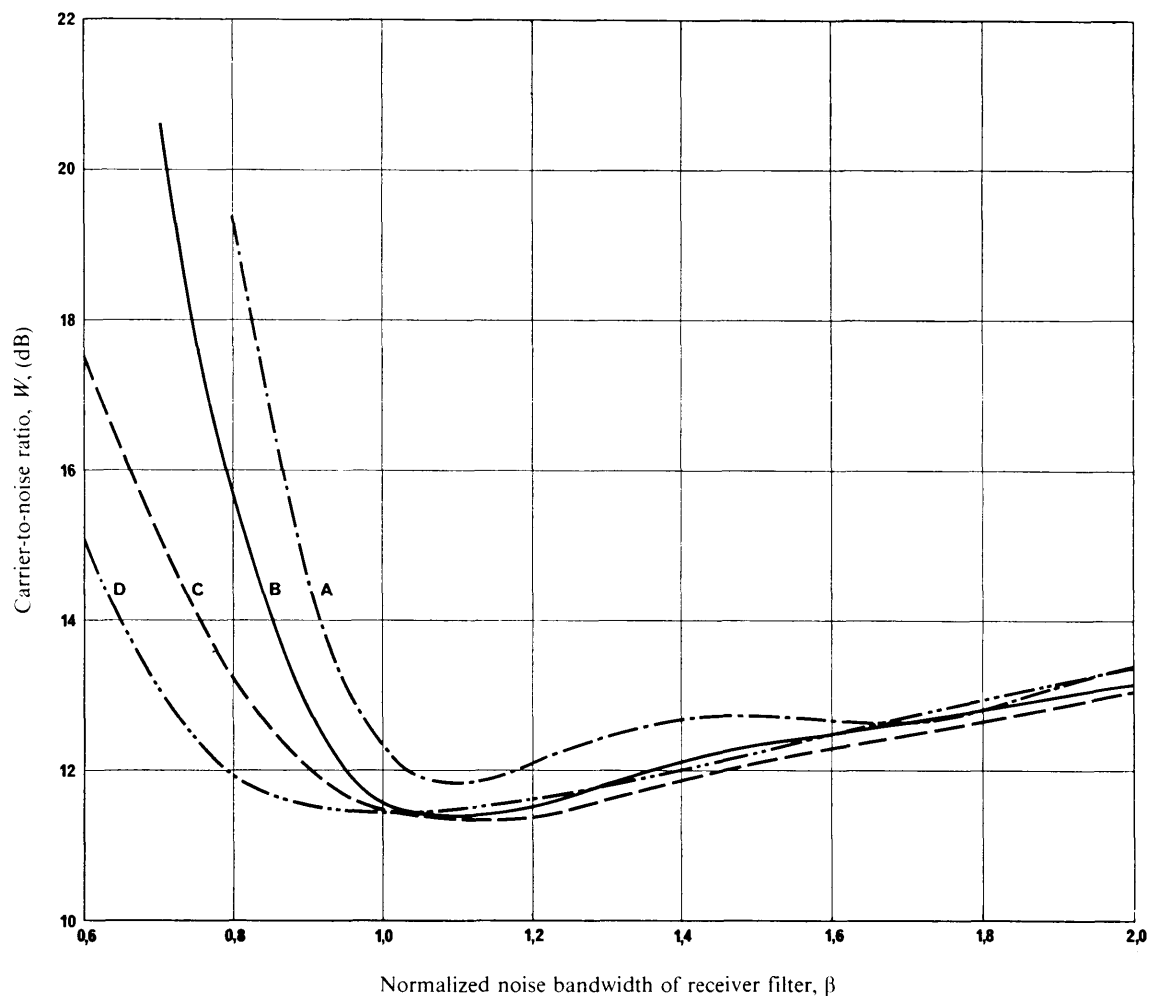


FIGURE 1 — Carrier-to-noise ratio versus filter bandwidth of binary or quaternary CPSK systems

$BER = 10^{-6}$

- A: Butterworth 6-pole receiver filter without group-delay equalization
- B: Butterworth 4-pole receiver filter without group-delay equalization
- C: Butterworth 2-pole receiver filter without group-delay equalization
- D: Gaussian receiver filter with linear phase

The eye opening at the decision points may be a useful parameter to indicate the presence in the system of such imperfections as non-ideal demodulators, timing errors and jitter. Hence the performance of the system filters should be assessed not only in terms of maximum eye amplitude but also in terms of symmetry and width of the open region. An indication of the latter is given by the width of the crossover on the eye pattern.

The eye diagrams presented in Figs. 2 and 3 have been computed for an ideal quaternary phase-shift keyed digital system with coherent detection using a filter arrangement as shown in Table I [CCIR, 1974-78a].

TABLE I

Transmit and receive RF filters	Receive IF filter
Chebychev 5-pole, 1% reflection coefficient (Equal-ripple passband, loss 0.0004343 dB) Normalized 3 dB bandwidth = 1.75	7-pole Bessel filter 3 dB bandwidth = symbol rate

A value of $X = 1.75$ was used in the computation, where X is the channel spacing as defined in Report 378.

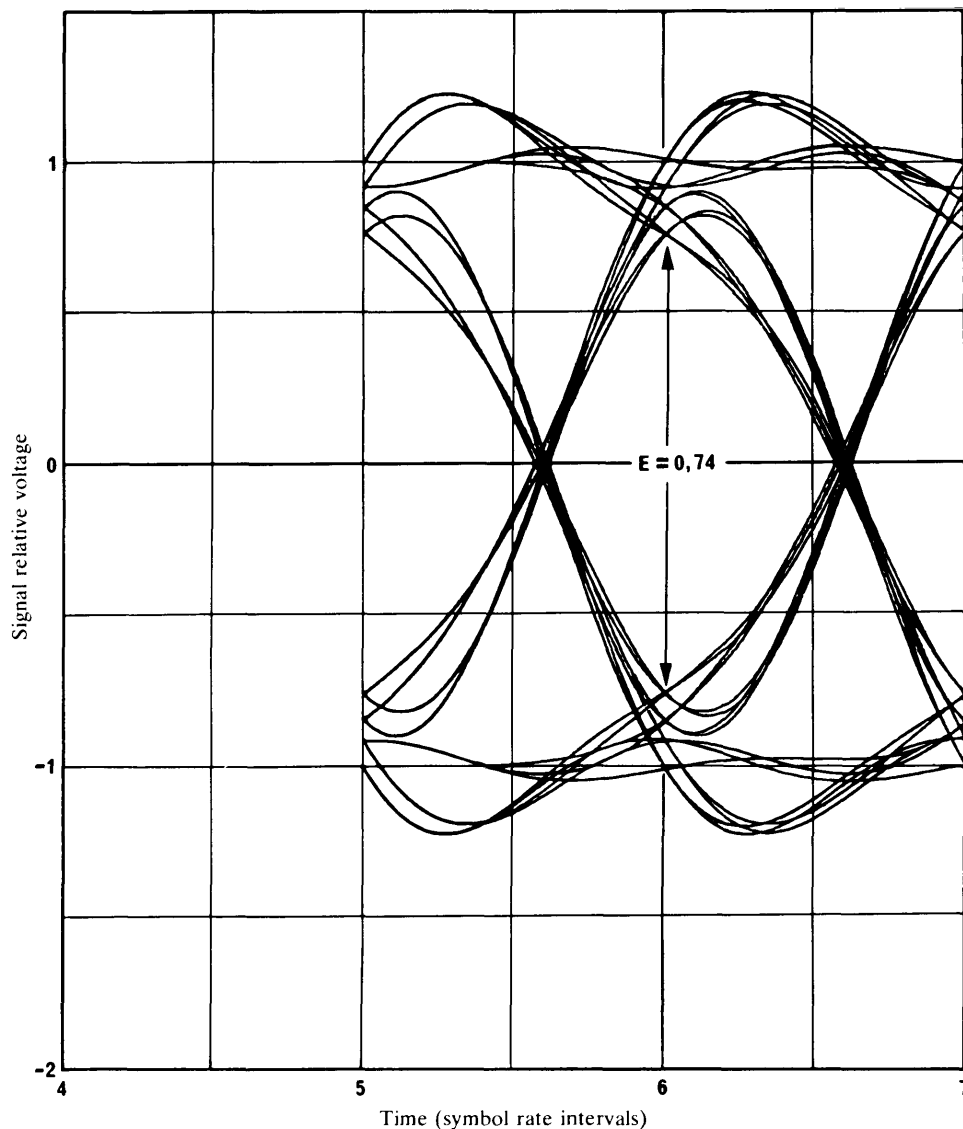


FIGURE 2 — The eye-diagram pattern (without equalization)

Filters as Table I: no equalization

E : eye-diagram amplitude

X : 1.75

RF filter normalized 3 dB bandwidth: 1.75

Note. — The eye-diagram pattern is derived from one output port of a 4-phase demodulator.

2.1 Inter-symbol interference equalization

2.1.1 Time domain equalizers

Inter-symbol interference due to band limiting by filters can be effectively equalized in the time domain [Bennett, 1956; Lucky *et al.*, 1968]. Figure 4 shows the measured improvement in inter-symbol interference for a 4-phase system having a high inter-symbol degradation. It can be seen that the degradation in carrier-to-noise power ratio is reduced by more than 2 dB.

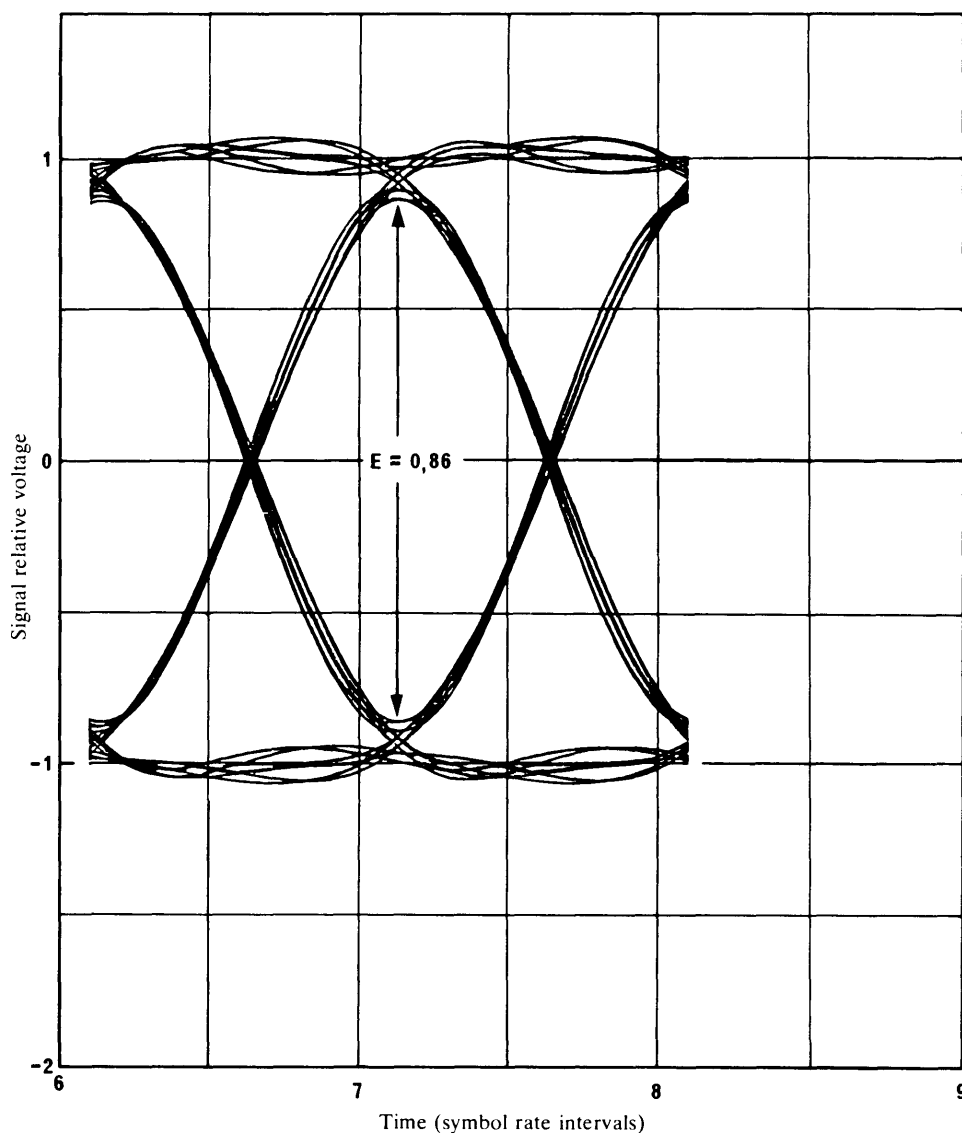


FIGURE 3 — *The eye-diagram pattern (with equalization)*

Filters as Table I: practical equalization by a 2nd order group delay equalizer

E : eye-diagram amplitude

X : 1.75

RF filter normalized 3 dB bandwidth: 1.75

Note. — The eye-diagram pattern is derived from one output port of a 4-phase demodulator.

2.1.2 Fixed group-delay equalizers

The passbands of the RF filters may be equalized by all-pass networks.

Table II gives the C/N ratio theoretically required for error ratios of 1 in 10^9 and 1 in 10^5 for the filter system described in Table I. It can be seen that fixed equalization of the RF filters reduces the degradation in carrier-to-noise power ratio by over 1 dB.

TABLE II — Required carrier-to-noise ratio W (dB)
Filters as for Table I

Theoretical error ratio	Chebychev filter		
	No group delay (ideal)	Equalized by all-pass network	Unequalized
1 in 10^5	10.1	10.2	11.3
1 in 10^9	13.2	13.3	14.6

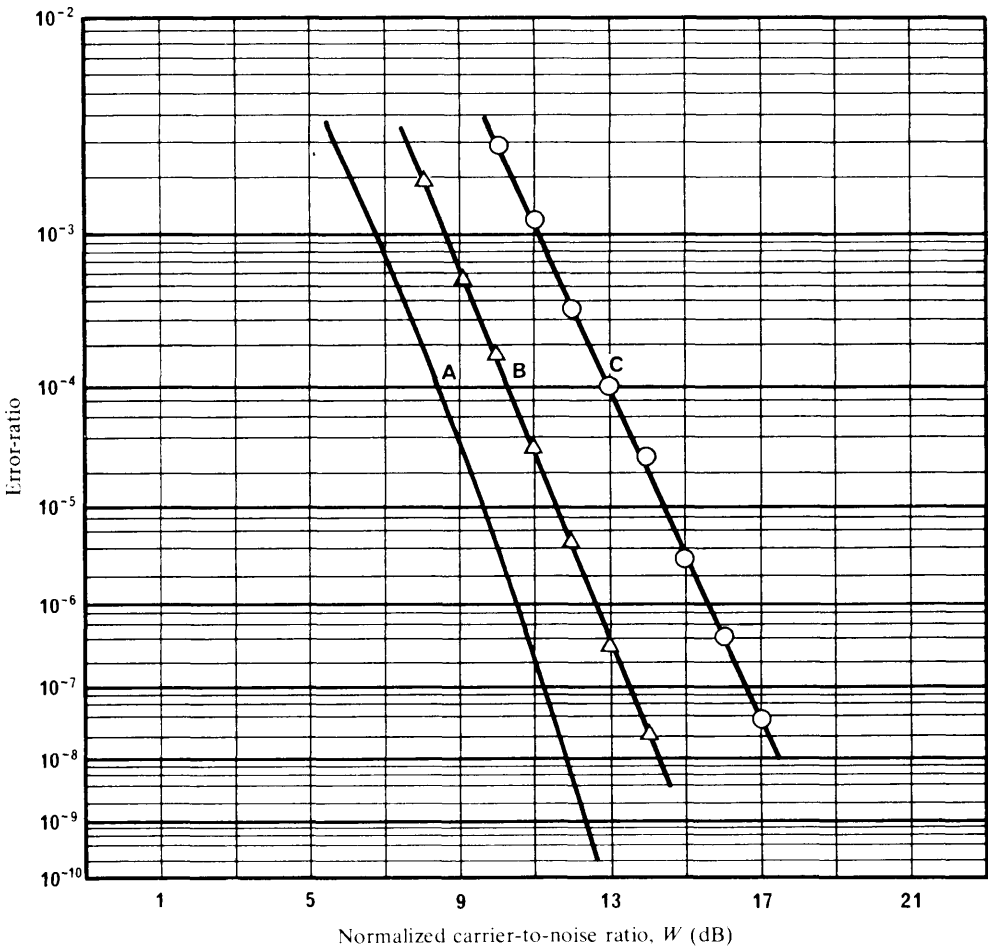
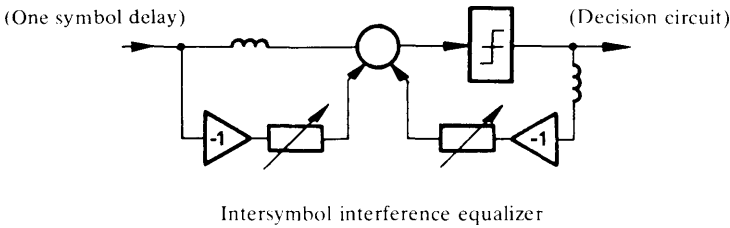


FIGURE 4 — Error-ratio performance of experimental 20 GHz band 400 Mbit/s 4-level PSK repeater

- A: ideal theoretical value without band limitation
- B: measured with equalizer
- C: measured without equalizer

3. Sources of noise and RF interferences

Table III lists (and Fig. 5 illustrates) typical sources of noise and interference that may disturb a digital radio-relay system. The interference sources can be divided into two groups as follows:

S_{1i} : those sources which share, either partly or wholly, a path common to the wanted signal and to a large extent fade simultaneously with the wanted signal, for example, during rain attenuation;

S_{2i} : those sources which do not have a common path with the wanted signal and in general, do not fade simultaneously with the wanted signal, or fade to a much lesser extent than the wanted signal.

TABLE III – Interference sources

Location on diagram		Power	Classification (note 4)
	<i>Examples of sources fading with the wanted signal</i>		
1	Cross polarized channel(s) (Note 3)	S_{11}	M
2	Front to back radiation	S_{12}	W
4	Over-reach (3 hops)	S_{14}	W
8	Front to back reradiation and over-reach	S_{18}	W
7	Adjacent co-polarized channel(s) (Note 2)	S_{17}	M/W
	Transmitter noise	N_T	
	Total power (Note 1)	$S_1 \& N_T$	
	<i>Examples of sources not fading with the wanted signal</i>		
	Receiver noise	N_R	
x	Transmitter into receiver	S_{2x}	W
6	Extraneous reflections	S_{26}	W
5	Opposite hop over-reach (3 hop)	S_{25}	W
3	Opposite hop front to back reception	S_{23}	M
D	Other digital systems	S_{2D}	W
A	Other analogue systems	S_{2A}	W
S	Satellites	S_{2S}	W
	Total power (Note 1)	$N_R \& S_2$	

Note 1. – S_1 and S_2 represent the ensemble of each of the two groups of interferences, evaluated under faded conditions. It should not be construed that a summation of interference powers can be interpreted as being equivalent to Gaussian noise for the purpose of calculating error-ratio (see § 4).

Note 2. – Adjacent channel interference may be subject to frequency-selective fading.

Note 3. – Cross-polarization discrimination is known to be a function of rainfall attenuation and of multipath propagation.

Note 4. – Classification:

M : Main interferers;

W : Weak interferers.

The distinction as to whether an interfering source should be classified as M or W depends on the criteria used in the system design.

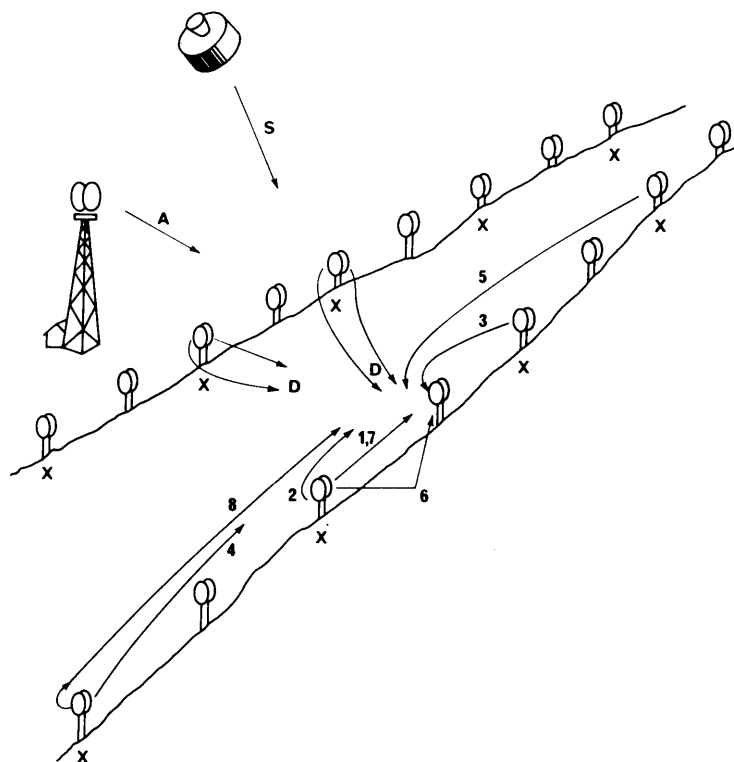


FIGURE 5 – RF interference sources in a long-haul trunk

The model assumes a two-frequency plan. All repeaters marked "X" transmit on the same frequency. See Table III for an explanation of the numbered interference paths.

Interference source No. 1 is due to the transmission of two radio signals with the same carrier frequency and with opposite planes of polarization of the radiated wave (so-called frequency re-use, see also Report 378).

This technique is used to enhance the utilization of the spectrum. Under normal propagation conditions the decoupling between the horizontally polarized and the vertically polarized signals is more than adequate. However, when the signals fade due to multipath effects, rain attenuation or other causes *, it has been shown that the decoupling is reduced and that the level of co-channel interference is correspondingly increased. It is generally agreed, however, that even under such conditions a system can be designed to meet availability requirements by a careful choice of repeater spacings, transmitter power, receiver noise figure, antenna size, the possible use of automatic transmit power control, etc.

An alternative approach is to frequency interleave the channels on opposite planes of polarization and perhaps also to increase the channel spacing, thus reducing the level of interference. This arrangement may lead to a more economic system, for example, by permitting the use of longer repeater spacings. However, it will reduce the capacity of a given frequency band and should therefore be used only when the propagation behaviour would make impractical the use of the co-channel arrangement.

It should also be remembered that the interleaving of opposite polarizations is again a kind of frequency re-use, because of the wide overlap of the radiated spectra.

* See Sections Radiometeorology (5C) and Broadcasting and mobile services (5D) of Volume V.

The need to make efficient use of the spectrum means that X should be as small as possible. As the value of X is reduced there is a corresponding increase in the amount of interference falling into adjacent channels. One effect of this can be seen from Fig. 6; Fig. 7 shows the change of eye-diagram pattern with change of X (CCIR, 1974-78b).

Calculations made with $X = 1.6$ and $X = 2.0$ [Colavito and Sant'Agostino, 1974] show that the interleaved plan has a 2 dB improvement in fade margin (compared with the interference from a co-channel plan) while some greater advantage is gained at $X = 2.0$.

4. Effects of RF interferences

Each one of the interference sources listed in Table III produces a degradation of the transmission quality (increase of the error ratio). The most suitable parameter to represent this degradation is the increase in the received carrier power which is necessary to satisfy the higher error ratio objective.

This is the error ratio that should not be exceeded on the hop, subject to the above-mentioned interferences for a very small time percentage – the percentage depending on the choice of the overall system objective and on the subdivision of such time among the regenerative hops.

The difference between the carrier power levels corresponding to the worst error ratio in the presence and in the absence of interference, can be considered as a receiver threshold deterioration.

Inter-system interferences are not considered at the present time, but those interference sources originating within the same disturbed system must be taken into account in a fundamental way because they are unavoidable.

A distinction must be made between the energy from disturbing RF channels which falls into the receiver bandwidth (co-channel interference) and that from adjacent co-polar RF channels (inter-channel interference).

The second type of interference source is of particular concern in the choice of the channel spacing discussed in Report 378. The main contributions of co-channel interference are from sources numbered 1 and 3 in Table III and their main effect is to limit the usable fading margin of those hops on which they appear. [Colavito and Sant'Agostino, 1973].

The bit error ratio (BER) produced by co-channel interference is a function of the carrier-to-noise ratio W (as defined in Report 378) and of the power level of each interfering channel.

Some measured data on the effect of one co-channel interferer are presented in Fig. 8 [Yamamoto *et al.*, 1973] where a simple approximate method to evaluate the quality degradation due to interferences is also presented. Such a method is based on summing the interference power with the noise power and it clearly provides pessimistic results with respect to the measured ones.

For a BER of about 10^{-4} to 10^{-5} , the results so obtained are acceptable for C/I ratios not less than about 20 dB. For a BER of 10^{-8} a minimum C/I of about 25 dB would be required for reliable results.

In principle the Gaussian assumption can be applied to evaluate the degradation due to interferences with respect to any basic reference curve. It appears that acceptable results can be obtained when the basic curve is measured, as in Fig. 8, the equipment implementation degradation (5 dB in Fig. 8) having been already taken into account.

When the effects of varying the level and the number of interfering channels have to be investigated it is desirable to use the more compact representation shown in Fig. 9. Only the values of the carrier noise degradation δW_4 corresponding to a 10^{-4} error ratio (a value often used in Italy as a threshold error ratio) are presented as a function of the carrier to interference ratio.

The calculated degradation due to inter-symbol interference (ISI) is 0.9 dB. The experimental results (dashed line) have been measured on a simulated hop with commercial equipment operating at 13 GHz in the Italian network, with four-phase coherent modulation at 34 368 kbit/s. The filtering characteristics were very similar to those adopted in the theoretical calculations. All the measurements were performed with the service channels loaded (frequency modulation of the carrier in the band 4 to 16 kHz).

The reference value W_4 for the experimental results is 10.4 dB. The basic degradation due to ISI, differential encoding and implementation impairments is therefore 2 dB.

As far as adjacent channel interference is concerned, the results presented in Fig. 10 show the behaviour of the normalized carrier-to-noise ratio W (corresponding to a BER of 10^{-6}) as a function of the normalized channel spacing X , when the two co-polar adjacent RF channels are assumed to have the same power level as the disturbed one.

The degradation measured on the above-mentioned 13 GHz equipment, caused by two adjacent equal level channels spaced by 28 MHz, is typically 0.5 dB.

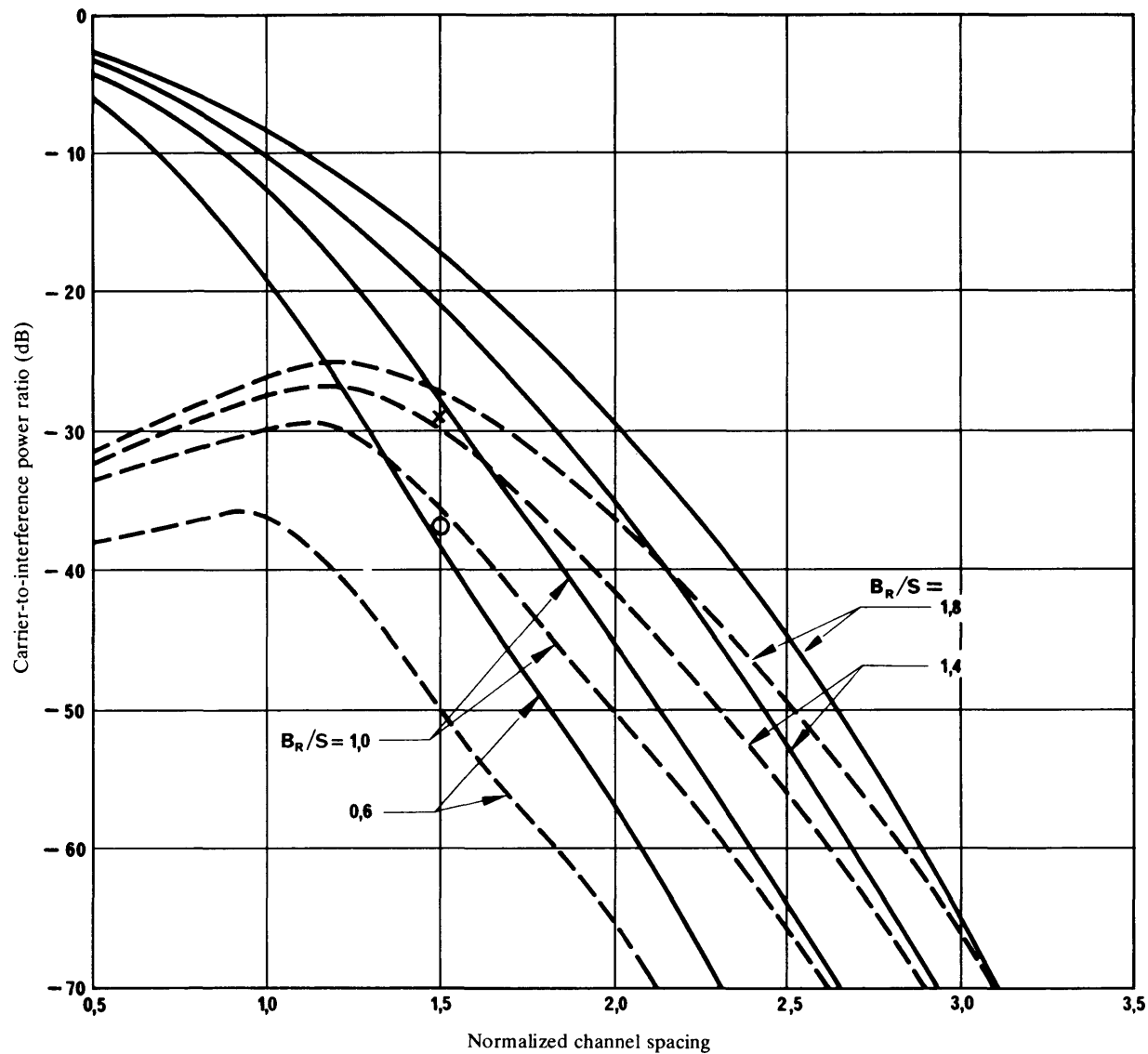
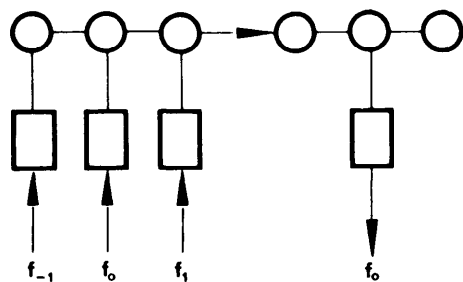


FIGURE 6 – Adjacent channel interference characteristics

Normalized bandwidth of transmitting filter : 2.0

Normalized bandwidth of channel branching filter: 1.5



- B_R/S : Normalized bandwidth of receiving filter
- f_1 ——— } : Theoretical value of interference
 f_{-1} - - - }
- X, O : Measured values at B_R/S : 1.0
- that is:
- X : Interference from f_1
O : Interference from f_{-1}

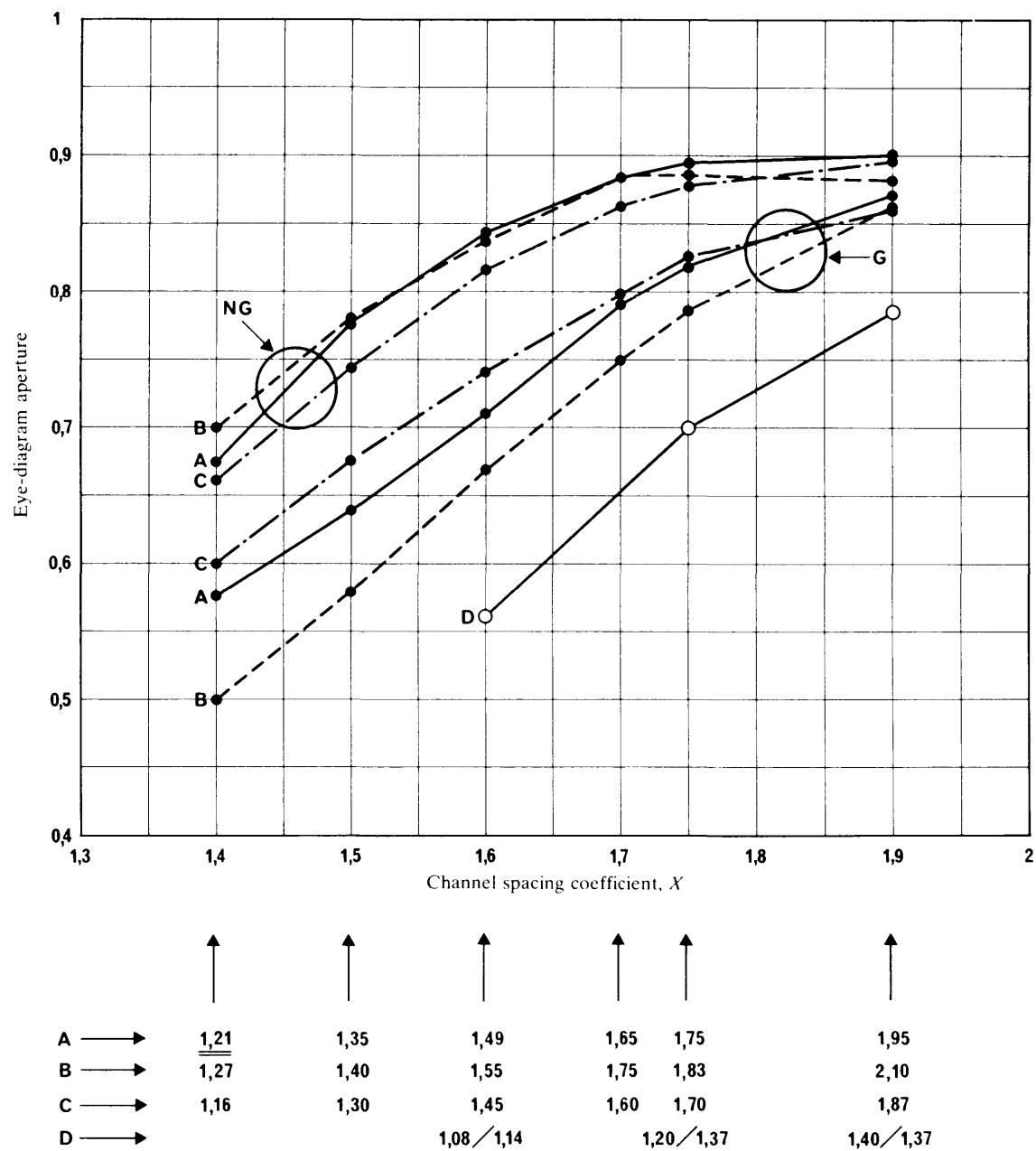


FIGURE 7 — The relationship between channel spacing and eye-diagram amplitude

A, B, C and D refer to filters defined in Table IV
G : with group delay
NG: group delay set to zero

Note. — The figures given below the graph refer to the normalized 3 dB bandwidth of each RF filter. For example, the underlined figure refers to a 3 dB bandwidth of 1.21 B for filter type A at $X = 1.4$. For arrangement D the second figure refers to the 3 dB bandwidth of the IF filter.
 B : symbol rate.

TABLE IV

Filter arrangement code letter	Transmit and receive RF filters	Receive IF filter
A	Chebyshev 5-pole, 1% reflection coefficient. (Equal-ripple passband, loss 0.0004343 dB)	7-pole Bessel filter 3 dB bandwidth = B
B	Chebyshev 5-pole. (Equal-ripple passband, loss 0.1 dB)	— idem —
C	5-pole Butterworth	— idem —
D	Schussler 5-pole 4% overshoot	Catenary 4-pole filter 3 dB bandwidth, see Figs. 2 & 3

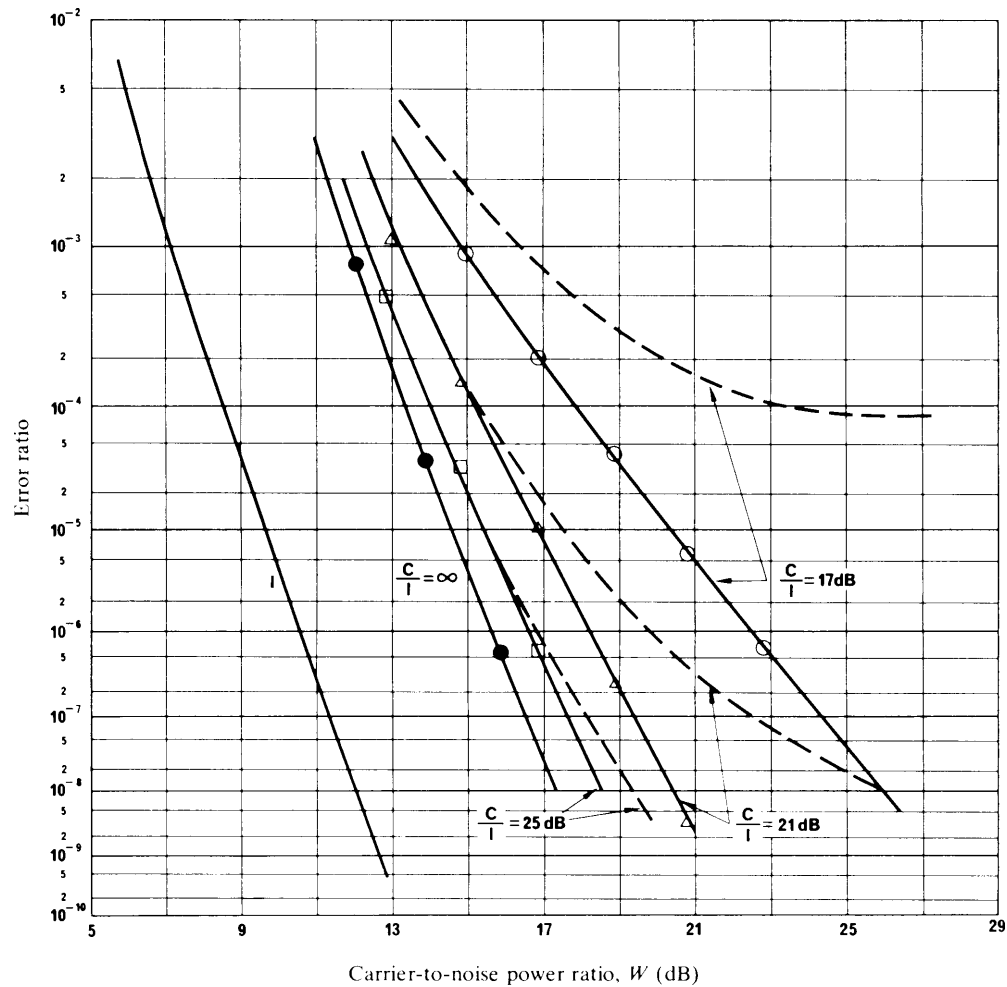


FIGURE 8 — Error ratio performance in case of co-channel interference

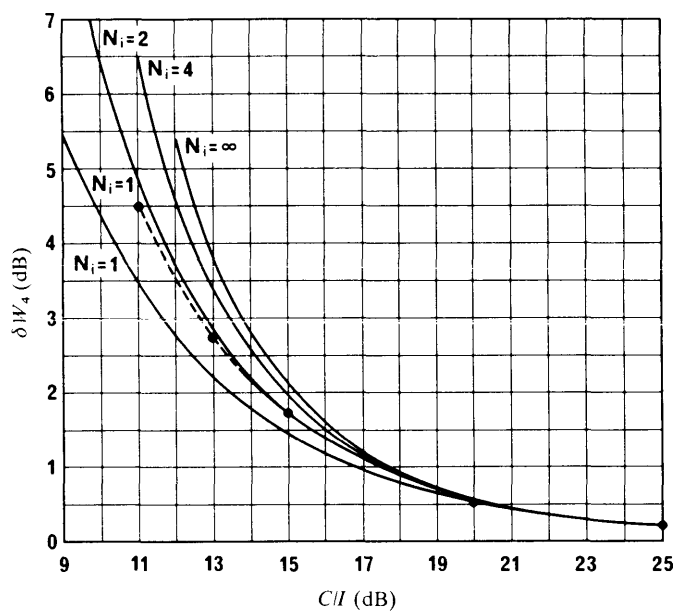


FIGURE 9 – Effects of co-channel interferences in four phase coherent PSK systems

δW_4 : degradation of the normalized carrier-to-noise ratio corresponding to a BER = 10^{-4}

C/I : carrier to interference ratio (I is the total power of interference)

N_i : number of equal level interfering channels

◆---◆: experimental results

—: calculated by computer simulation (transmitter and receiver filters as in Fig. 6—first line of the legend)

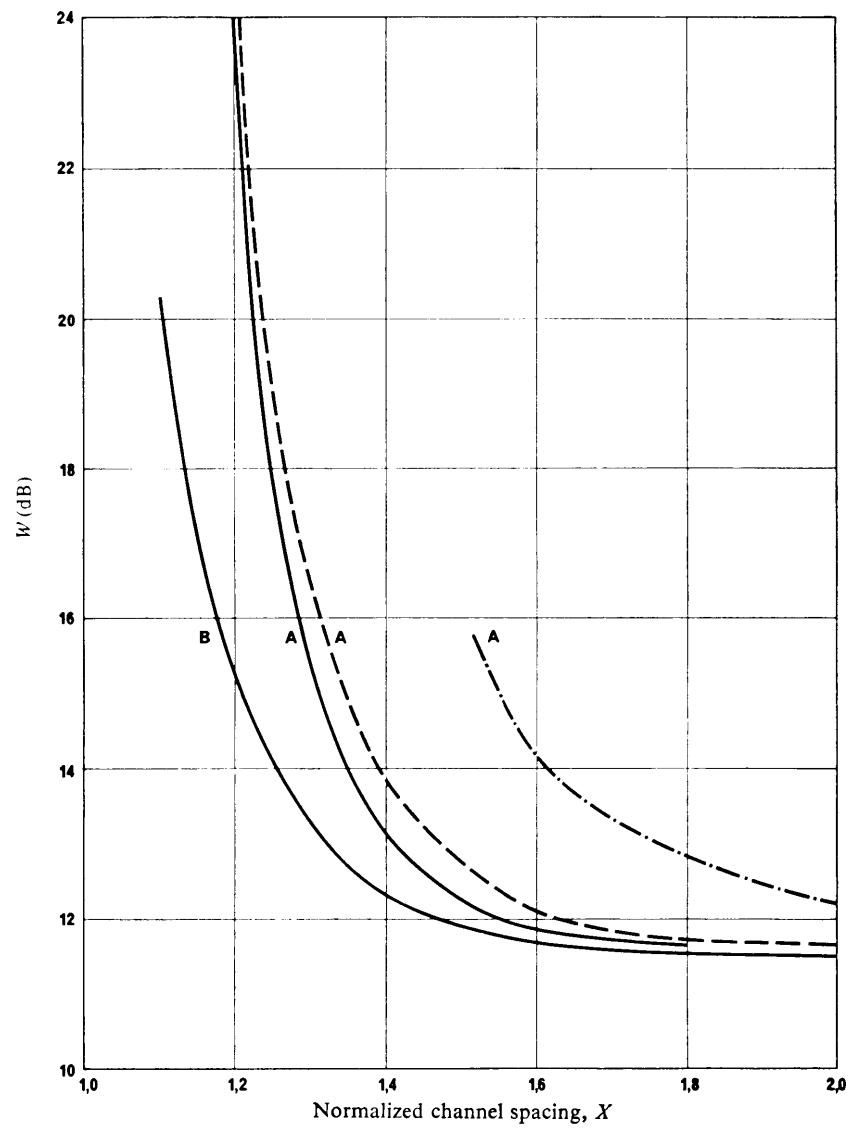


FIGURE 10 — Interchannel interference due to two adjacent channels at the same power level as the wanted carrier

$BER = 10^{-6}$

A: Quaternary
B: Binary

	Transmitter filter	Normalized noise bandwidth β	Receiver filter	Normalized noise bandwidth β
————	6-pole Butterworth	2.0	4-pole Butterworth	1.1
- - - -	6-pole Butterworth	1.8	6-pole Bessel	0.9
- · - · -	4-pole Butterworth	1.5	Gaussian	1.0

5. Overall performance degradation

In principle, the only way of correctly evaluating the degradation effect when all the interference sources are active at a given moment, is to take each of them individually into account with one of the methods referred to in the Introduction.

In practice it is important to reduce the number of disturbing sources to be considered in the performance evaluation. The reason for distinguishing between main and weak interference sources in Table III is to indicate those sources (W) which can be added, on a power basis, to the thermal noise, and those sources (M) which must be treated individually.

Having made this distinction it is then possible to ascribe to each an overall equivalent degradation factor. These factors (δ_W and δ_M) are defined as the difference between the receiver threshold power without interference and the power necessary to achieve threshold performance in the presence of interference.

It can be shown that values for δ_M and δ_W are dependent on the value of threshold error ratio and signal to interference ratio. The ranges of values δ_M and δ_W are shown in [Colavito and Sant'Agostino, 1974].

A problem may arise when adopting the same procedure to check the error objective under normal propagation conditions. It can be shown however (see Annex I) that under such conditions the interference which does not fade with the wanted signal may be ignored.

As the interference effect produces only an increase in the errors due to noise, it is clear from Annex I that both interference and noise powers are considerably reduced and are therefore, unable to produce an appreciable error ratio.

However, in some system designs it may be necessary to check that an adequate margin exists for equipment drift, etc. above the interference-limited case under normal propagation conditions.

The case of asymptotic error behaviour, due to eye pattern closure by the interferences should be prevented in the system design, both in faded and non-faded conditions.

6. Conclusions

The present Report is intended to assist the system designer to locate the interference sources and to assess the performance degradation budget.

The usable fade margin on a regenerative hop which is subject to the above-described interferences is reduced with respect to that theoretically achievable by an amount equal to the overall performance degradation.

Further information on such degradation is needed. Administrations are requested to contribute more information on this subject. Reference should also be made to previous CCIR documents: [CCIR, 1974-78c, d, and e].

REFERENCES

- BENNETT, W. R. [1956] Synthesis of active network. Proc. Symposium of Modern Network Synthesis, 45-61.
- CASTELLANI, V. and SANT'AGOSTINO, M. [May, 1971] Intersymbol and interchannel interference effects in PCM signal transmission on radio links. Binary coherent phase modulation. *Alta Frequenza*, Vol. 40, 389-397.
- COLAVITO, C. and SANT'AGOSTINO, M. [September, 1973] Binary and quaternary PSK radio systems in a multiple-interference environment. *IEEE Trans. Comm.*, Vol. COM-21, 1056-1067.
- COLAVITO, C. and SANT'AGOSTINO, M. [May, 1974] Interference evaluation and RF channel arrangement in digital radio systems. *Alta Frequenza*, Vol. 43, 5, 250-259.
- LUCKY, R. W., SALZ, J. and WELDON E. J. [1968] *Principles of Data Communications*. McGraw-Hill, New York, NY, USA.
- ROSENBAUM, A. S. and GLAVE, F. E. [January, 1974] An error probability upper bound for coherent phase shift keying with peak limited interference. *IEEE Trans. Comm.*, Vol. COM-22, 1, 6-16.
- YAMAMOTO, H., MORITA, K. and NAKAMURA, Y. [11-13 June, 1973] Experimental considerations on 20 GHz high-speed digital radio-relay system. IEEE International Conference on Communications (ICC '73), Seattle, Wa., USA, Conf. Record, Vol. II, Session 28: New developments in radio relay systems, 28-37 — 28-42.

CCIR Documents

[1974-78] a. 9/235 (UK); b. 9/63 (UK); c. 9/36 (Italy); d. 9/38 (Italy); e. 9/60 (UK).

BIBLIOGRAPHY

BENNETT, W. R. and DAVEY, J. R. [1965] *Data Transmission*. McGraw-Hill, New York, NY, USA.

CCIR Documents

[1974-78]: 9/236 (UK).

ANNEX I

Consider that during a fade the received carrier power is C , the transmitter noise is N_T , the receiver noise is N_R and that there are two groups of interfering signals indicated as S_1 and S_2 (see Table III). Then the carrier power to noise power plus interference power ratio is:

$$\frac{C}{S_1 + S_2 + N_T + N_R}$$

Generally, $S_1 + S_2$ is of the same order of magnitude as $N_{R,T}$ and S_1 and S_2 are comparable to each other. Consider that the fade is removed and that the carrier power increases by a factor K (typically a factor of between 1000 and 100 000 times corresponding to fades of 30 dB and 50 dB respectively). The interference power S_1 will be enhanced by the removal of the fade whereas interference power S_2 will remain constant. Then under the non-faded condition the carrier power to interference power plus noise power is:

$$\frac{KC}{KN_T + KS_1 + S_2 + N_R} = \frac{C}{S_1 + \left[\frac{S_2 + N_R}{K} \right] + N_T}$$

The factor $(S_2 + N_R)/K \leq S_1$ hence the signal power to interference power plus noise power ratio is dominated by the interference term and equals: $C/(S_1 + N_T)$.

The application of a factor K to all components of S_1 ignores the fact that some of these, e.g. those due to the cross-polarized signal, may not have faded by the same amount as the main signal. It is of course during the faded condition that this possibility applies.

This interference S_1 enhances the errors due to noise power and thereby controls the error ratio for the majority of the time. However, allowance would also have to be made for noise and distortion due to small changes in propagation conditions since this also could have a critical effect on the long-term error ratio performance.

REPORT 780-1

CONSIDERATIONS OF INTERFERENCE BETWEEN FDM-FM RADIO-RELAY SYSTEMS

(Question 23/9 and Study Programme 23A/9)

(1978-1982)

1. Introduction

The high density of line-of-sight microwave systems in a given geographical area gives rise to a need to pay particular attention to inter-system interference.

There are already CCIR texts covering the topics of sharing frequencies with other services. For example, line-of-sight radio-relay systems have been sharing frequency bands with the fixed-satellite service, in accordance with Recommendation 357. It is suggested that principles and interference criteria also need to be established for sharing frequencies among line-of-sight radio-relay systems.

It is recognized that the introduction and development of criteria and procedures to limit intraservice interference is difficult since radio-relay systems have been in service for more than two decades, and special consideration must be made for existing systems. Nevertheless, the control of inter-system and intrasystem interference is essential for the attainment of proper system performance and availability.

2. Interference coordination philosophy

The sharing Recommendations that have been established by the CCIR have usually been based on the aggregate interference limitation that one system was expected to receive but subdivided in practice into an arbitrary assumed "ultimate" number of equal interfering sources. This cumulative value is a necessary limitation in principle for proper system performance. It appears that this desirable aggregate interference can also be used for inter-system interference coordination.

A true limitation of the aggregate interference is likely to be difficult to administer considering the large number of possible interference exposures. In addition, the importance of the system aggregate interference should not be over-emphasized because the interference received in a hop reduces the available fade margin with respect to a given noise performance. This in turn increases the time for which the system is at the allowable noise performance as detailed in Recommendation 393 and hence the system outage. Consequently, it would be better to distribute the interference as uniformly as possible over the length of the system, and effort should not be concentrated on limiting only the cumulative interference.

As a result, it is suggested that another approach may be to subdivide an aggregate interference allowance to a per-hop value and further to an individual exposure value. This approach avoids the need to record an aggregate interference over an entire system while protecting the hypothetical reference circuit noise performance and, hence, the outage of the system.

Finally, it is suggested that the inter-system interference that each system will receive should not control system performance and it should play a much smaller part in the noise budget than thermal noise or intermodulation noise.

3. Linear interference calculation techniques

The techniques for the calculation of the interference between two terrestrial systems are given in Report 388. The assumptions are that the FM receiver is an ideal limiter discriminator and the signal-to-interference power ratio, at the input of the FM discriminator, is high.

Under these assumptions, the baseband interference is due to the interaction of the spectral densities of the wanted and interfering signals. The computation involves the convolution of the two spectral densities.

The interference that is computed by the aforementioned convolution method is a linear process, and the magnitude of the interference is proportional to the interfering-to-desired signal power ratio. Consequently, the baseband interference varies directly with input interference-to-signal ratio.

Results of interference calculations are often given in normalized form as "equal level interference noise power, N_{i0} ", i.e., the baseband interference noise power resulting from an interfering signal of power equal to that of the desired signal.

The convolution method described in the references can be used with any angle-modulated signal (analogue or digital) once the power spectral densities of both desired and interfering signals are known. Spectral characteristics of FDM-FM signals are discussed in § 4.

4. Spectral characteristics of FDM-FM signals

The evaluation of the baseband interference involves the knowledge of the spectral densities of both the wanted and the interfering signals.

The calculation of the spectral density of an FDM-FM signal when the modulating signal can be modelled by a band-limited Gaussian process is described in Report 388.

The low-pass equivalent of the RF power-spectrum of an FDM-FM signal can be expressed as the sum of a residual carrier and a series of terms involving convolutions of the spectral density of the baseband phase-modulating waveform.

Some results, useful for the evaluation of interference noise, are shown in Fig. 1 [Moreno, 1977]. Here the power spectral densities of the most important CCIR standardized FDM-FM signals are normalized, being multiplied by the top baseband frequency f_2 , and are plotted to a decibel scale: the 0 dB value corresponds to the unmodulated carrier power. The typical parameters of each signal are reported in Table I, together with the value of the residual carrier power. The standard CCIR pre-emphasis has been assumed.

5. Examples of interference noise calculations

Theoretical calculations have been carried out [Moreno, 1977] in order to evaluate the linear component of the interference, assuming that the desired and the interfering signals are identical.

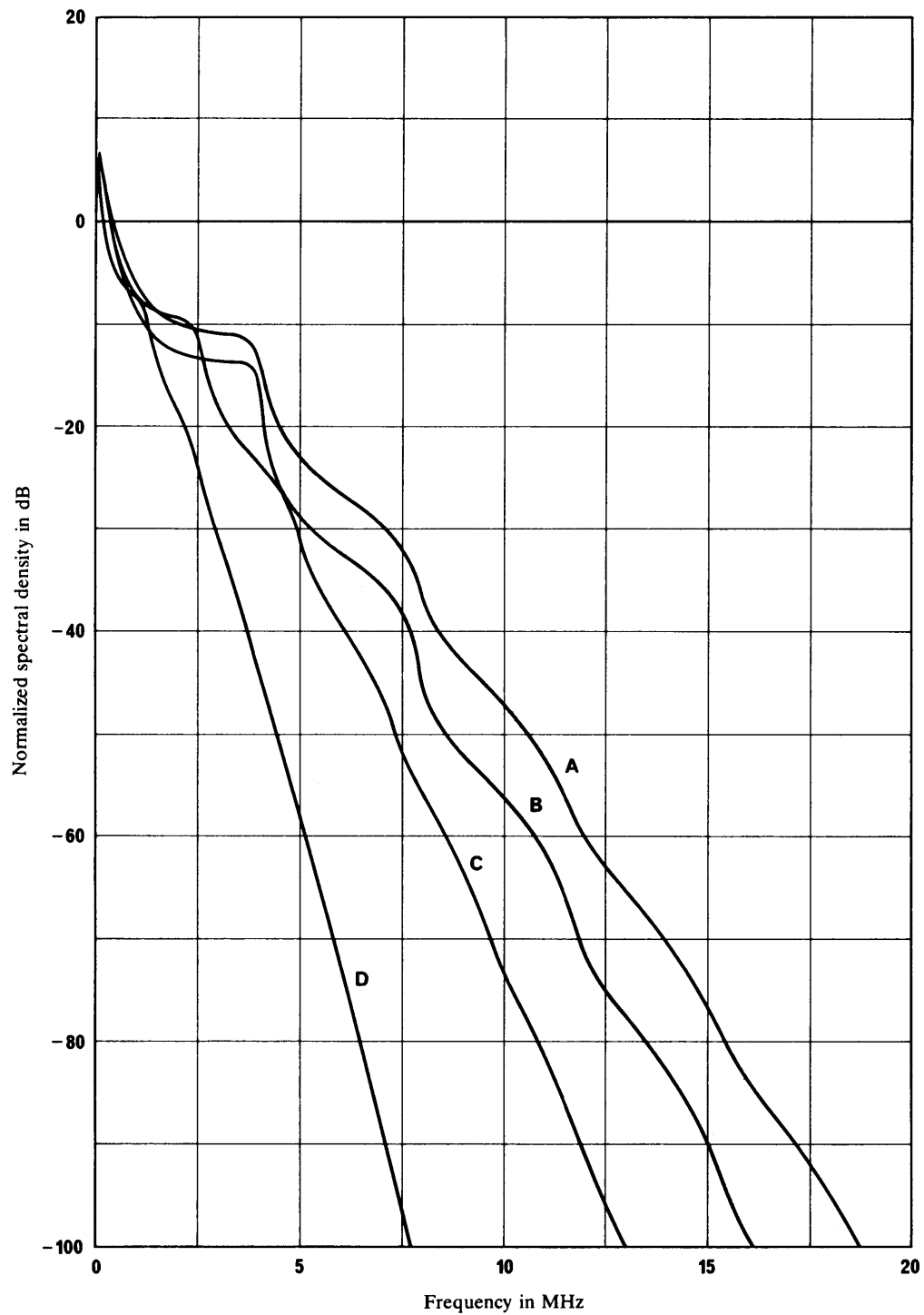


FIGURE 1a – Normalized power spectral density of FDM/FM signals

- A: 960 ch. ($\Delta f_0 = 200$ kHz)
- B: 960 ch. ($\Delta f_0 = 140$ kHz)
- C: 600 ch.
- D: 300 ch.

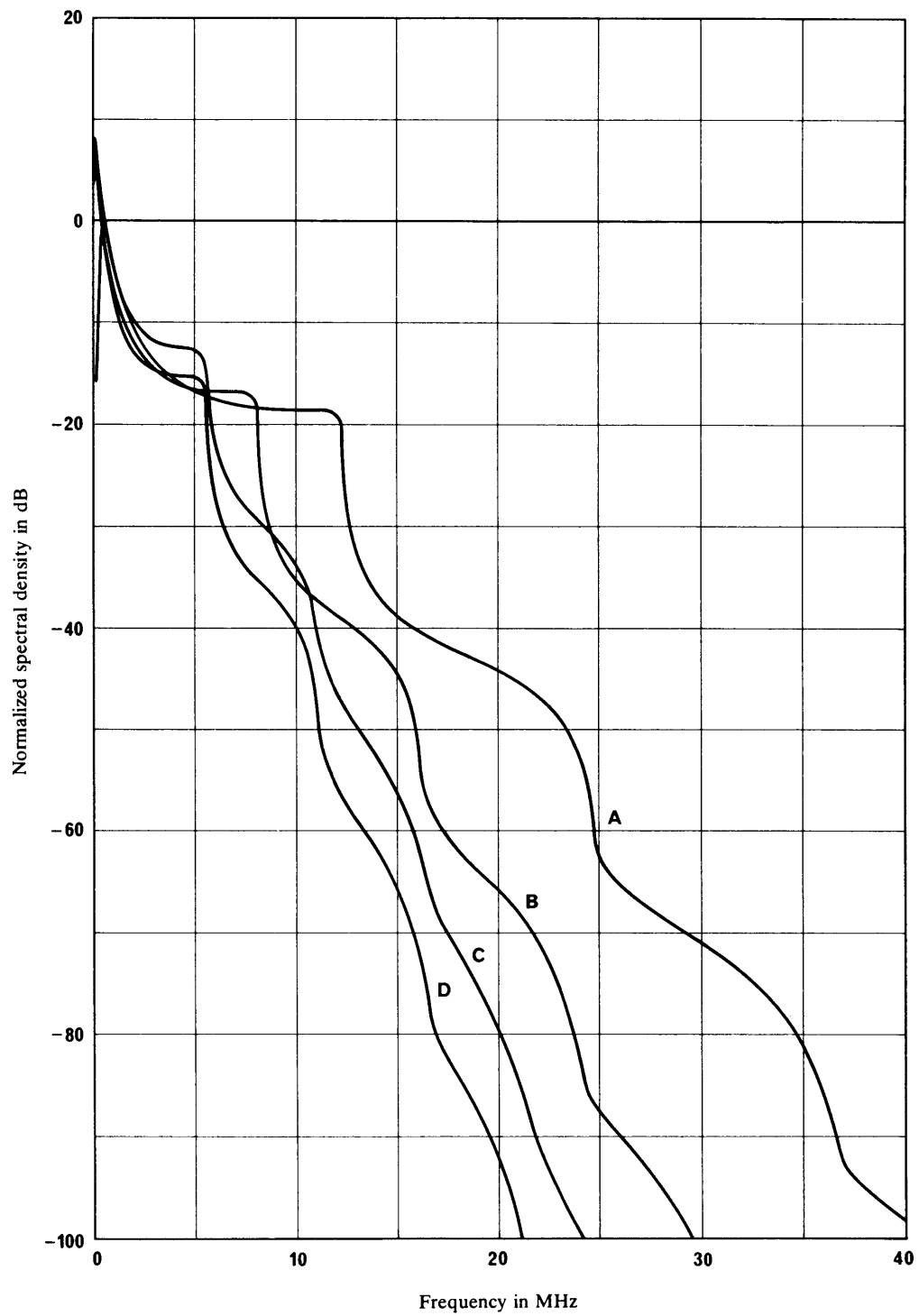
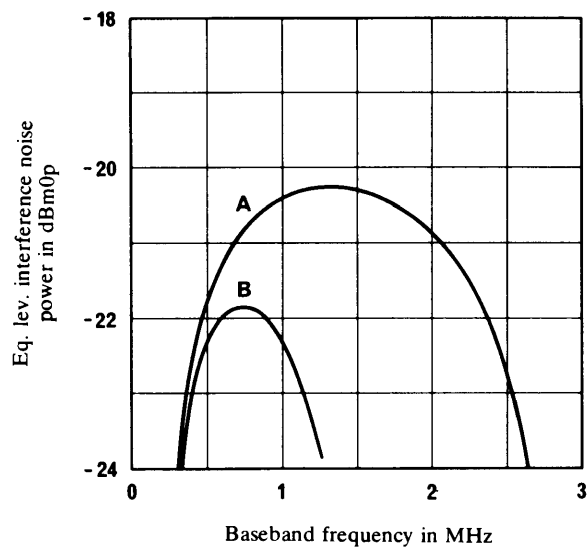


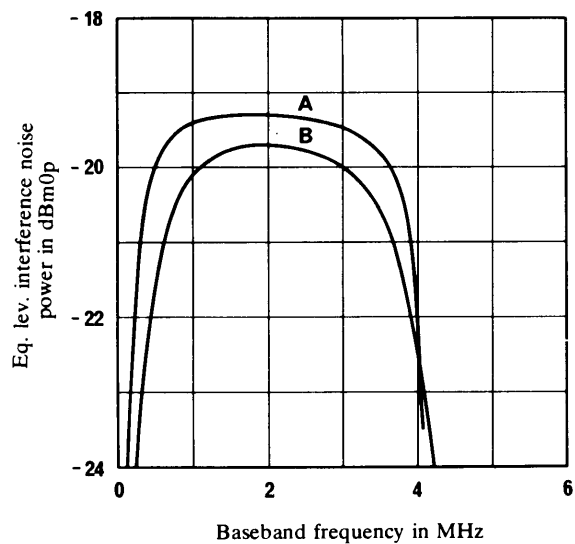
FIGURE 1b – Normalized power spectral density of FDM/FM signals

- A: 2700 ch.
- B: 1800 ch.
- C: 1260 ch. ($\Delta f_0 = 200$ kHz)
- D: 1260 ch. ($\Delta f_0 = 140$ kHz)



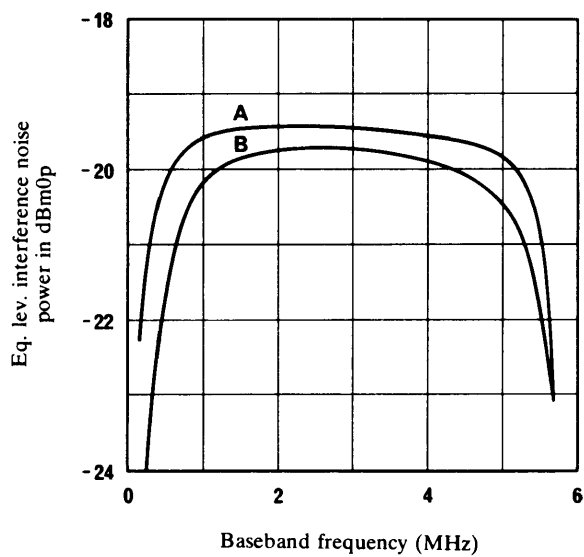
a)

A : 600 ch.
B : 300 ch.



b)

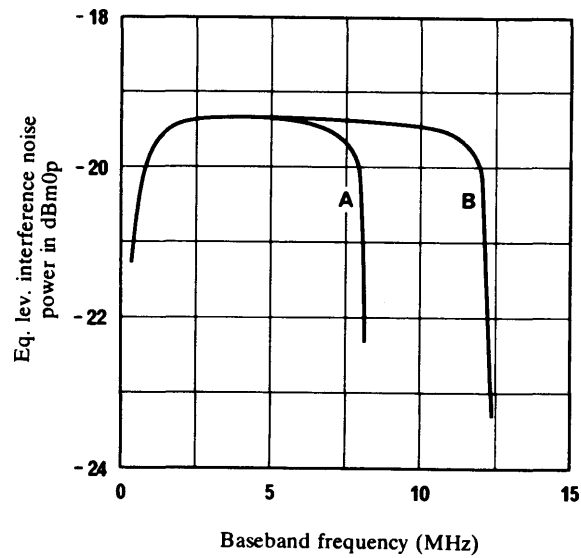
A : 960 ch. ($\Delta f_0 = 140$ kHz)
B : 960 ch. ($\Delta f_0 = 200$ kHz)



c)

A : 1260 ch. ($\Delta f_0 = 140$ kHz)
B : 1260 ch. ($\Delta f_0 = 200$ kHz)

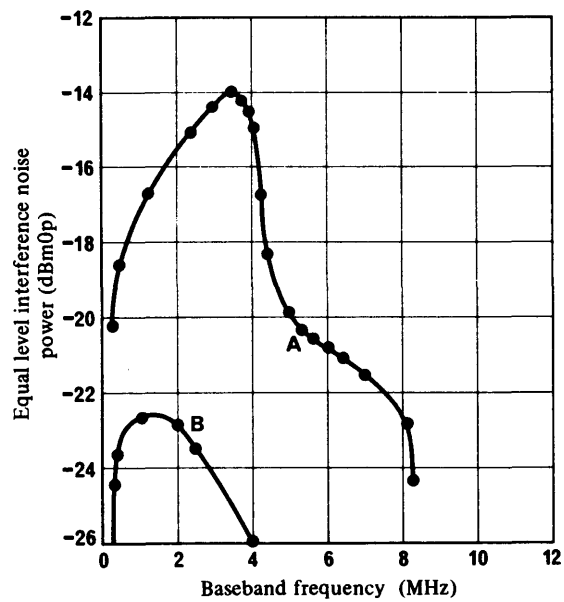
FIGURE 2 – Co-channel interference in FDM/FM systems: equal-level interference noise power N_{i0} as a function of baseband frequency



d)

A: 1800 ch.

B: 2700 ch.



e)

A: interference from a 960 channel carrier
into an 1800 channel carrier ($\Delta f_0 = 200$ kHz)B: interference from an 1800 channel carrier
into a 960 channel carrier ($\Delta f_0 = 200$ kHz)

FIGURE 2 – Co-channel interference in FDM/FM systems: equal-level interference noise power N_{i0} as a function of baseband frequency

TABLE 1 — *Main parameters of FDM-FM systems*

Number of voice channels	Baseband limits		Test tone deviation Δf_0 (kHz)	r.m.s. frequency deviation Δf_{rms} (kHz)	Mean-square phase deviation α (rad ²)	Residual carrier power (dB)
	f_1 (kHz)	f_2 (kHz)				
300	60	1300	200	616.0	2.287	−9.93
600	60	2540	200	871.2	2.166	−9.41
960	60	4028	200	1102.0	2.118	−9.20
960	60	4028	140	771.4	1.038	−4.51
1260	60	5636	200	1262.4	1.956	−8.49
1260	60	5636	140	883.7	0.958	−4.16
1800	316	8204	140	1056.2	0.197	−0.86
2700	316	12388	140	1293.6	0.187	−0.81

5.1 Co-channel interference

The resulting equal-level interference noise power N_{i0} [dBm0p] as function of the baseband frequency is illustrated in Fig. 2. Because of the frequency instability of transmitters, the actual carrier frequency (f_{c1}, f_{c2}) of the two signals may not be exactly the same; because of the presence of residual carriers, beating may occur which will give rise to an interference tone at a frequency equal to $|f_{c1} - f_{c2}|$. The interference noise between different capacity systems is considered specifically for 960 and 1800 channel carriers; other carrier capacities seem to be of interest in several practical situations.

5.2 Adjacent channel interference

Table II gives the equal-level interference noise power N_{i0} [dBm0p] computed in the highest measuring channel in the baseband of the desired signal. The receiver IF filter considered in such calculations is shown in Fig. 3, where the frequency scale is normalized with respect to the channel spacing s . The values of s have been chosen in accordance with CCIR Recommendations (the numbers of such Recommendations and the RF frequency bands are specified in the same table).

The results suggest the basic possibility of extending some RF channel arrangements to FDM-FM systems with a capacity greater than the maximum specified by CCIR Recommendations; although in some bands at least, other factors may render this difficult in practice.

5.3 Tone interference

In determining the influence of the co-channel and the adjacent channel interferences, when the effective modulation index of the wanted FDM-FM signal is very small, special attention should be focused on the serious influence of the tone interference due to the residual carriers, and on the protection margin of threshold performance.

The influence of the tone interference tends to become substantial in such cases, where the separation f_d between carriers of the wanted and interfering signals falls into the baseband or some particular regions such as the pilot, the frequency slot of detected noise, a possible super-baseband service channel and data above voice sub-carrier [Chen, 1980]. In this case, the design requirements with respect to interference should be determined in the light of the tone interference.

6. Non-linear interference considerations

The aforementioned interference calculation techniques dealt with high signal-to-interference ratios where the output interference was calculated by a linear process.

However, when the signal-to-interference ratio decreases below 10 dB, additional interference mechanisms may appear. In this case, the interference cannot be calculated in general form, since it depends on the specific characteristics of the receiver subject to the interference.

In such cases, the important consideration is not the baseband interference noise that is generated, but the possible degradation of the threshold of the receiver and the possibility that the interference may appear as direct cross-talk and thereby become the controlling criteria.

This condition is likely to occur when the wanted system is experiencing a deep fade condition and the interfering signal is uncorrelated with the wanted signal.

TABLE II — Equal-level interference noise power N_{i0} (dBm0p) for various FDM-FM systems and RF channel arrangements

FDM-FM systems Capacity in telephone channels	Channel spacing (MHz)										
	7	11.66	14	14.5	14.82	20	23.32	28	29	29.65	40
	2 GHz Rec. 283	8 GHz Rec. 386	2 GHz Rec. 283	2 GHz 4 GHz Rec. 382	6 GHz Rec. 383	6 GHz Rec. 384	8 GHz Rec. 386	7 GHz Rec. 385	2 GHz 4 GHz Rec. 382	6 GHz Rec. 383	4 GHz Rec. 382
	7 GHz Rec. 385		7 GHz Rec. 385		8 GHz Rec. 386	11 GHz Rec. 387		13 GHz Rec. 497		8 GHz Rec. 386	6 GHz Rec. 384
300	-72.5	< -100	—	—	—	—	—	—	—	—	—
600	—	-71.1	-88.2	-92.2	-94.5	< -100	—	—	—	—	—
960 ($\Delta f_0 = 140$ kHz)	—	—	-61.7	-64.0	-65.6	-97.9	—	—	—	—	—
960 ($\Delta f_0 = 200$ kHz)	—	—	-55.5	-57.6	-59.0	-85.6	< -100	< -100	< -100	< -100	—
1260 ($\Delta f_0 = 140$ kHz)	—	—	—	—	—	-67.2	-83.6	< -100	—	—	—
1260 ($\Delta f_0 = 200$ kHz)	—	—	—	—	—	-60.9	-74.4	-93.3	-96.9	-99.2	—
1800	—	—	—	—	—	—	—	-68.2	-70.7	-72.2	< -100
2700	—	—	—	—	—	—	—	—	—	—	-68.5

(Some of the values shown here are not necessarily used in practical systems)

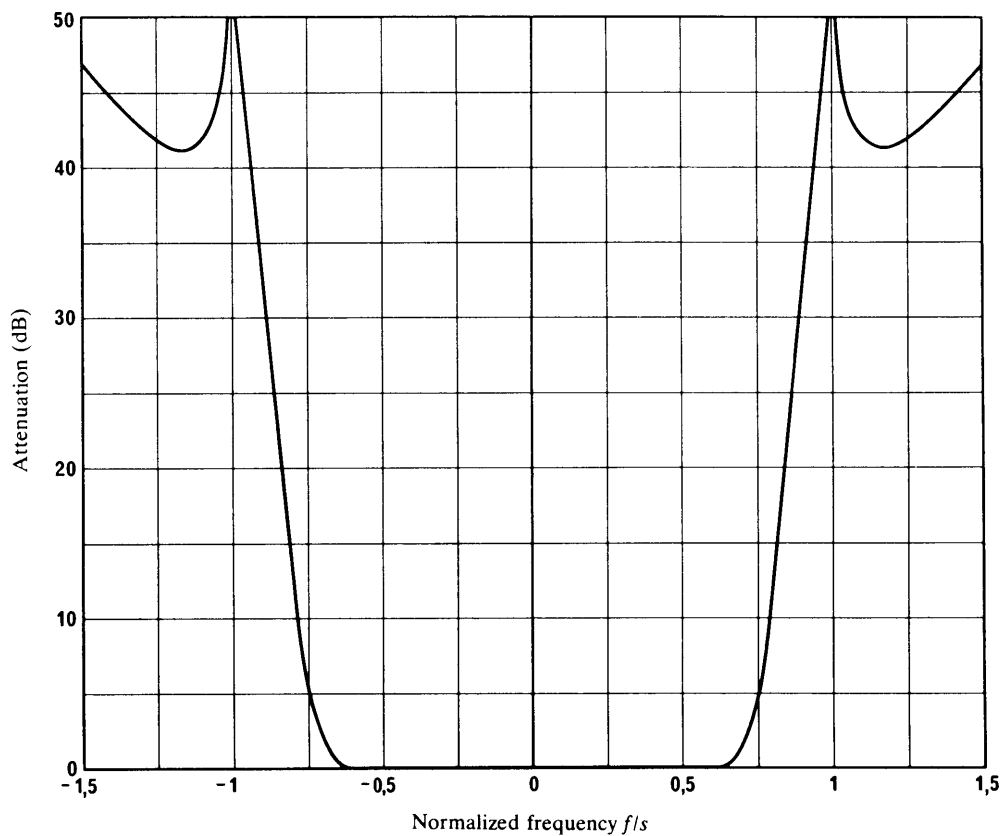


FIGURE 3 — Selectivity of IF receiver filter

Consequently it appears necessary to establish a minimum signal-to-interference ratio in order to protect the system from these non-linear interference effects.

7. Summary

An attempt has been made to identify some principles for inter-system frequency sharing. The penalty for sharing is the accumulation of interference which needs to be budgeted, and thus to claim its place in the total noise of a radio-relay system. Administrations are invited to submit further contributions based on measurements.

REFERENCES

- CHEN, R. M. [May, 1980] Radio frequency interference noise in FDM-FM radio-relay systems. *Rev. Res. Inst. Posts and Telecomm.*, Beijing, China (People's Republic of) Vol. 1, 1, 86-102.
- MORENO, L. [June, 1977] Spectral characteristics and channel spacing criteria in FDM-FM radio links. *CSELT Rapporti Tecnici*, Vol. 5, 141-148.

BIBLIOGRAPHY

- MEUCCI, C. and RUDILOSSO, C. [July, 1963] Spettri di potenza nei ponti radio a modulazione di frequenza con grandissimo numero di canali telefonici (Power spectra in FM radio-relay links with a great number of voice channels). *Alta Frequenza*, Vol. 32, 489-506.

CCIR Documents

[1978-82]: 9/316 (Brazil).

REPORT 931

STUDY OF THE EFFECTS OF CO-CHANNEL INTERFERENCE IN THE TV CHANNELS OF FM RADIO-RELAY SYSTEMS

(Question 2/9 and Study Programme 2C/9)

(1982)

1. Introduction

This Report considers the effects of co-channel interference in TV channels of FM radio systems. The problems caused by opposite hop front to back reception of the RF duplex channel of two frequency channel plans is also considered.

The Report describes the results of studies performed on the transmission of TV signals in the K/SECAM system. These studies were aimed at:

- the definition of a law of visual perception of interference caused by several radio-relay return FM signals;
- assessment of the combined effect produced on the TV picture by FM interference and random noise.

A description is given here only of the visible effects of interference on the TV picture with the K/SECAM system. The effects of interference on the waveforms of the signal or the sound channel accompanying the picture are not taken into account.

2. Test results

The measurements were conducted by the subjective statistical method, using the procedure described in Recommendation 500. The interference and noise were observed on a background of colour TV pictures similar in character to slides. The interfering FM signals were modulated by the colour bar generator signal.

In the experiments aimed at determining the perceptibility of interference, identical levels were established for the interfering FM signals (ranging in number from 1 to 5). Summation with the wanted signal was effected on the intermediate frequency. The FM signal carrier frequency instability was ensured, in the same way as in real conditions, by passing the interfering FM signal obtained from a single modulator through several transmitters and receivers successively (the experiment is described in detail in [Lokshin *et al.*, 1981]). The time shifts of the modulating signals were not introduced, although this phenomenon does occur in real conditions. Owing to the absence of these time shifts, interference caused by a number of FM signals occurred simultaneously. It should be

noted that this variant is equivalent to a radio-relay link with equal sections of such length that the time it takes for the signal to pass along them is a multiple of the line scanning period. It may be assumed here that the perception of interference will be worse than in the case when the interference is randomly distributed over the screen.

The experimental results, using the definition of the perceptibility of FM interference, are shown in Fig. 1.

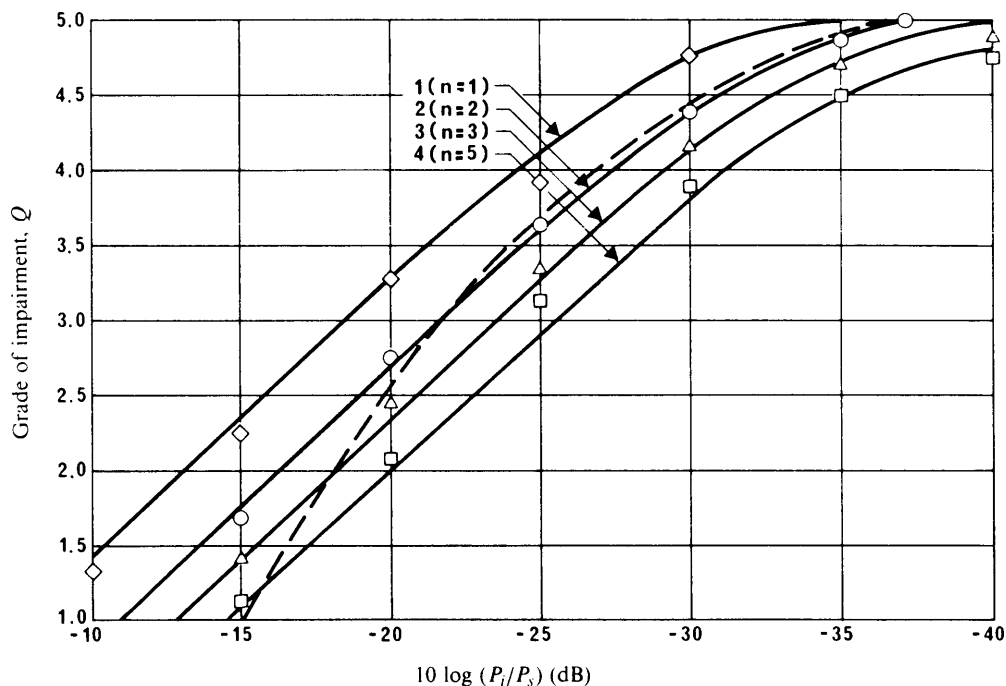


FIGURE 1

The family of curves in Fig. 1 reflects the median assessment of picture quality Q as a function of the P_i/P_s ratio at the radio-relay receiver input; curve 1 corresponds to the effect of a single interfering FM signal and curves 2, 3 and 4 correspond respectively to two, three and five simultaneous interfering FM signals of equal level.

From the experimental results, N interfering FM signals with different ratios at the radio-relay receiver inputs, may be represented as a single equivalent interfering FM signal.

$$\left(\frac{P_i}{P_s}\right)_{eq} = \sum_{n=1}^N \left(\frac{P_i}{P_s}\right)_n \quad (1)$$

The relationship between the median assessment of quality Q to the sum of $(P_i/P_s)_n$ ratios may be represented, on the basis of the experimental results, by the following expression:

$$Q = \frac{1}{6} \left[-1 - 10 \log \left(\frac{P_i}{P_s} \right)_{eq} \right] \quad (2)$$

where

$(P_i/P_s)_{eq}$ is obtained from equation (1).

Report 634 gives a relationship between the interference protection ratio and the grade of picture impairment for a single interfering FM signal:

$$PR_0 = C - 20 \log (D_v/12) - Q + 1.1 Q^2 \quad (3)$$

where:

- D_v : nominal peak-to-peak frequency deviation;
- Q : the impairment grade, concerning the effect of interference only, measured on the 5-point scale recommended in Recommendation 500.
- C : a constant depending on the television standard (18.5 for 625-line standard K/SECAM).

The results obtained from formula (3) are plotted as a dotted line in Fig. 1.

The curves in Fig. 2 represent the results of the studies of the quality of the colour TV pictures as a function of the combined level of random noise and interfering FM signals. The conditions and the procedure for the subjective statistical tests are similar to those applied in the test described above. The signal-to-noise ratio was defined at the output of a frequency demodulator with a standard de-emphasis network, the noise level being measured in the range 10 kHz to 6 MHz using weighting networks with $\tau = 0.245 \mu\text{s}$.

The curves in Fig. 2 describe the colour TV picture quality as a function of the P_i/P_s ratio at the frequency demodulator input with various noise levels at the picture channel output (the corresponding ratios, expressed in dB, of the video signal level to the noise voltage weighted by the $\tau = 0.245 \mu\text{s}$ network are shown to the right of each curve in the figure).

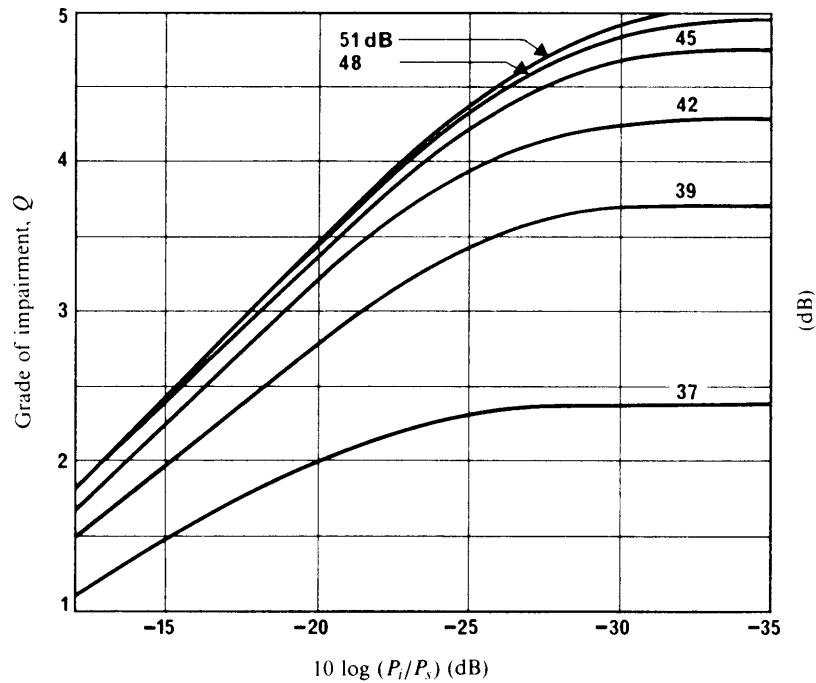


FIGURE 2

Figure 3, which is based on the results of the expert assessments given in Fig. 2, contains curves of "equal assessment" of the sum of random noise and interference caused by the FM signal modulated by the vertical colour bar picture signal. The values of this interference were calculated, allowing for the weighting network, by the formula:

$$20 \log \left(\frac{U_{r.m.s. \text{ interf.}}}{U_{\text{signal}}} \right) = 10 \log \left(\frac{P_i}{P_s} \right) - 23 \quad \text{dB} \quad (4)$$

where:

$U_{r.m.s. \text{ interf.}}$: r.m.s. value of the interference voltage measured at the weighting network output;

U_{signal} : peak-to-peak amplitude of the video signal between the white and black levels;

P_i/P_s : ratio of interfering to wanted FM signal power levels at the radio-relay receiver input.

The 23 dB value shown in equation (4) was obtained experimentally, for both $\tau_2 = 0.33 \mu\text{s}$ and $\tau_1 = 0.245 \mu\text{s}$.

It is interesting to note that the assessment of picture quality remains practically constant if the sum of $(U_{r.m.s. \text{ noise}})^2 + (U_{r.m.s. \text{ interf.}})^2$ is likewise maintained as a constant value.

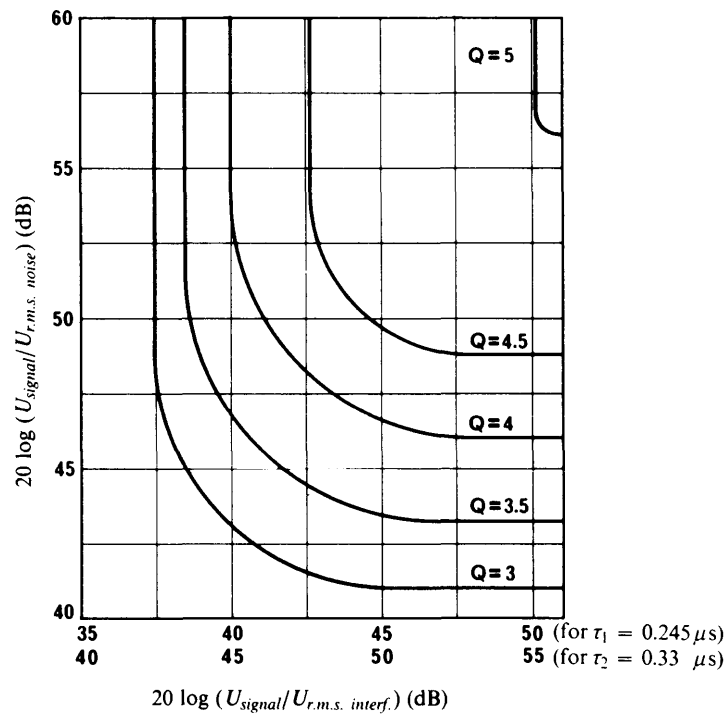


FIGURE 3

REFERENCE

LOKSHIN, M. G., MERMELSSTEIN D. V., SMANTSER, A. N. and SHCHERBAKOV, N. F. [1981] Pomekhi v televizionnykh kanalah RRL, vyzvannye priemom s obratnogo napravleniya (Interference caused in radio-relay TV channels by return signal reception). *Elektrosviaz*, 3.

BIBLIOGRAPHY

CCIR Documents

[1978-82]: 9/298(Rev.1) (U.S.S.R.).

REPORT 784-1

EFFECTS OF PROPAGATION ON THE DESIGN AND OPERATION OF LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(Question 25/9)

(1978-1982)

1. Introduction

The texts established by Study Group 5 contain a wealth of information on the propagation phenomena to be taken into account in designing and operating a radio-relay system. In particular, "Section 5C (Effects of the atmosphere (radiometeorology)) of Volume V" deals with the basic propagation phenomena, while Report 338 is especially concerned with "Propagation data required for line-of-sight radio-relay systems".

The purpose of the present Report is to assemble practical data from Study Group 5 texts or from measurements conducted by administrations. The mathematical expressions used in this Report to describe propagation characteristics are discussed in detail in Report 338.

2. Fading on a single frequency

Fading observed on a radio-relay section stems from two main causes: multipath interference and attenuation due to rainfall or atmospheric gases. Diffraction (or obstruction) fading which is due to sub-refractive atmospheric conditions (low k -factor values) is not discussed in this Report. Planning criteria for path clearance are described in Report 338.

Multipath effects due to atmosphere increase slowly with frequency, but much more rapidly with path length (the deep fading probability follows an approximate law $f \cdot d^{3.5}$).

Multipath effects due to ground reflection may produce deep fading of long duration, especially when the ground is strongly reflecting (flat ground, sea, etc.). This fading can be greatly reduced using vertical space diversity.

Attenuation due to gases should be taken into consideration above about 15 GHz.

Attenuation due to rainfall is virtually negligible below 8 GHz, but increases very rapidly with frequency (the number of dB/km increases roughly as f^2 between about 8 and 20 GHz and a little less rapidly beyond this frequency). On the other hand, in view of the limited size of rainfall areas, particularly for heavy rainfall, attenuation is not proportional to path length.

Multipath effects are therefore the main factor in attenuation at frequencies below 10 GHz, and the rainfall element predominates above a frequency which depends on the climate and the path length, but which is generally of the order of 10 to 12 GHz.

3. Selective fading in a frequency band — limitation of transmission bandwidth

If, as a result of frequency selective fading, the amplitude and phase relationships of all the component frequencies of the signal transmitted are not preserved, the signal is distorted. The effect of this distortion will clearly depend on the type of modulation used but it will in all cases increase rapidly with the bandwidth and hence with the channel capacity.

3.1 FM analogue systems

In this case, the distortion results in intermodulation noise and a variation in the baseband level.

Intermodulation noise due to multipaths in the atmosphere is usually not very troublesome, since it only begins to appear when the fading is very deep, i.e., when the thermal noise is high. It is therefore generally negligible in relation to thermal noise at least in systems up to 1800 telephone channels capacity.

On the other hand, when the multipaths are caused by ground reflections, the intermodulation noise may be much higher, since the reflected signal delays may be more. Hence the greater the channel capacity, the greater care must be exercised to avoid ground reflections. Although this may not be entirely achieved by the choice of path and by using directional antennas, the effect of reflections may be considerably mitigated by using vertical space diversity on reception.

The variation in baseband level is particularly manifest as a large and rapid increase in level when the fading trough passes exactly over the carrier, since this is equivalent to an increase in the modulation index. This effect increases rapidly with channel capacity and may become troublesome at above 1800 channels, but it can be very effectively remedied by diversity reception.

3.2 Digital systems

Frequency selective attenuation results in an error ratio greater than that which would be caused by non-selective attenuation of the same mean amplitude. This phenomenon which is of great importance to the designers of digital radio-relay systems, is shown in Fig. 1, which consists of measurements on an actual system. Each dot represents a period of one second during which errors were observed on the 45 Mbit/s bit stream. The figure also shows a theoretical curve and a curve that was measured over the 42.5 km (26.4 mile) hop where the signal was artificially faded by an attenuator. With flat fading an error ratio of 10^{-3} should be reached with a fade depth of 41 dB, the so-called (flat) "fade margin". Only a few such events were recorded: in most cases a 10^{-3} error ratio was obtained long before a fade of 41 dB was reached beginning with fade depths as low as 19 dB in some cases. From this we conclude that the main source of degradation is inter-symbol interference due to multipath effects [CCIR, 1978-82a].

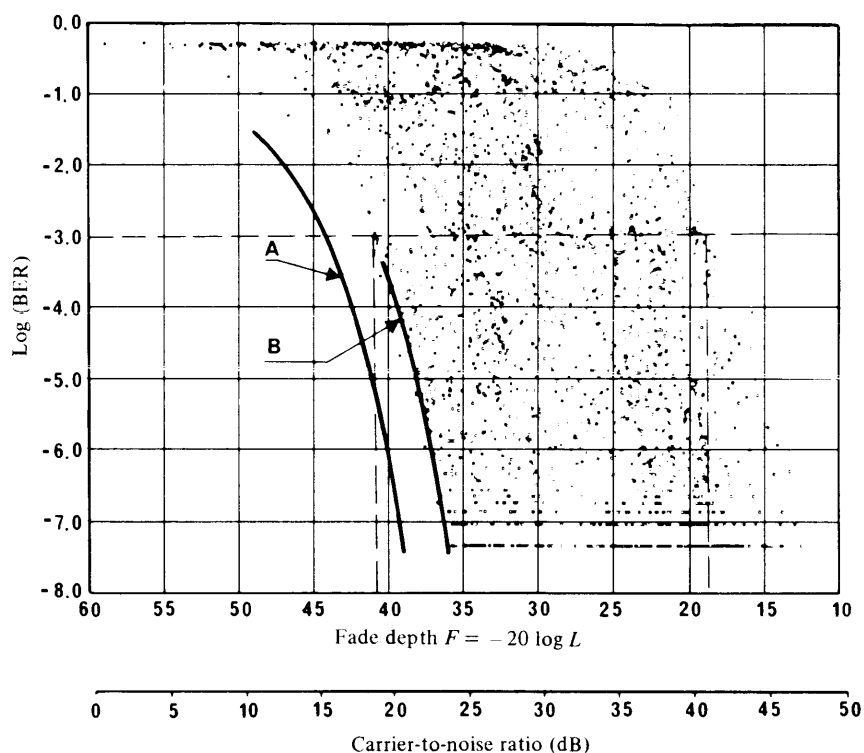


FIGURE 1 — Example of an error ratio scatter plot.
Each dot represents a one-second measurement interval

Frequency: 4 GHz
 Bit rate: 45 Mbit/s
 Modulation: 8 PSK (roll-off factor $\alpha = 0.5$)
 Channel spacing: 20 MHz
 Hop length: 42.5 km
 A: ideal 8 PSK
 B: measured with flat fade

The conventional method for calculating outages is based on the concept of flat fades and cannot therefore be used for high speed digital radio-relay systems. An increase in the flat fade margin, while in analogue systems will tend to reduce the thermal noise, in digital systems cannot improve the performance if multipath fading has already collapsed the eye-diagram amplitude to zero. It therefore follows that increasing the transmitter power cannot be employed to make digital radio systems meet their outage requirements.

The extent to which the fade margin of a digital system will be eroded by frequency selective effects during multipath propagation will be dependent upon:

- the properties of the digital radio system (modulation method, capacity, utilized bandwidth etc.) and its susceptibility to these dispersion effects (see § 6);
- the degree to which frequency selective effects occur on a given radio path. This will depend upon such factors as path length, atmospheric conditions, location, clearance, roughness, and types of antenna utilized.

The concept of “net” or “effective” fade margin has been introduced for digital systems, defined as the fade depth exceeded for the same number of seconds as a threshold error ratio of, for instance, 10^{-3} [CCIR, 1978-82b]. Referring to Fig. 1, the net fade margin is defined by a vertical line, to the left of which are as many one-second dots as are above the horizontal line defined by an error ratio of 10^{-3} . In Fig. 2, this is shown by the dashed lines, giving a net fade margin of 29 dB for the unprotected hop, and 33 dB for the hop with the adaptive equalizer. The flat fade margin of this system is 46 dB. Similar values of net fade margin have also been found in 4 PSK systems operating at 70 and 140 Mbit/s in the 8 and 11 GHz bands, respectively [CCIR, 1978-82c and d].

Some administrations have used the net fade margin concept for the design of digital radio systems. By substituting net fade margin for flat fade margin the outage on the hop can be approximately obtained from Report 338.

Another administration has used a different concept of fade margin as shown in Fig. 3 to characterize the performance of systems during multipath fading. The curve shows a joint probability distribution, and can be used to determine the probability that a fade of a certain depth will result in outage [Muir and de Belin, 1981]. The curve shows that the erosion of the fade margin even on the same hop is variable, and dependent upon the properties of the fading conditions.

Space diversity and adaptive equalization have become powerful tools to lessen the outages in digital radio systems. This is illustrated in Fig. 2, which shows results taken by one administration on a 42.5 km (26.4 miles) hop. Space diversity combiners are very effective in high speed digital systems because they reduce the large amplitude and delay dispersions found in a single radio channel during fading. This effect is not obtained by switched space diversity if the switch point is simply based on a threshold in the received signal level. If, however, the switchover is initiated by a fast error ratio measurement, space diversity with hitless baseband switching has been found very effective. From Fig. 2 we find that the benefits of space diversity combining are manifested by about a factor 6 reduction in outage time at 10^{-3} error ratio level. Adaptive equalizers effectively reduce the effects of inter-symbol interference. The very large improvement obtained by the simultaneous operation of the combiner and the equalizer should be noted in particular. It is larger than the product of the improvements of each alone, a very desirable synergistic effect. Another method for reducing outages due to multipath fading is the use of crossband diversity with hitless 1 + 1 baseband switching. The improvement factor associated with diversity systems is likely to be heavily dependent upon parameters including path length, atmospheric conditions, location, clearance, roughness, antenna types and antenna spacing. Measurements made in the United Kingdom on a 54 km path using an RF combining phase adaptive space diversity system with an 11 GHz, 140 Mbit/s system showed, over a period of one year, an average improvement factor of 25 for 3 m antennas vertically spaced by 10 m.

Certain propagation conditions can occur where the use of more elaborate adaptive equalizers may be necessary. Inversion layers and elevated ducts are known to exist in certain geographical areas at elevations up to and exceeding 1000 m (Report 718). In such cases the possibility exists for reflected signals to arrive at the receive antenna, delayed with respect to the direct signal, by in excess of one half of the duration of one signalling element. This type of distortion cannot be corrected by the use of simple adaptive equalizers used to deal with multipath distortion. Certain system design parameters which can have an effect in reducing this distortion are modulation method, path geometry and antenna beamwidth. In locations where elevated ducts are known to exist, and digital microwave radio-relay systems are to be operated, attention should be given to the following factors in system design:

- the antenna beamwidth, required to minimize the amount of energy radiated towards a reflection layer;
- the modulation scheme used, in order to increase the inter-symbol duration;
- the hop length, required to minimize the probability of destructive reflections.

4. Effects of propagation on orthogonal polarization discrimination

Digital modulation suggests the use of the same frequency on two orthogonal polarizations in order to increase the transmission capacity. This frequency re-use is possible only if the propagation does not cause an undue decrease in the decoupling between orthogonally polarized signals.

Orthogonal polarization is also frequently used to increase the isolation of digital or analogue channels operating on adjacent frequencies. In this case channel isolation is additionally increased by the effects of frequency filtering.

The following indications were drawn from the measurements carried out by various administrations:

4.1 Effects of rainfall on orthogonal polarization discrimination in co-channel digital systems

The decrease in decoupling due to rainfall depends to only a small extent on the length of the path.

For a given fade margin, a co-frequency orthogonally-polarized channel system will experience a time percentage during which the error ratio exceeds 10^{-3} (for instance) greater than one using only one channel on each frequency. This effect becomes more significant as the fade margin is increased.

Moreover, cross-polarization can be produced by the accumulation of snow or raindrops on the antenna feed system. This effect may be avoided by using a radome.

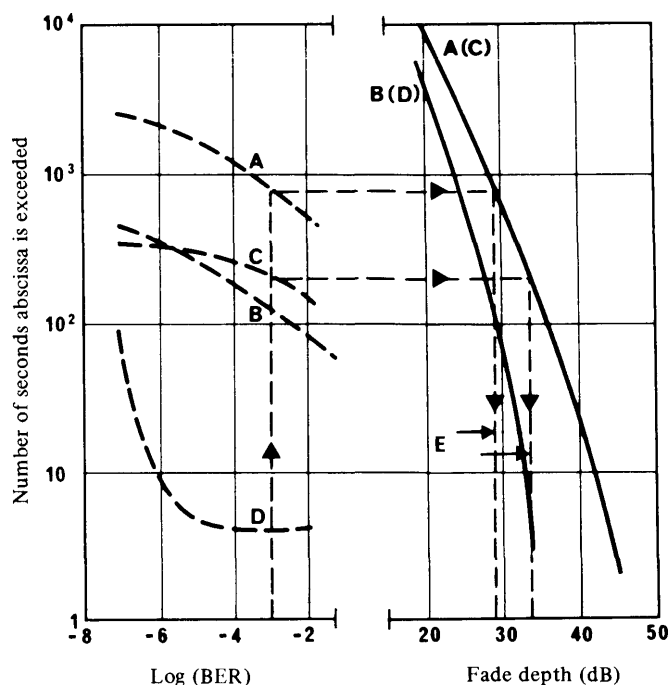


FIGURE 2 — Example of cumulative fading and BER distributions

Frequency: 6 GHz
 Bit rate: 78 Mbit/s
 Modulation: 8 PSK (roll-off factor $\alpha = 0.5$)
 Channel spacing: 30 MHz
 Hop length: 42.5 km

Curves A: unprotected hop 3 m (10-foot) horn reflector antenna)
 B: space diversity with IF combiner
 C: adaptive IF amplitude slope equalizer
 D: with B and C
 E: "Net" fade margin

Total observation period = 38 days (August-September, 1978)

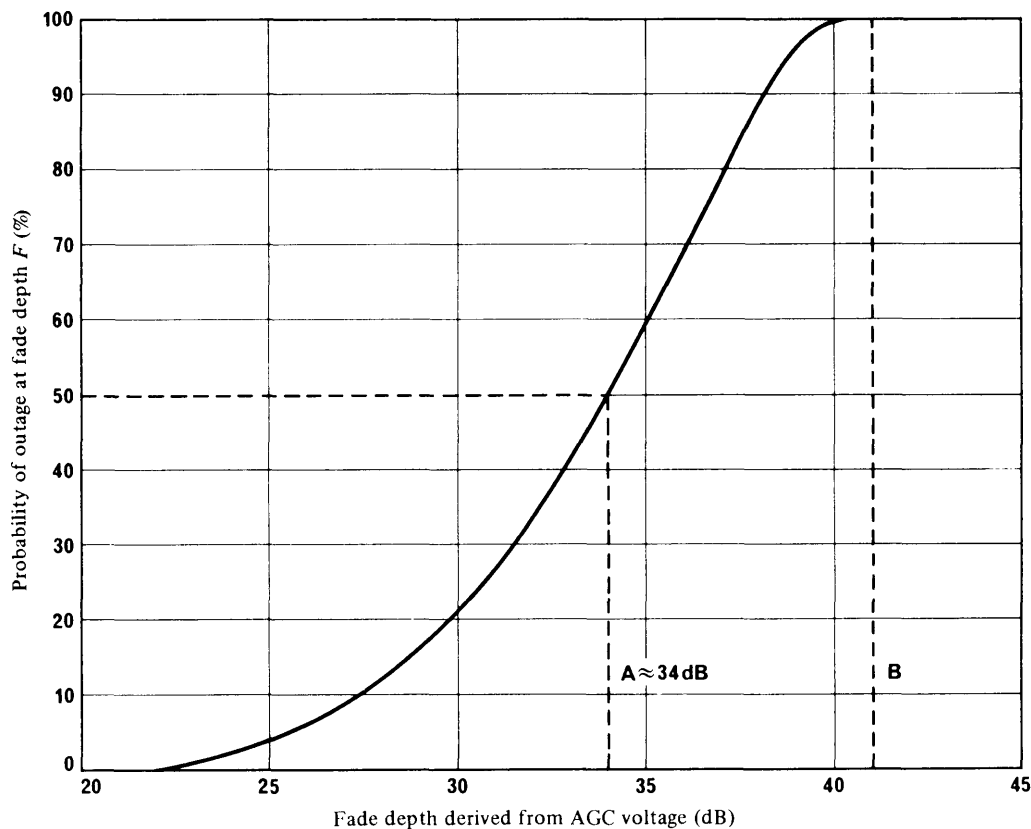


FIGURE 3 — Example of a joint probability distribution showing the effects of multipath propagation on fade margin

Frequency: 11 GHz
 Bit rate: 140 Mbit/s
 Modulation: QPSK
 Hop length: 54 km
 A: a fade of 34 dB has a 50% probability of causing an outage
 B: flat fade margin

4.2 Effects of multipath on orthogonal polarization discrimination in co-channel digital systems

The decrease in decoupling due to multipath effects can result from several mechanisms. As discussed in Report 722, these mechanisms can generally be divided into two groups: those in which the cross-polarized patterns of the antennas do not play a role and those in which they have a role. In the latter group, variations in the angle of arrival of the received signal during multipath conditions require good cross-polar radiation patterns to maintain cross-polar discrimination. Based largely on work carried out in France and Japan, a prediction technique is proposed in Report 338, in which both the fade depth of the co-polarized signal and the cross-polarized patterns of the receive and transmit antennas are important factors in the decoupling achieved during multipath conditions. Space-diversity reception has been shown to be effective in helping to maintain cross-polar discrimination.

An extensive series of tests carried out on an 8 GHz system in Canada has shown that a digital system operating in an orthogonally polarized co-channel mode and using space diversity reception, is capable of meeting the performance requirements of a long-haul large capacity system [CCIR, 1978-82e].

Experience in the USA with cross-polarized systems is given in [Cronin, 1980].

Separate knowledge of the cross-polarization decoupling (or cross-polarization discrimination, *XPD*) in the absence of multipath fading is often desired by the designer of orthogonally polarized radio systems. *XPD* surveys made by one administration are summarized in Table I. All measurements were made on 3 m (10 foot) pyramidal horn reflector antennas including waveguide feeds after boresight alignment with the TM_{01} – mode method, in many cases several years after the initial alignment.

TABLE I — *XPD surveys*

Year	Number measured		Frequency band (GHz)	<i>XPD</i> mean (dB)	<i>XPD</i> ⁽¹⁾ (dB)
	Radio channels	Hops			
1967	60	5	4	35.0	30.0
1967	1223	111	4	37.4	33.0
1967	270	23	4	34.8	29.4
1975	277	52	4	32.0	28.5
1967	255	23	6	34.2	29.5

⁽¹⁾ 90% of the measurements exceeded the tabulated values.

4.3 *Effects of multipath on orthogonal polarization discrimination in interleaved channel analogue systems*

If the ratio of carrier separation to top baseband frequency is less than approximately 3, filtering becomes less effective and the effects of orthogonal polarization discrimination become more and more important.

4.4 *Effects of multipath on orthogonal polarization discrimination in interleaved channel digital systems*

The frequency selective nature of multipath fading may cause interference from cross-polarized and co-polarized adjacent channels; the contribution from the former being the more critical of the two. In order to allow for this interference in system performance calculations, a knowledge of the statistics of frequency selective fading is needed.

5. Optimum length of hops – tandem hops

A radio-relay link of a given overall length should generally be divided into a number of tandem hops and it is important to select the optimum length for these hops.

This optimum length may be defined, for instance, as the length which produces the shortest possible total outage time (see Recommendation 557) or as the length which gives the highest possible mean value for the signal/noise ratio (see Recommendation 395). It depends on the propagation and on the reliability of the equipment, including the power sources. It also depends on the structure of the radio-relay system (stand-by channels, diversity, etc.) and on the topography of the region.

With regard to the propagation, account should be taken of the correlation between the fading on two successive hops. Rapid fading due to multipaths is generally uncorrelated. The same applies to attenuation due to rainfall when the length of the hop is clearly greater than the dimensions of the rain cells. On the other hand, if the length of the hop is about the same or less than the dimensions of the rain cells, there is a certain correlation, and hence the outage probability for the overall circuit is less than the sum of the outage probabilities for each hop.

Although there may be hops over 100 km long, the usual lengths are between 40 and 50 km in the frequency bands below 10 GHz. This length may still be used for the frequency band 10.7 to 11.7 GHz, at least with certain types of modulation, except in regions where the rainfall is very heavy. In the higher frequency bands the length of the hops may have to be progressively reduced because of the rain, which at the same time reduces multipath fading. However, there would be a limit to this trend, which is reached when the length of the hops becomes far less than the dimensions of heavy rain cells, i.e. a few kilometres.

6. Characterization of radio equipment taking into account the effects of multipath fading

A method of measuring an equipment "signature" has been found very useful in comparing various digital systems in the presence of multipath fading [Giger and Barnett, 1981]. The method consists of approximating actual fades by a two-ray simulator in the laboratory and determining the model parameters that cause, for instance, an error ratio of 10^{-3} (outage or threshold point). The two-ray model has the transfer function:

$$H(\omega) = 1 - b \cdot e^{-j(\omega - \omega_0)\tau}$$

where a unity-amplitude direct ray and a delayed (delay τ) ray of amplitude b is assumed. The lowest point of this fade is f_0 away from the channel centre frequency and has a depth $B = -20 \log \lambda$ with $\lambda = 1 - b$. The "signature" is then the plot of the critical value B_c versus f_0 at the outage error ratio. A value of 6.3 ns for τ has been used by one administration, and the associated statistical distributions for b and f_0 have been determined from the study of a large number of fading events. No loss of generality is obtained by using the fixed value for τ .

Signatures are sometimes measured for values of τ other than 6.3 ns. A simple scaling rule can be applied to still get the critical curve λ_c ($\tau = 6.3$ ns). This rule says that the width (in f_0) of the signature is independent of τ and its height (in λ) is proportional to τ .

Figure 4 shows measured signatures for three digital radio systems now commercially operating in the 5925 to 6425 MHz band. The figure indicates that the signature is narrowed by reducing the symbol rate and that it can be narrowed by using adaptive equalizers.

In most signatures, a typical dip has been found in the centre of the band indicating a lesser susceptibility for band centred fades than for fades off centre. The centred fades generate even order (parabolic, etc.) amplitude and delay distortions, which cause less inter-symbol interference than the odd-order (linear, etc.) distortions produced by the off-centred fades.

Signatures can be used to compare the relative sensitivity of different digital radio systems to the effects of frequency selective fading. Since the lowest point of the fade has equal probability of occurring at any value of f_0 , and since the probability of a given fade depth occurring will decrease with increasing fade depth, it is clear that a system with a "small" signature will be less affected by fading than one with a "large" signature.

A method of using signatures to predict relative outages has been reported by one administration. In this method an approximation for the relative outage due to selective fading can be obtained by squaring the signature $\lambda_c(f)$ and integrating over f_0 . If signatures obtained in this way from two types of equipment are compared, then the equipment which has the lower signature may suffer less outage than the other. If the signature is very "small" the simple approximation is not a good measure of the overall outage. Flat-fade margin and thermal noise will tend to dictate the outage in such systems.

The prediction of absolute outages from signatures is however only meaningful when the propagation model assumed in the signature is truly representative of operational conditions. These conditions are likely to be heavily dependent upon hop parameters such as location, length, roughness, etc. The two-ray model described above has been shown to give a good fit to experimental observations in the USA, and a precise method of determining outage from this model can be found in [Lundgren and Rummler, 1979]. Results from experimental observations in Europe show that in some cases more complex propagation models are required, as discussed in Report 881.

Figure 5 shows the signatures for a variety of signals transmitted over a 20 MHz channel operating at 4 GHz. An interesting comparison is made between a high speed 45 Mbit/s 8 PSK system which uses neither space diversity reception or adaptive equalization and a conventional 1200 circuit FDM-FM system. Using the approximate method described above it can be estimated that the total outage caused by selective fading of the digital system will exceed that of the FDM-FM system by about sixty times. The criterion for an interruption of the FDM-FM system is 316 000 pW0p in a noise measuring slot located at 9 MHz in the baseband [CCIR, 1978-82a]. As is suggested by curve C of Fig. 4, considerable improvements could probably have been made in the digital system by the use of an adaptive equalizer. Also calculations showed that the outages due to selective fading of the FDM-FM systems were not important compared to the outages caused by the increased thermal noise during a fade. Therefore no conclusions can, in general, be drawn with respect to the relative availability performance of the digital and FDM-FM systems.

It is worthy of note that the use of a signature to estimate the outages due to selective fading can be used for FDM-FM systems which include "data under voice" (DUV) signals, and can also be used for analogue television signals. In both cases a suitable criterion for generating the signature must be determined. Some typical signatures are shown in Fig. 5.

Another method for outage calculation has been used that makes use of the statistical distributions of in-band amplitude and delay dispersion [Komaki *et al.*, 1979]. This method could be simpler when the calculation of outage from the curves shown in Figs. 4 and 5 is difficult [CCIR, 1978-82f].

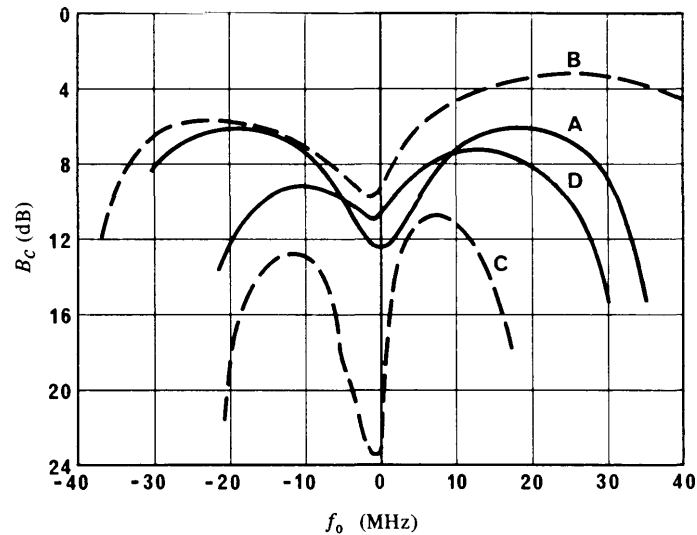


FIGURE 4 — Signatures B_c for 6 GHz digital radio system operating with a 30 MHz channel spacing

- Curves A: 78 Mbit/s, 8 PSK ($\alpha = 0.3$), 26 Mbaud
 B: 90 Mbit/s, 8 PSK ($\alpha = 0.5$), 30 Mbaud
 C: same as B but with amplitude slope and notch adaptive equalizers
 D: 90 Mbit/s, 16 QAM ($\alpha = 0.5$), 22.5 Mbaud
 α : roll-off factor
 $\tau = 6.3$ ns
 BER = 10^{-3}

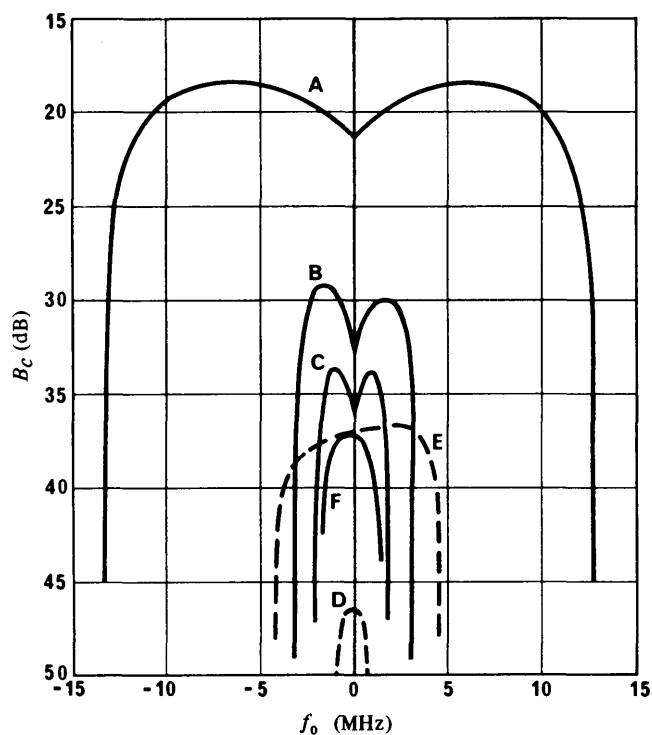


FIGURE 5 — Signatures B_c for various digital and analogue signals on a 4 GHz TD-2 channel with a 20 MHz channel spacing and using a value of $\tau = 2.3$ ns

System	Outage criteria (See §6)	Relative outage
Curves A: 45 Mbit/s, 8 PSK	BER = 10^{-3}	377
B: 1200 circuit FDM-FM Average circuit load = -15 dBm0	316 000 pW0p	6.2
C: 1200 circuit FDM-FM Average circuit load = -19.6 dBm0	316 000 pW0p	1.0
D: DUV only	BER = 10^{-6}	0.01
E: DUV with signal B	BER = 10^{-6}	1.1
F: NTSC TV signal	316 000 pW0p	

REFERENCES

- CRONIN, P. M. [11 June, 1980] Dual-polarized digital radio operation in a fading environment. IEEE International Conference on Communications (ICC '80), Seattle, Wa., USA, Conf. Record, Vol. 3, Session 52: Digital radio buffet, 52.5.1.-52.5.6.
- GIGER, A. J. and BARNETT, W. T. [1981] Effects of multipath propagation on digital radio. *IEEE Trans. Comm.*, Vol. COM-29, 9, 1345-1352.
- KOMAKI, S., HORIKAWA, I., MORITA, K. and OKAMOTO, Y. [1979] Characteristics of a high capacity 16 QAM digital radio system in multipath fading. *IEEE Trans. Comm.*, Vol. COM-27, 12, 1854-1861.
- LUNDGREN, C. W. and RUMMLER, W. D. [May-June, 1979] Digital radio outage due to selective fading — observations vs. prediction from laboratory simulations. *BSTJ*, Vol. 58, 5, 1073-1100.
- MUIR, A. W. and DE BELIN, M. J. [March, 1981] The field evaluation of a 140 Mbit/s digital radio relay system in the 11 GHz band. IEE Conf. Publ. No. 193 Proc. IEE Conference on Telecommunication Transmission — Into the Digital Era.

CCIR Documents

- [1978-82]: a. 9/56 (United States of America); b. 9/38 (France); c. 9/25 (United Kingdom); d. 9/68 (Finland); e. 9/71 (Canada); f. 9/12 (Japan).

REPORT 285-5

**PROPAGATION EFFECTS ON THE DESIGN AND OPERATION
OF TRANS-HORIZON RADIO-RELAY SYSTEMS ***

(Question 7/9)

(1963-1966-1970-1974-1978-1982)

1. Introduction

This Report is based on consideration of systems with capacities from about 12 to 120 voice channels and, in certain cases, up to 300 voice channels or a monochrome television signal.

Transmission characteristics can be defined in terms of the amplitude and phase properties of a received signal. Given a tropospheric-scatter path, both amplitude and phase transmission characteristics vary with frequency and time.

Amplitude variation as a function of time and frequency is affected by meteorological phenomena, terrain and other environmental conditions, and by aircraft.

Amplitude variation as a function of time consists of a rapid variation superimposed on a slow change. Rapid variations, which are basically caused by multipath phase interference phenomena, can be mitigated in many cases by diversity techniques. The effects of slow variations of received power may be minimized through the use of high-power transmitting equipment, high-gain antennas, very low-noise receiving systems, low-loss feeders, adaptive message-loading techniques, and improved detection and other practices for system optimization, which are associated with the choice of radio-frequency carrier, bandwidth and modulation.

2. Drop in antenna gain

The combined gain of the transmitting and receiving antennas may be less than the sum of their plane-wave gains. This apparent drop in gain is termed "gain degradation" or "antenna-to-medium coupling loss". Theoretical analyses [Hartman and Wilkerson, 1959; Rice *et al.*, 1967] state that the amount of loss is dependent on the antenna gain and scatter angle.

The path antenna gain or total effective antenna gain over a trans-horizon system has been observed experimentally to be practically independent of distance between about 150 and 500 km [Boithias and Battesti, 1964]. According to these experiments, the total effective gain (Fig. 1) may be assumed to depend only on the sum of the free-space antenna gains, without large corrections provided that neither of the free-space antenna gains exceeds about 50 dB, and the gains of the two antennas do not differ greatly.

More recent studies [Battesti and Boithias, 1971] indicate that the drop in antenna gain is related to the slope of the refractive index gradient-altitude curve within the common volume, consequently the variations of drop in antenna gain as a function of distance depend slightly on the climate. These studies also show that, with increasing antenna gain, the slope of the curve in Fig. 1 tends asymptotically to 1/4.

3. Noise in trans-horizon radio-relay systems**3.1 Noise due to propagation**

Noise due to propagation consists of thermal noise caused by fading and intermodulation noise caused by multipath phenomena.

Thermal noise is connected with wave propagation [Gough, 1968; Boithias and Battesti, 1965]. Information on this subject is given in Report 238. It should also be noted that slow fading in adjacent radio-relay hops may be considered to be statistically independent.

Owing to fast and slow random fading, noise power in the telephone channels will also be random. To obtain reliable results may take a considerable period of time. The first information concerning noise measurement methods in trans-horizon radio-relay systems which shorten the time required for the measurements to be made, is already available. Further information is needed.

* This Report applies to trans-horizon systems using tropospheric scatter but not necessarily to trans-horizon systems using another mode of propagation (diffraction, etc.).

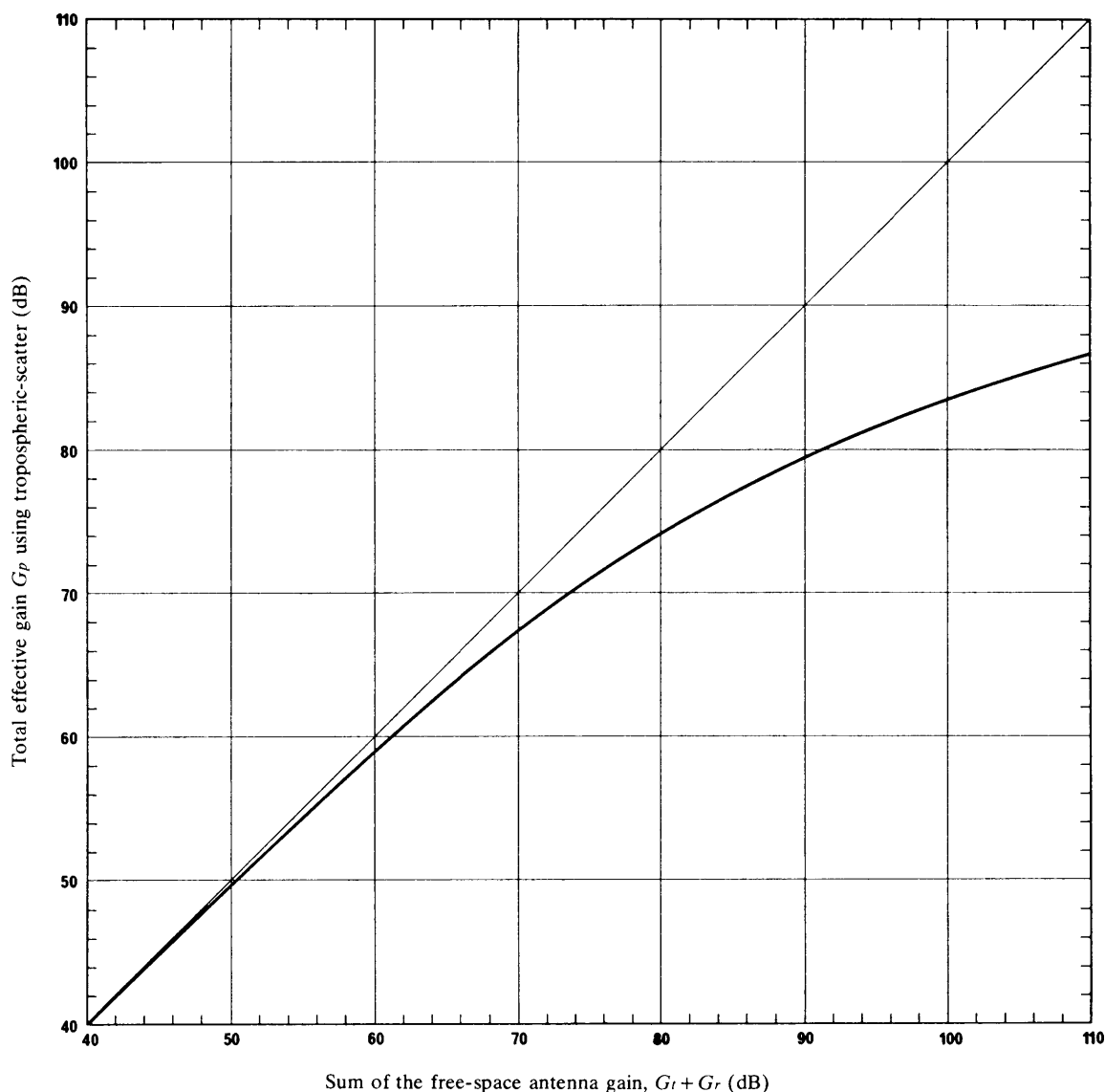


FIGURE 1 – Relations between antenna gains (tropospheric scatter)

With regard to intermodulation noise due to propagation, theoretical considerations and test results have led to the following conclusions: Intermodulation noise increases with the length of the circuit; increase of the antenna gain generally reduces intermodulation noise, however, one experiment [Battesti and Boithias, 1971] indicated that when the antenna gain is less than about 30 dB, there was no sign of dependence of intermodulation noise on antenna gain. For fixed antenna gains the carrier frequency appears to have no influence on intermodulation noise.

Intermodulation noise increases with frequency deviation. The optimum frequency deviation, corresponding to the lowest total noise power in telephone channels, thus depends on both equipment and propagation characteristics. For this reason it is desirable to determine the optimum frequency deviation separately for each hop of a trans-horizon radio-relay link.

3.2 Noise in real circuits of less than 2500 km

For circuits of the class defined in § 3 of Recommendation 397 the required noise performance is specified in Recommendation 593. Further studies are required to specify the required noise performance of circuits of the class defined in § 2 of Recommendation 397.

3.3 Noise in real circuits of more than 2500 km

As the circuit length is increased beyond 2500 km, the psophometric weighted noise power exceeded for 20% of any month increases in a virtually linear manner, and can be approximated by the formula:

$$P_{(20\%)} = X \cdot L \quad \text{pW}$$

in which:

L : circuit length in km;

X : a multiplying factor which depends on the system design characteristics.

For systems designed to meet the requirements of Recommendation 593, X will be equal to 10 or less.

As the circuit length is increased beyond 2500 km, the 20% noise target figure of $X \cdot L$ pW will approach the 0.5% noise target figure. For circuits of the class specified in § 3 of Recommendation 397, the 0.5% target figure is 63 000 pW0p and for circuits which exceed 2500 km in length this should be changed to:

$$PN_{(p\%)} = 63\,000 + 10 (L - 2500) \quad \text{pW} \quad \text{for } L > 2500 \text{ km}$$

where:

L : circuit length in km;

$PN_{(p\%)}$: psophometrically weighted noise exceeded for $p\%$ of any month;

$$p\% = 0.5 \frac{L}{2500} \%$$

4. Choice of frequency range, antenna diameter and transmitting power

4.1 As a function of received level (thermal noise)

Existing trans-horizon radio-relay systems normally use transmitter powers which are of the same order of magnitude for different frequency ranges. The sensitivity of modern receivers (often using parametric or tunnel-diode amplifiers) is, to a large extent, independent of the frequency band used.

Long-term variations in received power levels, as a function of carrier frequency, depend essentially on three phenomena:

- the loss between isotropic antennas; it is usually assumed that this loss is proportional to the cube of the frequency;
- the free-space gain of the antennas used; for an antenna of a given diameter this gain is proportional to the square of the frequency;
- the drop in antenna gain; for an antenna of a given diameter this drop depends on the frequency and can be calculated from Fig. 1.

The effect of variations of all these three parameters, as a function of the frequency for antenna diameters between 3 and 30 m, is shown in Fig. 2.

Figure 2 represents the relative loss between the terminals of two antennas of the same diameter, located at the two ends of a trans-horizon radio-relay system; the reference loss (0 dB) is taken as that which exists under the same conditions between two antennas 10 m in diameter at 1000 MHz. As regards the length of the connection, the validity of Fig. 2 is the same as that giving the loss in antenna gain, i.e. the link under consideration is assumed to be between about 150 and 500 km in length.

It can be seen that, for an antenna of given diameter, the relative loss passes through a minimum at a particular frequency and increases on either side; at the lower frequencies, because the relative dimensions of the antenna measured in wavelengths decrease (with a consequent decrease in free-space gain) and at the upper frequencies, because the drop in antenna gain increases as the free-space gain increases. The optimum operating frequency lies between 300 MHz for an antenna with a diameter of 30 m and 3 GHz for an antenna 3 m in diameter; however, the minimum is very flat and a frequency departure on either side in the ratio of 2/1 is possible without substantially increasing the relative loss.

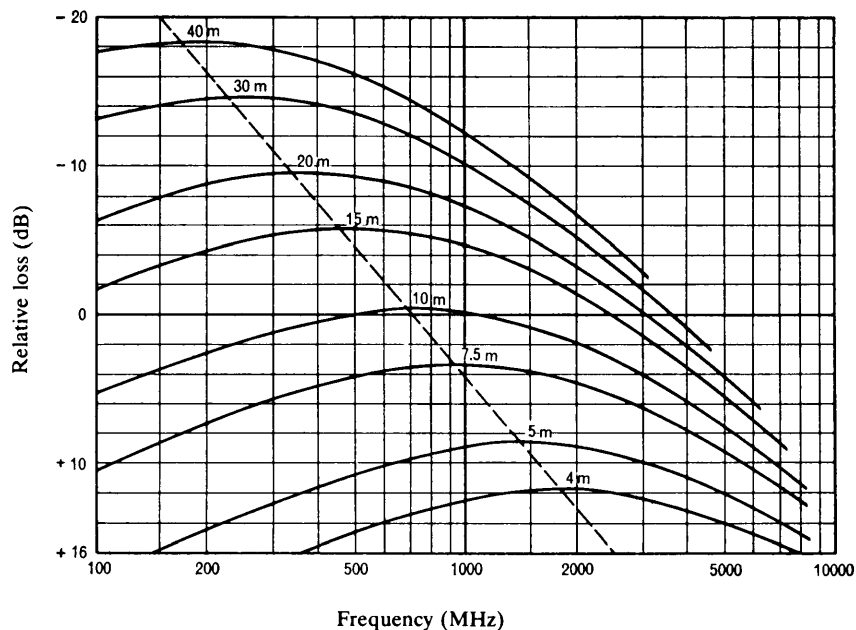


FIGURE 2 — Relative loss between antennas of a given diameter

4.2 As a function of total noise (thermal and intermodulation) for analogue systems

The reduction of intermodulation noise due to propagation may demand higher antenna gains than would be strictly necessary for the reduction of thermal noise. For the given antenna gain, the dimensions of the antennas are obviously smaller at high frequencies. The choice of frequency does not depend essentially on the intermodulation noise if the antenna gain is fixed, but that is not true if the antenna diameter is fixed.

Regarding intermodulation noise, theoretical considerations have shown that intermodulation noise increases in proportion to the fourth power of multipath delay in the radio path [Parry, 1963; Sunde, 1964; Okumura, 1964].

The multipath delay on the path is proportional to the beamwidths of the antennas employed, and the antenna beamwidth is inversely proportional to the radio frequency. Thereby, it can be expressed that the intermodulation noise decreases in inverse-proportion to the fourth power of the radio frequency when the antenna diameter employed is constant. An estimate of the intermodulation noise for each radio frequency band and channel capacity is shown in Fig. 3 for a path length of 200 km and an antenna diameter of 10 m.

As shown in Fig. 3, no conspicuous differences appear in total noise in the bands of 900 MHz, 2 GHz and 2.6 GHz for the transmission capacity of 24 channels. These bands have more advantages over bands higher than 3 GHz. It appears that when the transmission capacity increases to as large as 300 channels, frequency bands of about 2 GHz are more suitable than other bands.

An example of how path intermodulation noise or thermal noise can determine the minimum antenna size is shown in Fig. 4. There are two groups of curves as follows:

- the first group of curves (which decrease from left to right) show antenna size versus frequency for a signal-to-path intermodulation noise ratio of 60 dB. Each curve corresponds to given values of path length and channel capacity;
- the second group of curves (which dip to a minimum value) show antenna size versus frequency for a signal-to-thermal noise ratio of 50 dB (assuming a received signal level of 20 dB above threshold and a signal-to-thermal noise ratio of 30 dB at threshold). Each curve corresponds to given values of transmitter power and distance.

The two groups of curves must be used together to determine the limiting parameter on antenna size (or frequency). For example, with a transmitter power of 1 kW, a frequency of 1 GHz and a distance of 200 km, the minimum antenna diameter would be about 8 m for 24 telephone channels (due to thermal noise), 13 m for 120 telephone channels and 24 m for 300 telephone channels (the last two being due to path intermodulation noise).

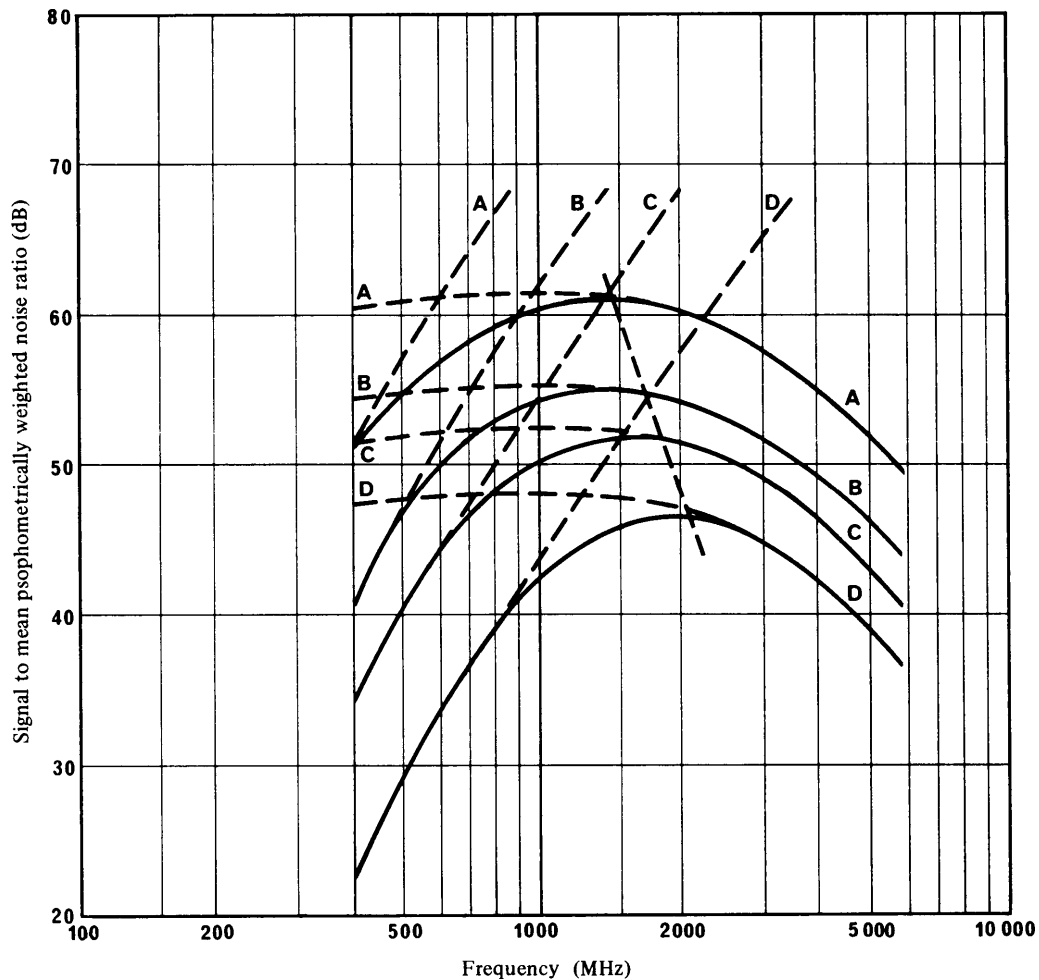


FIGURE 3 — *Signal to mean psophometrically weighted noise (thermal and intermodulation noise) ratio*

Curves A: 24 channels
 B: 60 channels
 C: 120 channels
 D: 300 channels

Link length: 200 km
 Antenna diameter: 10 m
 Output power: 1 kW

The power levels shown in Fig. 4 cover the range of transmitter powers actually available. For practical reasons, the maximum transmitter power considered is 10 kW, but lower powers are desirable to achieve system economy and practical maintainability.

Using a large aperture antenna is preferable to using large transmit power, but the cost of the antenna and support tower increases significantly, and therefore, for large capacities, lower frequency bands are less economical.

4.3 As a function of interference with other radio systems and services

Communications systems employing tropospheric scatter wave must pay particular consideration to possible interference to other radio systems and services.

The reduction of antenna radiated power, in all directions except in the required direction, is necessary to minimize interference to other systems. This requires excellent radiation patterns for antennas used in trans-horizon radio-relay systems. The reference radiation pattern for an actual system is shown in Report 614.

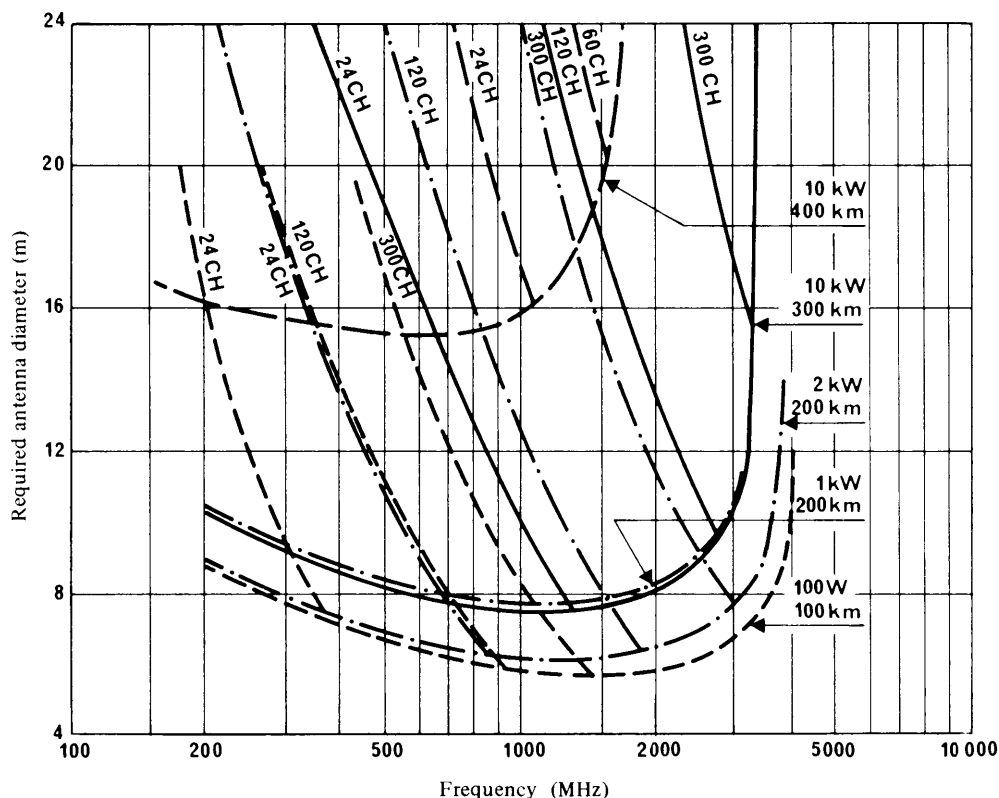
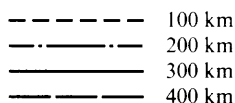


FIGURE 4 — Required minimum antenna diameter for frequency bands

(For the explanation of this Figure see §4.2)



As a higher transmission power is required compared with a line-of-sight radio-relay system, the radiation hazard must also be taken into consideration. For this reason, a narrow main beam width will be required to reduce radiation power except in the required direction.

4.4 General conclusions

It appears that the following broad conclusions apply:

Considering all the relevant factors, including the mechanical aspects, the maximum useful physical diameter of antennas is approximately $40/f$ m (where f is in GHz) for frequencies above 1 GHz. This corresponds to a plane wave gain of about 50 dB and an antenna-to-medium coupling loss of about 15 dB for two identical antennas. The higher antenna-to-medium coupling loss and higher thermal noise may be partially offset by an increase in deviation; for example, thermal and intermodulation noise contributions could be approximately equal.

On links of approximately 400 to 700 km relatively low frequencies with large antennas are necessary to provide adequate performance including low intermodulation noise. The telephone capacities may be small. Operation above 1 GHz may result in poor performance except for very favourably sited terminals and for very favourable propagation conditions.

On links of approximately 200 to 400 km the telephone channel capacity may be somewhat greater. Multipath intermodulation noise may be a major factor; frequencies about 2 GHz may be preferable to lower frequencies in order to reduce intermodulation noise.

For shorter links (approximately 100 to 200 km) operation at frequencies up to about 5 GHz is possible, resulting in low multipath intermodulation noise even with relatively small antennas. Frequencies between about 2 GHz and 3 GHz may be optimum for higher telephone channel capacities on links of these lengths.

5. Choice of optimum frequency deviation

5.1 Noise components

The designer of trans-horizon radio-relay systems has to evaluate several noise components when choosing the optimum frequency deviation. The main noise components are:

N_{th} : thermal noise which depends on received level and receiver noise figure,

N_{ip} : intermodulation noise due to multipath propagation,

N_{ie} : intermodulation noise due to equipment and feeder echo.

Of these, N_{th} and N_{ip} depend on the propagation and are quoted statistically. All depend on the deviation. They arise due to different effects and can therefore be added on a power basis to give the total noise in a telephone channel.

5.1.1 Signal-to-thermal noise power ratio, S/N_{th} , at the input to the radio receiver

This ratio in the top telephone channel of a frequency-modulation system with frequency-division multiplex and pre-emphasis may be calculated by the method given in Report 708 and CCITT Recommendation G.223.

The signal-to-thermal noise power ratio, S/N_{th} , is dependent on the fading characteristics. As a point of reference, S/N_{th} is usually computed for 50% of the worst month: computation for 20% or other time availabilities of the worst month (Recommendation 397) can also be made if necessary. The signal-to-thermal noise power ratio is directly proportional to the square of the deviation ratio.

5.1.2 Signal-to-intermodulation noise power ratio, S/N_{ie} , due to the radio equipment and feeder echo

Noise from intermodulation products in radio equipment is commonly measured by a white noise loading test (Recommendation 399). The result obtained is called the equipment noise power ratio. The variation of noise power ratio may be taken as the "square" of the deviation ratio. This factor may be different from "square" and measured characteristics are to be preferred, if available.

Discontinuities at the transmission line and antenna interface, the transmission line and receiver interface, and the transmission line and transmitter interface produce echoes or reflections which interfere with the fundamental signal. The net result of these echoes is the production of intermodulation noise in every voice channel, although its magnitude is usually small in comparison with other sources of noise.

The method of Medhurst for the calculation of intermodulation noise in a telephone channel due to feeder echo, phased for maximum delay, is generally used [Medhurst, 1959].

5.1.3 Signal-to-intermodulation noise power ratio, S/N_{ip} , due to multipath effects

This ratio, according to general practice in the United Kingdom and the United States of America, is calculated from the method of [Beach and Trecker, 1963]. Other techniques such as those presented in [Sunde, 1964] may also be employed.

Signal-to-intermodulation noise power ratio, S/N_{ip} is proportional to the relative path delay, the reflection plus radiation pattern loss and the square of the deviation ratio [Beach and Trecker, 1963]. It is usually calculated for 50% of the worst month.

For other time percentages it has been postulated [Beach and Trecker, 1963] that an adjustment of 0.7 dB in S/N_{ip} for each 1 dB long-term change of path loss should be made. On the other hand, for every 1 dB short-term change of path loss, measurement in Japan [Tsuzuki *et al.*, 1979] shows variation of 2 dB in S/N_{ip} with non-diversity reception, 1 dB with dual diversity and 0.7 dB with quadruple diversity. When the signal-to-intermodulation noise power ratio is calculated for the small percentage of time described in Recommendation 397, § 4, attention must be paid to the influence of short-term fading.

5.2 Optimum deviation

Since the signal-to-thermal noise power ratio at the input to the radio receiver is proportional to the square of the deviation ratio while all the signal-to-intermodulation noise power ratios due to equipment, feeder echo and the path are inversely proportional to the square of the deviation ratio, an optimum deviation ratio exists.

The system designer is concerned with deciding the equipment parameters necessary for the link performance to be in accordance with Recommendation 397. One of the on-site adjustments made during installation is the determination and setting up of an optimum deviation. This is done by measuring channel signal-to-noise ratio, or its equivalent (e.g., signal-to-noise power ratio, Recommendation 399), over a range of deviations and then by plotting curves, to find the optimum.

If desired, for international connection purposes, the deviation as calculated, may be used to select the closest approximate value from a geometric series starting with 35 kHz and with common ratio $\sqrt{2}$.

6. The effects of multipath dispersion on the performance of digital trans-horizon systems

6.1 General effects of time dispersion of multipath

The multipath dispersion over a digital trans-horizon link is considerably worse than the corresponding dispersion over a line-of-sight link for a given frequency band. Consequently the onset of multipath dispersion rather than signal-to-noise ratio as a limiting factor in communications performance occurs at a lower transmission rate for trans-horizon links than for line-of-sight links.

A significant improvement in the performance can be obtained by intrinsic diversity improvement using adaptive equalization.

Predictions of:

- the increase in error probability due to multipath dispersion for a given set of equipment and path parameters; and
- the improvements in diversity performance and/or the reduction of inter-symbol interference that can be achieved by adaptive equalization,

are expressed with respect to σ , the r.m.s. standard deviation of the delay time which is obtained by expressing the power impulse response of the trans-horizon path as a probability density function.

6.2 Performance predictions

The average bit error probability P_e in a digital trans-horizon link subject to multipath dispersion is dependent on the following parameters:

$2\sigma/T$: the normalized multipath dispersion

where:

T : symbol period;

W : (energy per bit/noise spectral density) per diversity channel.

The variation of P_e with respect to $2\sigma/T$ and W as different power impulse responses are applied to a computer simulated troposcatter path model is shown in Fig. 5. The simulation is for ideal four-level CPSK demodulation in a dispersive Rayleigh channel with quadruple diversity. A Gaussian power impulse response and 50% raised cosine filtering are also assumed.

6.3 Adaptive equalization

The use of adaptive equalization to reduce inter-symbol interference and thereby increase the traffic capacity of digital trans-horizon systems has been described in the literature [Ural *et al.*, 1980]. Adaptive equalization permits the diversity inherent within multipath dispersion to be accommodated in receiver design thereby resulting in a predictable improvement in error performance for a given value of σ .

Successful transmission of information rates of up to 12.6 Mbit/s at 4.6 GHz using adaptive modems over trans-horizon links has been reported [Ehrman and Monsen, 1977].

7. Determination of time required for measurement of mean minute noise power P

It is known from experimental studies (for example [Gusyatinsky *et al.*, 1968]) that slow fades are governed by a log-normal law of probability distribution. Their standard deviation for one section of a link ranges from 3 to 7 dB and from 2 to 5 dB for an entire 1500 to 2500 km link. Other studies [Troitsky and Petrushko, 1974] show that the radius of the autocorrelation function τ_0 of these fades is in the region of 4 hours.

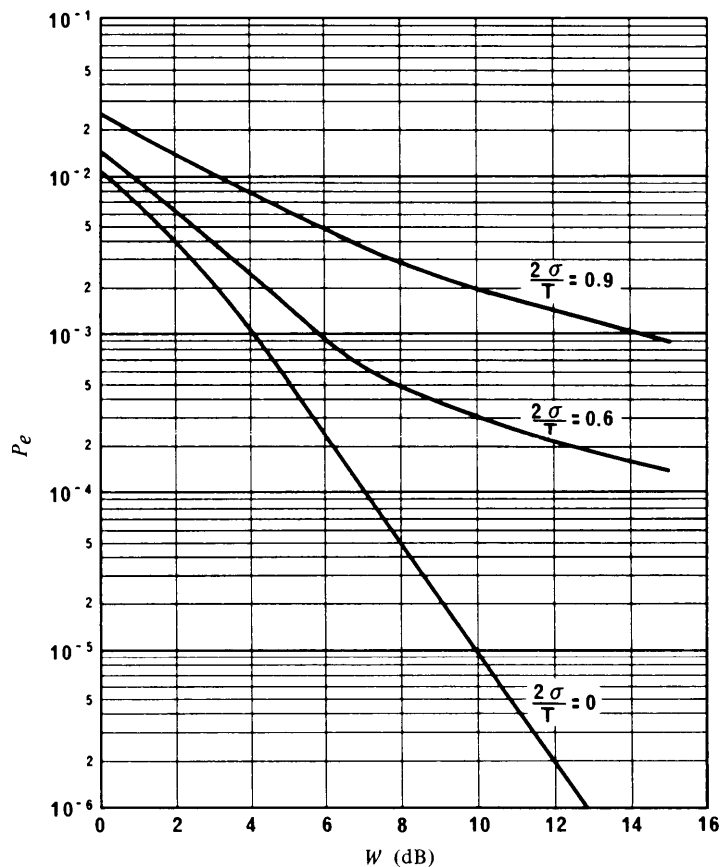


FIGURE 5 — The effect of multipath dispersion on bit error ratio with quadruple diversity

It is clear that the measurement period must be substantially greater than τ_0 .

Having assured that the measurements take place during the worst period of the year, measurement data of satisfactory statistical reliability (confidence level 0.8 to 0.9) may be obtained by limiting the measurement period to 4-10 days with levels of error not exceeding 1.1 dB and 2 dB for the noise power level given respectively in § 3.1 and 3.2 of Recommendation 397.

REFERENCES

- BATTESTI, J. and BOITHIAS, L. [January-February, 1971] Nouveaux éléments sur la propagation par les hétérogénéités de l'atmosphère (New information concerning propagation by irregularities in the atmosphere). *Ann. des Télécomm.*, Vol. 26, 1-2, 15-30.
- BEACH, C. D. and TRECKER, J. M. [January, 1963] A method for predicting interchannel modulation due to multipath propagation in FM and PM tropospheric radio systems. *BSTJ*, Vol. XLII, 1, 1-36.
- BOITHIAS, L. and BATTESTI, J. [September-October, 1964] Etude expérimentale de la baisse de gain d'antenne dans les liaisons transhorizon (Experimental study of the loss in antenna gain on trans-horizon links). *Ann. des Télécomm.*, Vol. 19, 9-10, 221-229.
- BOITHIAS, L. and BATTESTI, J. [July-August, 1965 and November-December, 1965] Les faisceaux hertziens transhorizon de haute qualité (High-quality trans-horizon radio-relay systems). *Ann. des Télécomm.*, Vol. 20, 7-8, 138-150; Vol. 20, 11-12, 237-254.
- EHRMAN, L. and MONSEN, P. [December, 1977] Troposcatter test results for a high-speed decision feedback equalizer modem. *IEEE Trans. Comm.*, Vol. COM-25, 12, 1499-1504.
- GOUGH, M. W. [1968] The implications of certain CCIR objectives to troposcatter system design. *Marconi Rev.*, Vol. XXI, 171, Fourth Quarter, 240-253.
- GUSYATINSKY, I. A., NEMIROVSKY, A. S., SOKOLOV, A. V. and TROITSKY, V. N. [1968] *Dalnia troposfernaya radiosvyaz* (Long-distance trans-horizon radiocommunications), Sviaz, Moscow, U.S.S.R.
- HARTMAN, W. J. and WILKERSON, R. E. [1959] Path antenna gain in an exponential atmosphere. *NBS J. Res.*, Vol. 63D, 3, 273-286.
- MEDHURST, R. G. [July, 1959] Echo distortion in frequency modulation. *Electron. Radio Eng.*, Vol. 36, 7, 253-259.

- OKUMURA, Y. [October, 1964] Estimation method of propagation quasi-crosstalk noise in tropospheric-scatter circuit. Electrical Communication Laboratories Res. Rep.
- PARRY, C. A. [1963] On the prediction of the inherent bandwidth capability of the tropospheric-scatter link. IEEE Conf. Record.
- RICE, P. L., LONGLEY, A. G., NORTON, K. A. and BARSIS, A. P. [1967] Transmission loss predictions for tropospheric communication circuits. National Bureau of Standards Tech. Note No. 101 (revised).
- SUNDE, E. D. [January, 1964] Intermodulation distortion in analog FM troposcatter systems. *BSTJ*, Vol. XLIII, 1, Part 2, 399-435.
- TROITSKY, V. N. and PETRUSHKO, Y. I. [1974] Eksperimentalnoe issledovanie medlennykh fluktuatsii urovnya signala santimetrovykh voln na trasse protyazhennostyu 430 km (Experimental study of slow fluctuations in SHF signal level on a 430 km path). *Proc. NIIR*, 4.
- TSUZUKI, T., KAJIHARA, H., SANO, Y. and KUROBE, A. [August, 1979] Characteristics of intermodulation noise due to multipath propagation on a troposcatter link. *Trans. Inst. Electron. Comm. Engrs. Japan*, Vol. 62-B, 8.
- URAL, A. T., VOGT, I. and PUSONE, E. [March, 1980] Technical aspects of digital transmission in the ACE HIGH system. Proc. Conference on Digital Tropospheric-Scatter Systems, Brussels, Belgium.

BIBLIOGRAPHY

- BOITHIAS, L. and BATTESTI, J. [May-June, 1963] Puissance moyenne de bruit dans les faisceaux hertziens trans-horizon à modulation de fréquence (Mean noise power in transhorizon FM radio-relay systems). *Ann. des Télécomm.*, Vol. 18, 5-6, 89-93.
- CAIRNS, J. B. S. [September, 1979] A review of digital troposcatter links. Proc. TELECOM 79 Conference, Geneva, Switzerland.
- ELLIOTT, J. C. and COLE, J. E. [September, 1965] Capabilities of troposcatter links. IEEE Military Electronics Conference Record, 221, Washington, DC, USA.
- MASSARO, M. A. and SPRINGEN, K. G. [June, 1968] Computer aided design optimization of FM/FDM communication systems. Proc. IEEE International Conference on Communications (ICC '68), 494, Philadelphia, Pa., USA.
- MONSEN, P. [1974] Troposcatter multipath availability considerations. IEEE National Telecommunications Conference (NTC '74), San Diego, Calif., USA.
- NEMIROVSKY, A. S. [1964] Eksperimentalnoe opredelenie korrelyatsii medlennykh izmenenii teplovykh shumov i perekhodnykh pomekh na troposfernykh liniyakh (Experimental determination of the correlation between slow variations in thermal noise and crosstalk interference in trans-horizon links). "*Elektrosvyaz*", 5, 75-76.
- PARRY, C. A. [April, 1966] The maximum capacity of tandem link multichannel troposcatter systems. *IEEE Trans. Comm. Tech.*, Vol. COM-14, 2, 130-139.
- SCHMITT, F. [October, 1977] Statistics of troposcatter channels with respect to the application of adaptive equalizing techniques. Proc. AGARD Symposium on Scatter Communications.
- SHERWOOD, A., WENGLIN, S. and WICK, J. [October, 1977] An experimental programme leading to development of a technical digital troposcatter system. Conference Report, 5.4-1 to 5.4-15, Aspects of electromagnetic scattering in radio communications, Cambridge, Mass., USA.
- SMITH, H. L. [June, 1968] Digital computers speed tropo system design. *Microwaves*, Vol. 7, 6, 88-97.
- CCIR Documents*
[1978-82]: 9/16 (Japan); 9/243 (Japan); 9/297 (U.S.S.R.); 9/296 (U.S.S.R.).

RECOMMENDATION 557

AVAILABILITY OBJECTIVE FOR A HYPOTHETICAL REFERENCE CIRCUIT
AND A HYPOTHETICAL REFERENCE DIGITAL PATH

(Question 5/9)

(1978)

The CCIR,

CONSIDERING

- (a) that the hypothetical reference circuit (HRC) and the hypothetical reference digital path are intended as a guide to designers and planners;
- (b) that the availability of a radio-relay system is dependent upon many factors and particularly upon: the maintenance organization (which determines the time to restore), the reliability of equipments and the system design and propagation conditions. The relative importance of these various factors may vary significantly, sometimes without possibility of control, from one area to another;
- (c) that it is desirable to apply common availability objectives to both cable and radio-relay systems,

UNANIMOUSLY RECOMMENDS

1. that the availability objective appropriate to a 2500 km hypothetical reference circuit for frequency division multiplex radio-relay systems (Recommendation 392) and for a 2500 km hypothetical reference digital path for digital radio-relay systems (Recommendation 556) should be 99.7% of the time, the percentage being considered over a period of time sufficiently long to be statistically valid, this period is probably greater than one year * (see Notes 1, 2 and 3);
2. that the concept of unavailability of an analogue HRC should be as follows: in at least one direction of transmission, one or both of the following conditions occur, for at least 10 consecutive seconds (Note 8):
 - 2.1 the level of the baseband frequencies falls by 10 dB or more from reference level;
 - 2.2 for any telephone channel the unweighted noise power with an integrating time of 5 ms is greater than 10^6 pW0 (Note 9);
3. that the concept of unavailability of a hypothetical reference digital path should be as follows: in at least one direction of transmission, one or both of the two following conditions occur for at least 10 consecutive seconds (Note 8):
 - 3.1 the digital signal is interrupted (i.e. alignment or timing are lost);
 - 3.2 the error ratio is greater than 10^{-3} (Note 10);
4. that in the estimate of unavailability, one must include all causes which are statistically predictable, unintentional and resulting from the radio equipment **, power supplies, propagation ***, interference and from auxiliary equipment and human activity. The estimate of unavailability includes consideration of the mean time to restore (see Notes 5 and 6);
5. that the following Notes should be treated as part of the Recommendation:

Note 1. — The value of 99.7% is a provisional one and it is recognized that, in practice, the objectives selected may fall into the range 99.5 to 99.9%. The choice of a specific value in this range depends on the optimum allocation of outage time among the various causes which may not be the same when local conditions are taken into account (i.e. propagation, geographical size, population distribution, organization of maintenance).

Furthermore, the availability of radio-relay systems is only one of the many aspects that ensure the acceptable grade of service of the telephony traffic; the choice of an optimum value for this particular aspect can only be done by considering all transmission systems either existing or planned in the network under study.

For these many reasons, administrations may select different values of availability objective for the use of their planning organization, the said values lying in the range shown above.

Note 2. — Availability of multiplex equipments is excluded from the foregoing. The CCITT is expected to establish availability objectives for these equipments.

Note 3. — This Recommendation relates to the hypothetical reference circuit and to the hypothetical reference digital path. Its purpose is to set an availability figure as planning objective for new radio-relay systems.

It is not intended that it will be quoted in specifications of real systems, for acceptance tests, or for operational agreements. Recommendations relating to real circuits availability have to be established.

Note 4. — The subdivision of the availability design objective in the radio portions of circuits to be established over real links, is under study.

Note 5. — Planners should indicate their assumptions concerning the mean time between failures, the mean time to restore, the precautions taken against interruptions and fading (in particular the use of protection channels and the number of hops per switching section) and the distribution of fading with a duration longer than 10 seconds.

Note 6. — The time to restore, which is the time elapsing between an interruption to traffic and its restoration, includes recognition time, travelling time as well as repair time. Differences in the time to restore will occur between Administrations due to various factors such as site accessibility, weather, maintenance policy and other economic considerations.

* The period of time is under study.

** This includes all equipment between points R and R' defined in Recommendation 380 for analogue systems, and all equipment within a digital radio section for digital systems.

*** The influence of the propagation-dependent part on the availability design objective is considered in Report 784.

Note 7. — This Recommendation does not take into account the improvements which could be obtained by means of re-routing traffic over other systems, e.g. cables and other radio-relay systems.

Note 8. — For interruptions with durations less than 10 seconds further study is necessary taking also into account intermittent interruptions.

Note 9. — Periods of less than 10 seconds during which the noise power in a telephone channel in frequency division multiplex systems is greater than 10^6 pW0 are taken into account in Recommendation 393.

Note 10. — Periods of less than 10 seconds during which the error ratio is greater than 10^{-3} are taken into account in Recommendation 594.

REPORT 445-2

AVAILABILITY AND RELIABILITY OF RADIO-RELAY SYSTEMS

(Question 5/9)

(1970–1974–1978)

1. Introduction

This Report is a partial answer to Question 5/9 on how the concept of reliability and availability could be applied to radio-relay systems. It suggests some parameters which could be specified, to meet satisfactory reliability and availability requirements. It seems desirable that uniform methods should be used when presenting data on reliability or on availability.

The Report gives some theoretical calculations of availability of radio-relay systems and presents some practical experience in several countries.

The figures and parameters quoted are by way of example only. More studies are required before a definitive answer can be given to this question.

The terms reliability and availability in this Report follow the definition agreed upon by the CCIR and IEC.

2. Application of the concept of reliability and availability to radio-relay systems

Availability should be defined for the hypothetical reference circuit or for the hypothetical reference digital path, since it should be defined without regard to any particular equipment arrangement. The system designer has the freedom to meet the requirements in any way he wishes.

2.1 Interruptions

The availability of a radio-relay system can be described in terms of interruptions. An interruption is a period in which there is complete or partial loss of signal, excessive noise, or a discontinuity or severe distortion in the signal. Two aspects should be considered:

- a definition of that which constitutes an interruption;
- a description of the time aspects, such as the length of an interruption, the period between successive interruptions, etc.

Two types of interruption which may occur in a radio-relay system are:

- long interruptions, for example lasting from 10 seconds to perhaps an hour but only occurring once per week or perhaps once per year;
- short interruptions, which are fairly frequent. Examples of such interruptions last from a number of seconds down to very small fractions of a second, but occur many times in an hour on some occasions.

These two types of interruption have separate significances in terms of the availability of the system. Hence, it might be useful to define each separately and put separate objectives upon each.

The parameters which require defining for each type are:

for long interruptions:

- mean time between interruptions. This is to ensure that long interruptions do not occur too frequently;
- total outage over a long period (e.g. one year). This would ensure that the availability of the system is adequate;
- mean duration of an interruption. This would ensure that, if an interruption occurs, it would not be too long;

for short interruptions:

- the rate of occurrence (e.g. measured on an hourly basis);
- the total outage time over a period (e.g. the worst month);
- the duration of these short interruptions. This should be defined statistically. It might be desirable to specify several points of an objective distribution.

2.2 *Causes of interruptions*

The major causes of interruption in radio-relay systems are:

2.2.1 *Equipment*

- failure or degradation of radio equipment including modulators and demodulators;
- failure of auxiliary equipment such as switch-over equipment;
- failure of primary power supply equipment;
- failure of antenna or feeder.

2.2.2 *Propagation*

- deep fading causing noise to exceed a certain limit. This may be due to ducting and usually lasts a fairly long time;
- excessive precipitation-attenuation which is caused mainly by heavy rainfall and in some cases by heavy snowfall. Generally, this effect lasts a fairly long time;
- fading causing short interruptions.

2.2.3 *Interference*

- noise in excess of a certain limit caused by interfering sources which may exist within or outside the system.

2.2.4 *Support facilities*

- collapse of towers or buildings in disastrous circumstances.

2.2.5 *Human activity*

- activity of operating personnel for maintenance or other purposes, including errors by such personnel.

3. **Calculation of the availability of hypothetical system**

3.1 *Availability in relation to equipment failures and protection channels*

3.1.1 *General*

A study [Walrond, 1971] of the availability to be expected over a fully-engineered system, using assumed values of individual component reliability and a 6 GHz system of current manufacture, fully transistorized except for the use of a travelling-wave tube in the output stages, was made.

Assessments were made under the following headings:

(a) *Individual equipment reliability*

This was taken to be a function of the component mean time between failures within an equipment.

(b) *Fundamental system availability*

For a system without built-in redundancy, this was taken to be a function of the mean time between failures of the equipment and of the mean time to repair.

(c) *Traffic availability*

This was taken to be a function of the mean time between failures of a system including duplication and automatic switching used for protection purposes and of the mean time to repair.

3.1.2 *Component reliability*

The assumed values of the mean time between failures were obtained from a mean of available figures from a number of sources [Dummer and Griffith, 1966; Karas, 1967]. A degradation outside the manufacturer's tolerance was taken as a failure.

3.1.3 *Results*

Figures 1 and 2 show examples of the calculated total outage per year for unidirectional channels and for two ratios of working to protection channels. Figure 2 assumed no priority channels. Failures due to primary power were ignored. These figures show the result for 30 hops.

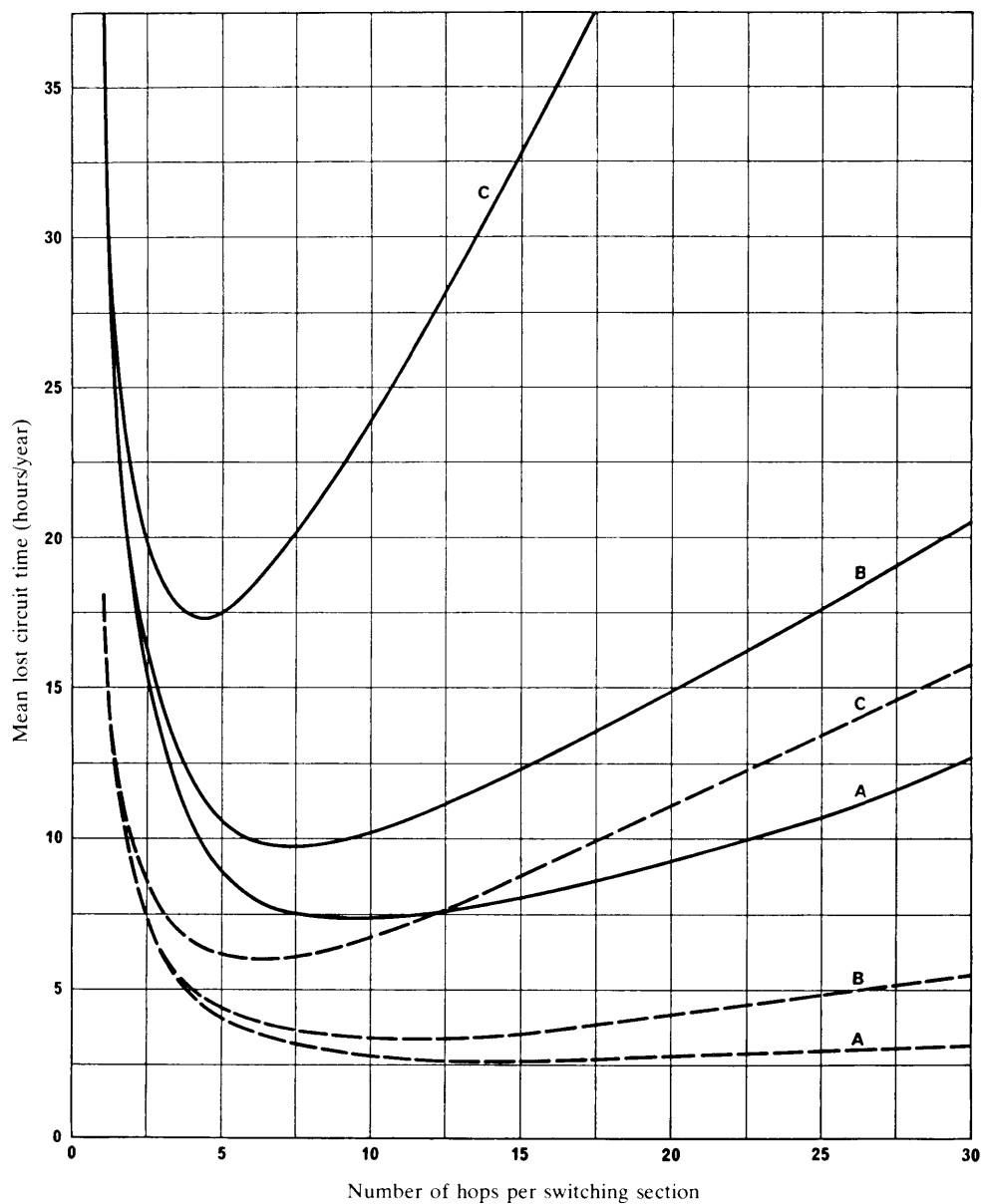


FIGURE 1 – System outage characteristic for a 6 GHz system using 1 for 7 switching at intermediate frequency, graded priorities (main channel—travelling-wave tube, auxiliary channel—all semiconductor devices)

— : repair time, 5 h
 - - - : repair time, 2 1/2 h

Curve A: first priority
 B: second priority
 C: seventh priority

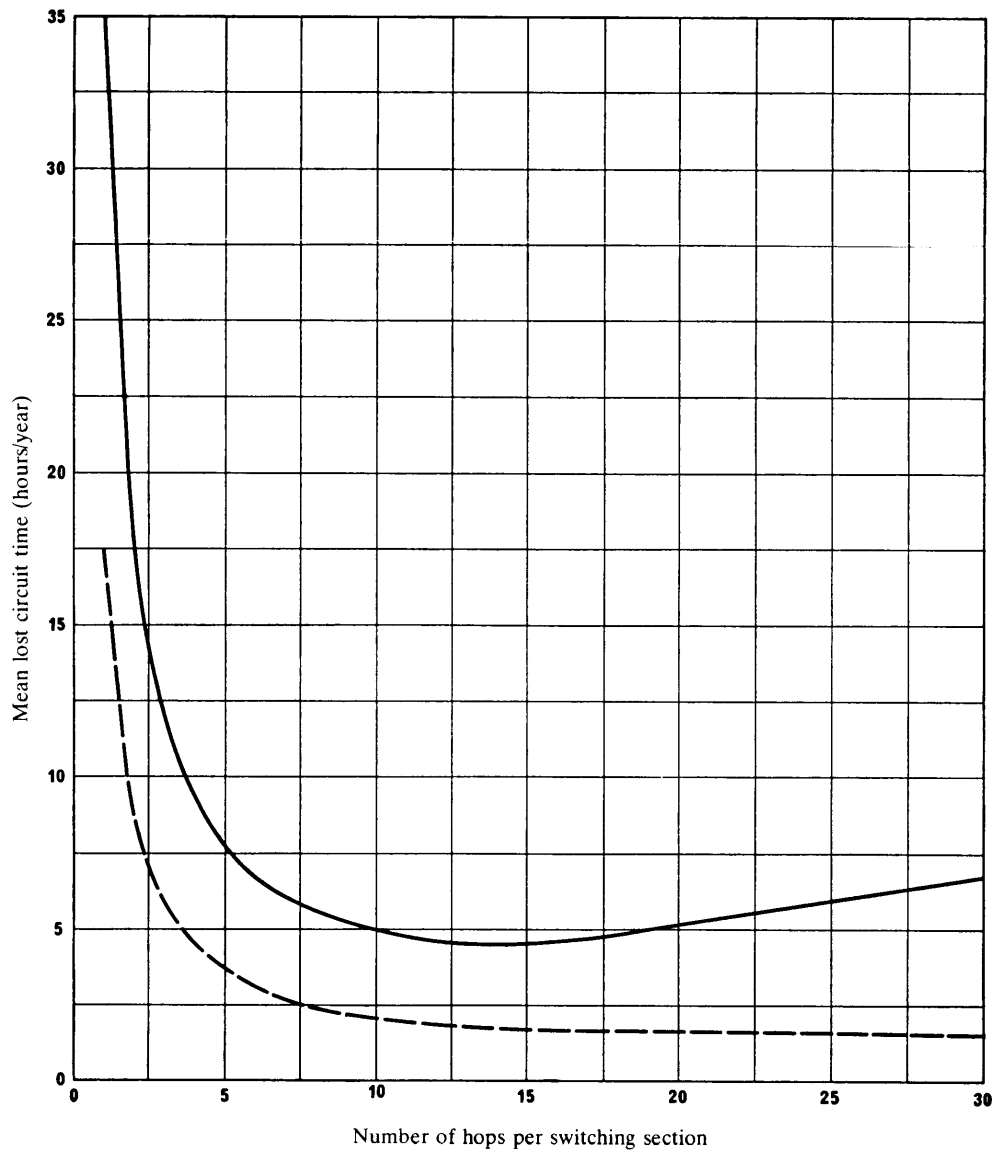


FIGURE 2 – System outage characteristic for a 6 GHz system using 2 for 6 switching at intermediate frequency, with no priorities (main channel—travelling-wave tube and semiconductor devices, auxiliary channel—all semiconductor devices)

— : repair time, 5 h
- - - : repair time, 2 1/2 h

3.2 Statistical prediction and estimation for unavailability

3.2.1 General

Unavailability is used as a planning objective and in this case, its numerical value is expected to be the average value obtained by observation on a large number of similar circuits and/or for a long period of time.

The unavailability per year of a circuit may show large variation from year to year. Thus, the statistical properties of unavailability need to be studied.

3.2.2 Examples of calculation

Examples of the expected unavailability distributions calculated for a circuit of $2500 \times S/9$ km with S switching sections and a design unavailability of $0.2 \times S/9\%$ are shown in Fig. 3 together with the assumptions made.

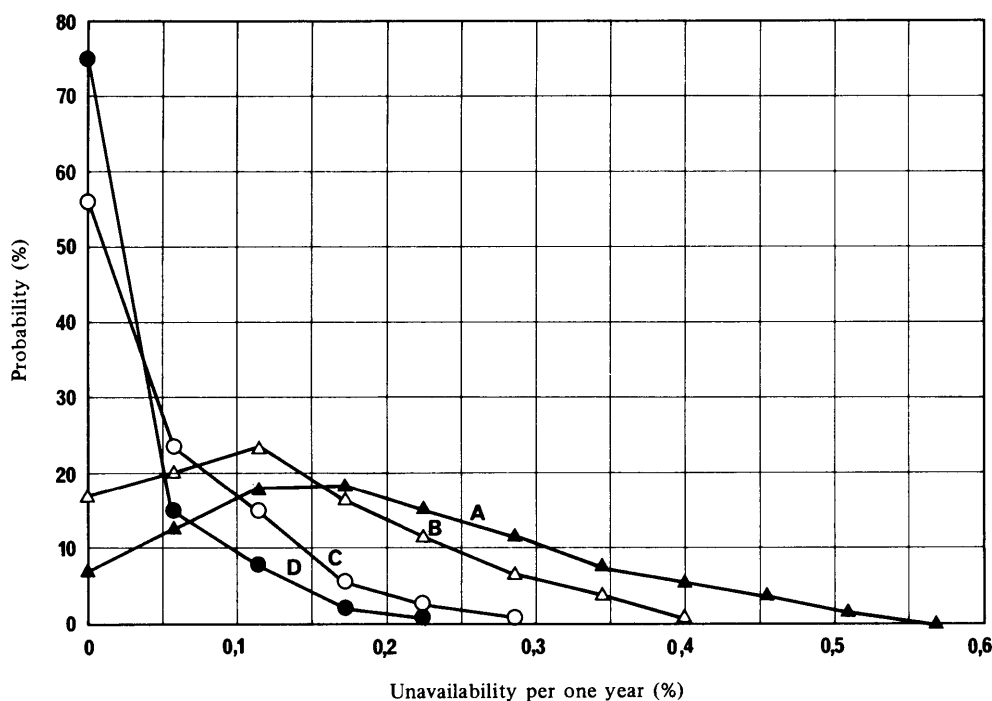


FIGURE 3 – Example of expected distribution of unavailability/year

Curve A: $S = 9$
 Curve B: $S = 6$
 Curve C: $S = 2$
 Curve D: $S = 1$

Assumption for calculation:

- S : The number of switching sections. $S = 9$ for 2500 km HRC
- Protection system: 1 for 7 switching with no priority switching
- Causes of interruption: Radio equipment and switch-over equipment
- The design objective: $0.2\%/2500$ km. (Series parts: 0.1% , Parallel parts: 0.1%)
- Repair time is fixed at 10 hours

Figure 4 shows the 90% confidence limits on the unavailability estimate determined from observed failures within one year. From Fig. 4 it can be seen that estimates based on failure of series parts (curves B and B') and of parallel parts (curves C and C') have a wide distribution [Sasaki and Hayashi, 1976].

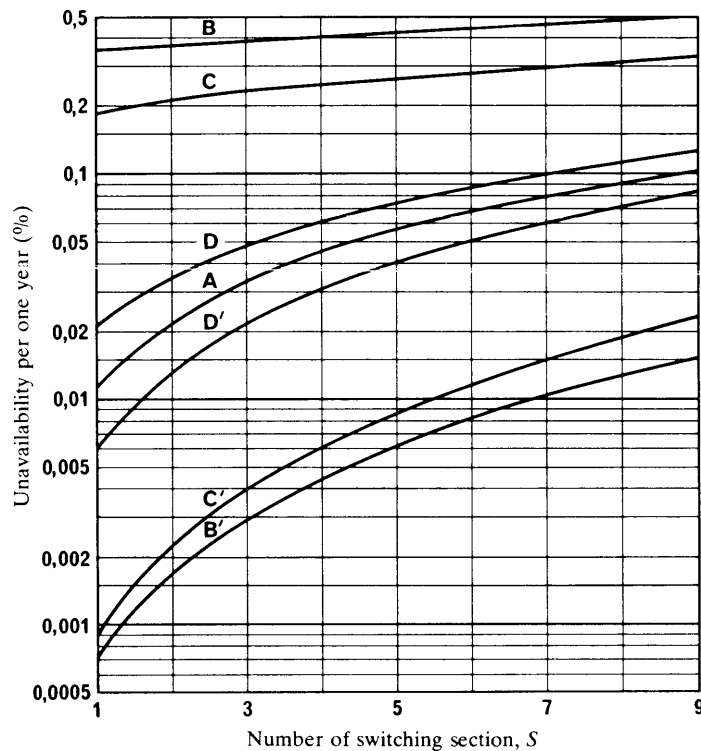


FIGURE 4 – *Example of interval estimation of unavailability*
(estimation of upper and lower 90% confidence levels)

Assumption: the same as shown in Fig. 3

A : Design objective

B, B' : Estimation from the number of occurrences of circuit failures in series parts

C, C' : Estimation of the number of occurrences of circuit failures in parallel parts

D, D' : Estimation from the number of occurrences of equipment failures in parallel parts

If the number of occurrences of equipment failures in a year can be obtained independently of circuit failures, then the estimate of unavailability based on the protected parallel parts has a narrow distribution as shown by curves D and D'.

4. Effects of equipment reliability and of propagation * on availability of radio relay-links

Studies have been carried out in France [Boithias and Battesti, 1971] to compare the respective effects of propagation and of equipment on the availability of an FM-FDM radio-relay circuit corresponding to a modulation section of 280 km. The shorter the hops chosen, the fewer interruptions there are due to propagation; on the other hand, the number of interruptions due to equipment increases. There must therefore be an optimum mean length of hops. However, this will depend on climatic and other considerations.

* See also Report 338.

For this study, the circuit was considered to have been interrupted when the weighted noise power exceeded 47 500 pW on any hop. Since most of the interruptions due to propagation were short but occurred in rapid succession, the effective outage time of the circuit was taken to be about four times greater than true break duration. These assumptions were purely arbitrary, and are not strictly in accordance with Recommendations 393 and 395 which deal with permissible noise levels including variations of noise level due to propagation.

The curves in Figs. 5 and 6 were plotted on the basis of the numerical values given in Report 338, as far as propagation was concerned, and, for equipment reliability, on those derived from measurements on French radio-relay systems using semi-conductors. These figures show, in particular, that the optimum mean length of hops depends largely on the structure of the radio-relay system (diversity or protection channels).

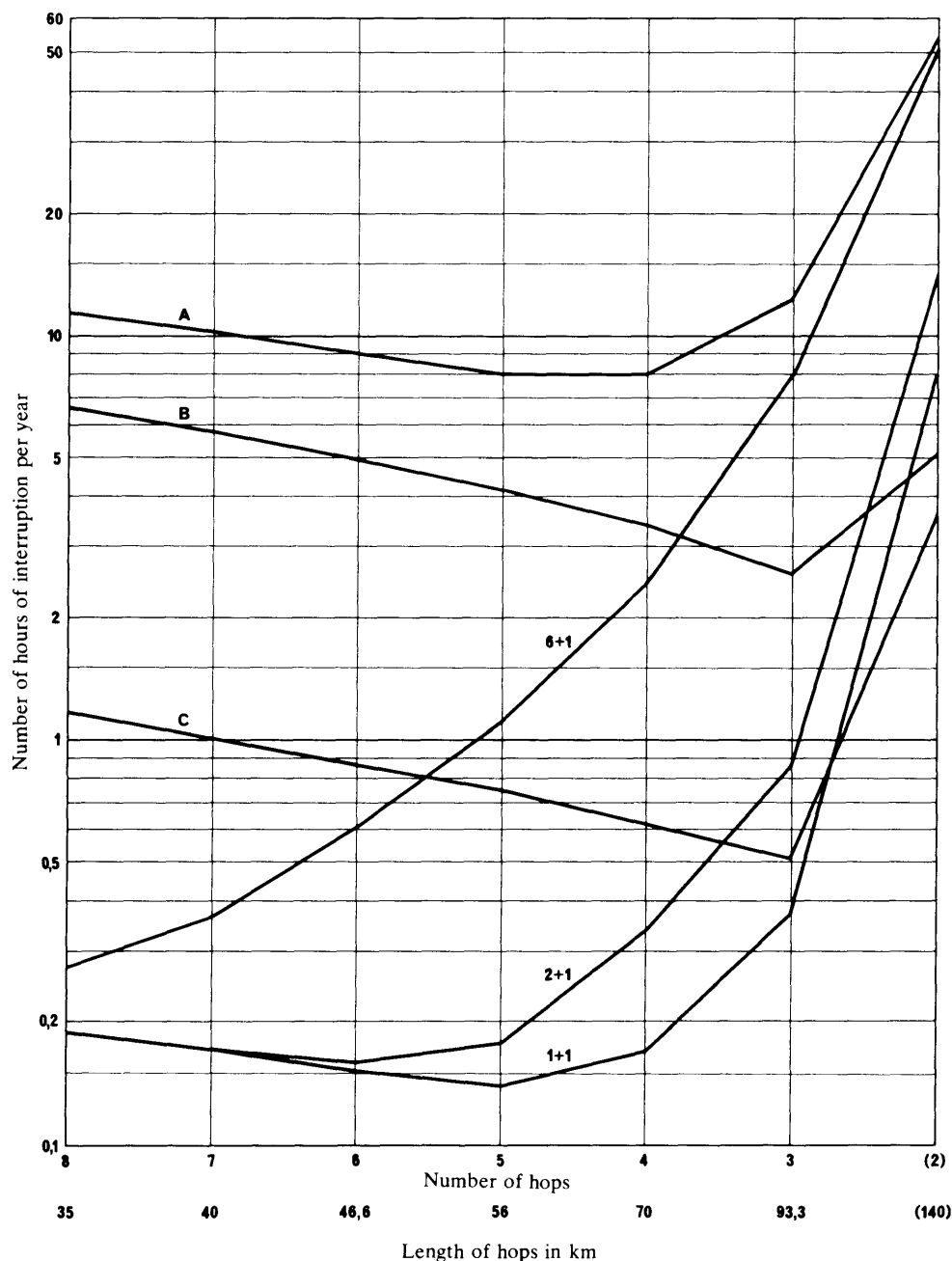


FIGURE 5 – Interruptions due to all causes (including 1 minute per year per station for failure of public and stand-by power supplies)

Curve A: without diversity and stand-by protection

B: with space diversity at each hop, without stand-by transmitter

C: with space diversity at each hop, with stand-by transmitter

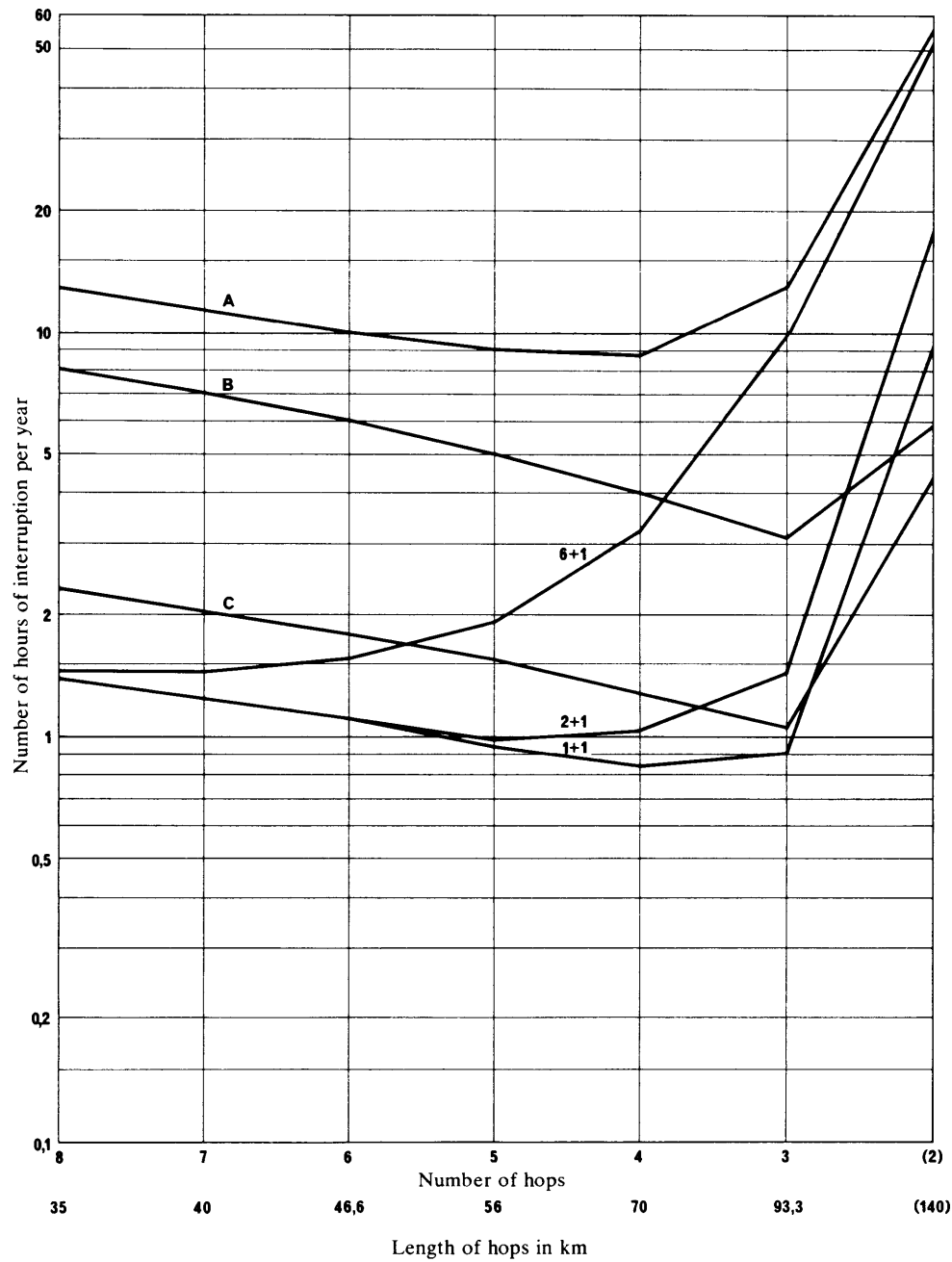


FIGURE 6 – Interruptions due to all causes (including 9 minutes per year per station for failure of public and stand-by power supplies)

- Curve A: without diversity and without stand-by protection
 B: with space diversity at each hop without stand-by transmitter
 C: with space diversity at each hop, with stand-by transmitter

5. Results of measured system availability

Several countries have provided results of the availability obtained on real radio-relay systems. As different measures of availability were used, the results are presented separately below.

5.1 Results from Canada

One suggested method of measuring the overall availability is the use of a "figure of merit". The following factors were used in defining this figure of merit:

- the figure should indicate the total time the radio systems are available for service;
- interruptions which do not affect service should not be included;
- the figure should take into account the expansion of the network of radio-relay systems;
- the data used should be readily available from normal operating reports;
- the results should be adjustable for different time periods to allow comparisons.

The figure of merit is defined as:

$$A = 100 - (2500 \times 100/L) [(2T + T_b)/T_s]$$

where

A : percentage availability based on 2500 km

L : length of one-way radio channel under consideration (km)

T : interruption time other than bi-directional interruptions (minutes)

T_b : bi-directional interruptions (minutes)

T_s : period of study (minutes).

Figure 7 shows the percentage availability based on 2500 km for the major long-distance Canadian radio-relay system, for the period 1963 to 1974 inclusive.

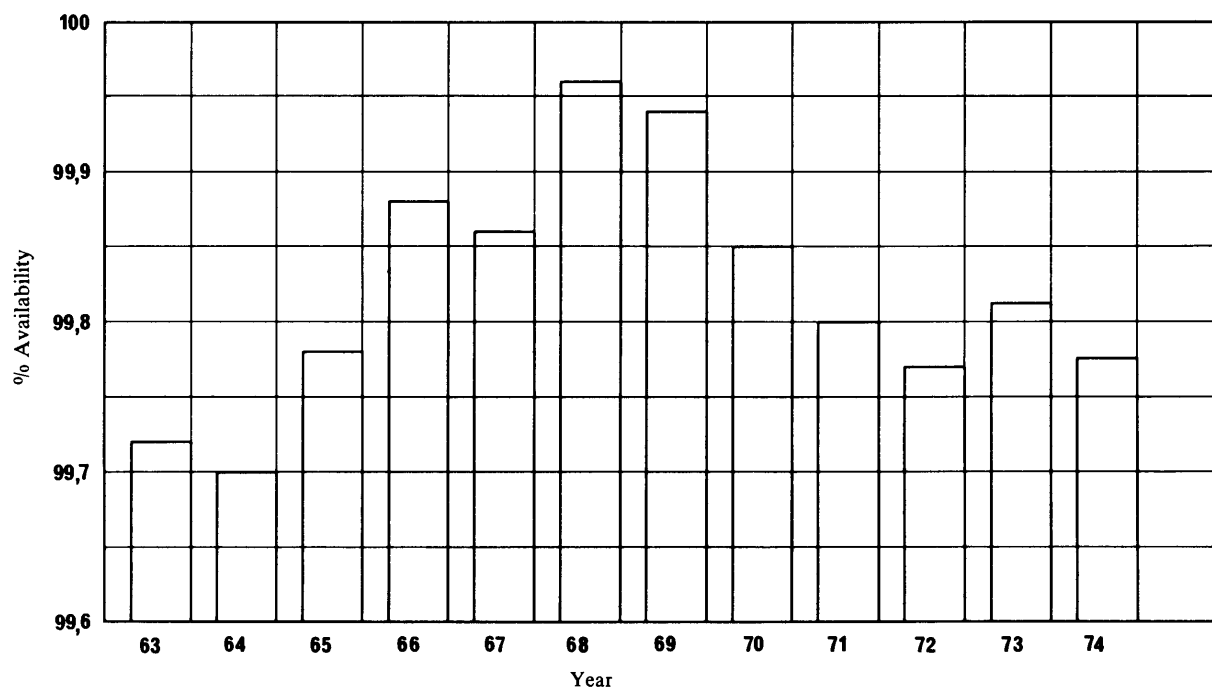


FIGURE 7 – Operating Availability (2500 km base)

The total interruption time has been subdivided into its four main constituents and the corresponding availabilities are shown separately in Fig. 8.

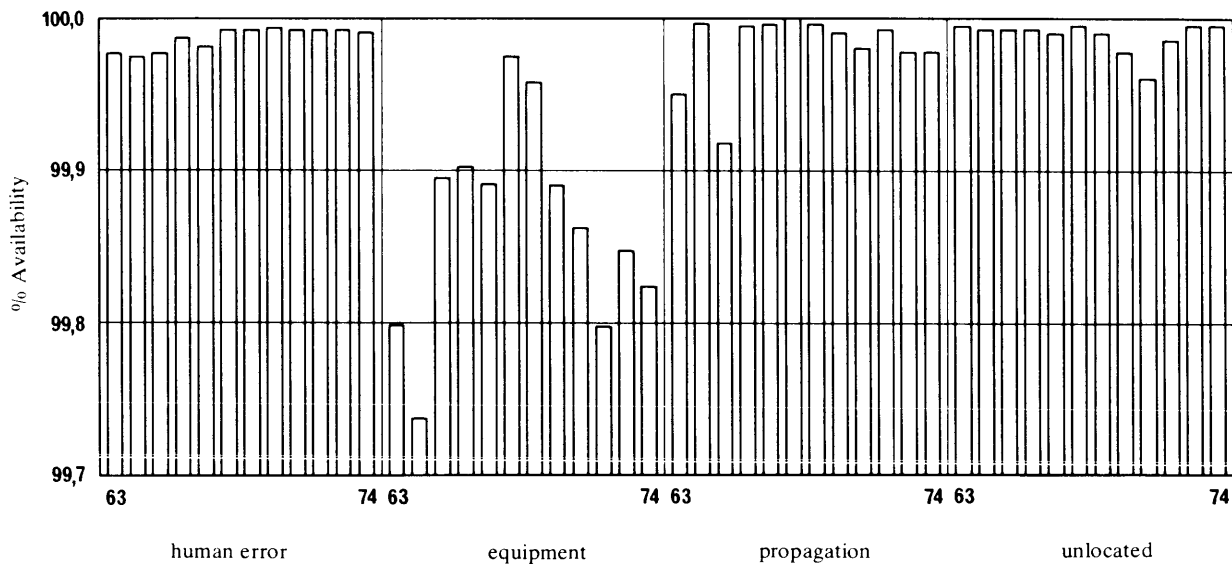


FIGURE 8 – Operating Availability vs causes of failure

A tentative operating objective of 99.97% is used in Canada for a 1000 mile one-way radio system. This corresponds to 99.95% on a 2500 km base. It is not the intention that this value be used as an objective for the design of new radio-relay systems.

Additional information presented in study period 1970-74 indicates that the mean duration of a long interruption is of the order of 5 to 20 min depending on the cause and that on protected routes, a high percentage of total interruption time is not dependent on the radio equipment and cannot be reduced by further protection channels.

5.2 Results from the United Kingdom

Tables I and II provide information concerning the reliability and availability of the Post Office microwave network in the United Kingdom for the year 1974.

Table I which refers to the whole network and all types of traffic shows under three headings the fault rate per RF channel hop for the whole network viz., thermionic equipment, hybrid equipment (i.e. all solid-state except for a travelling wave tube) and all solid-state equipment.

TABLE I

	Valve systems	Hybrid systems	Solid-state systems
Number of RF channel hops	1043	781	201
Failure rate (faults/channel hop/annum)	8.54	1.83	0.54
Mean time to restore (hours)	2.4	3.7	35
Availability per channel hop (discounting protection)	99.767	99.922	99.780

Note that the failure rate of the solid-state equipment which is of low power and low capacity is one third that of the high power hybrid equipment and one sixteenth that of the thermionic equipment. However, due to the special circumstances in which the solid-state equipment is operated in the United Kingdom, the availability achieved is no better than that of less reliable equipment which is situated at more easily accessible sites.

The solid-state equipment is mostly 300-channel capacity and was chosen specifically for its high reliability for those cases where it was known in advance that access times would be long, i.e. due to shortage of local staff or difficulty of physical access. For example, access to an island radio station may require a journey by sea and be possible only in good weather.

Table II gives the service data on those RF channel hops which are used to carry multi-channel telephone traffic. The radio equipment involved is of 300, 960 and 1800 telephone channel capacity. The table includes traffic failures from all causes which exceed 30 seconds.

TABLE II

Failure rate/100 km/annum per unidirectional channel	0.67
Failure rate/channel hop/annum	0.27
Average outage time per failure	0.31 hours
Availability/100 km unidirectional	99.9977%
Availability/2500 km bi-directional	99.885 %

The current United Kingdom availability objective for radio-relay links for bi-directional transmission is 99.994% per 100 km which corresponds to 99.84% for a 2500 km circuit.

5.3 Results from Italy

Figure 9 shows the availability results of the Italian radio-relay network operating in the 3600-4200 MHz band with a capacity per radio channel of 960 telephone channels. The system uses one stand-by channel for six operating channels.

Figures 10a and 10b refer to the Italian radio-relay network operating in the 7125 to 7750 MHz band with a capacity per radio channel from 120 to 960 telephone channels. The percentage of radio-relay systems with a capacity of 960 telephone channels has been continuously increased, from 24% in 1968 to 65% in 1974. This system mainly uses one stand-by channel for each operating channel with switching at every hop.

Figure 10b subdivides the total availability into its various components. It should be noted that the term "propagation" includes outages due to deep fading on one radio channel simultaneous with equipment failure or maintenance work on the other radio channel.

Figure 10a shows also the availability results of that part of the system operating in the frequency band 7125 to 7750 MHz using all solid-state equipment. The percentage of all solid state equipment in this system has been continuously increased from 18% in 1970 to 64% in 1974.

The availability results, in both Figs. 9 and 10, do not take into account periods of intentional interruptions due to installation or modification of equipment.

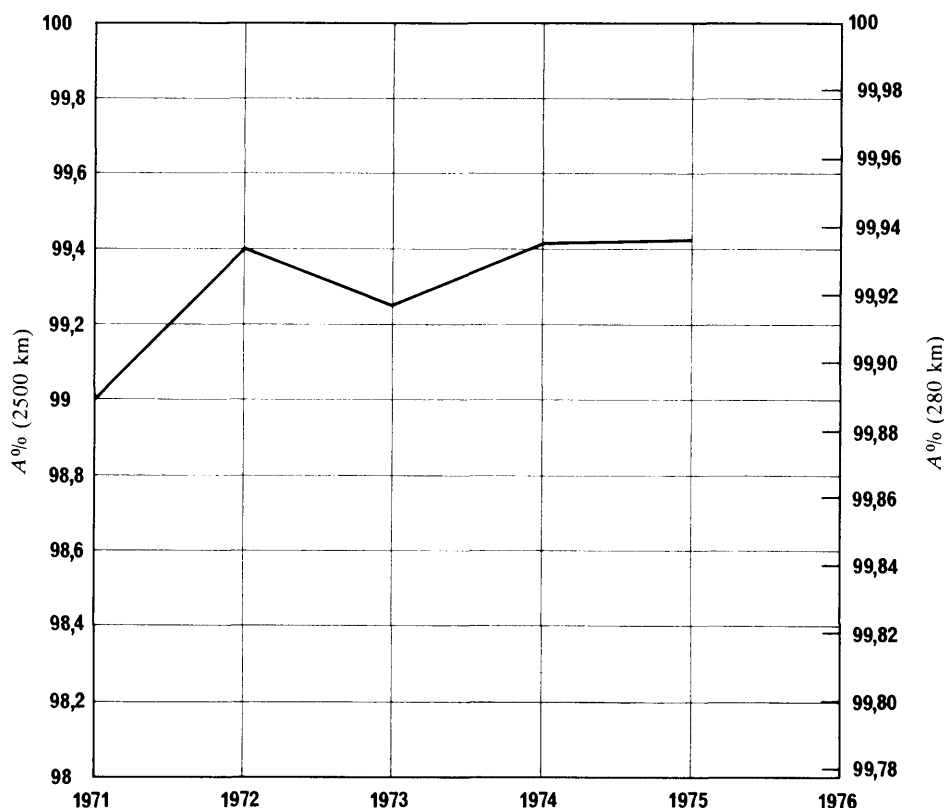


FIGURE 9 – Availability results of the Italian radio-relay system operating in the 4 GHz band

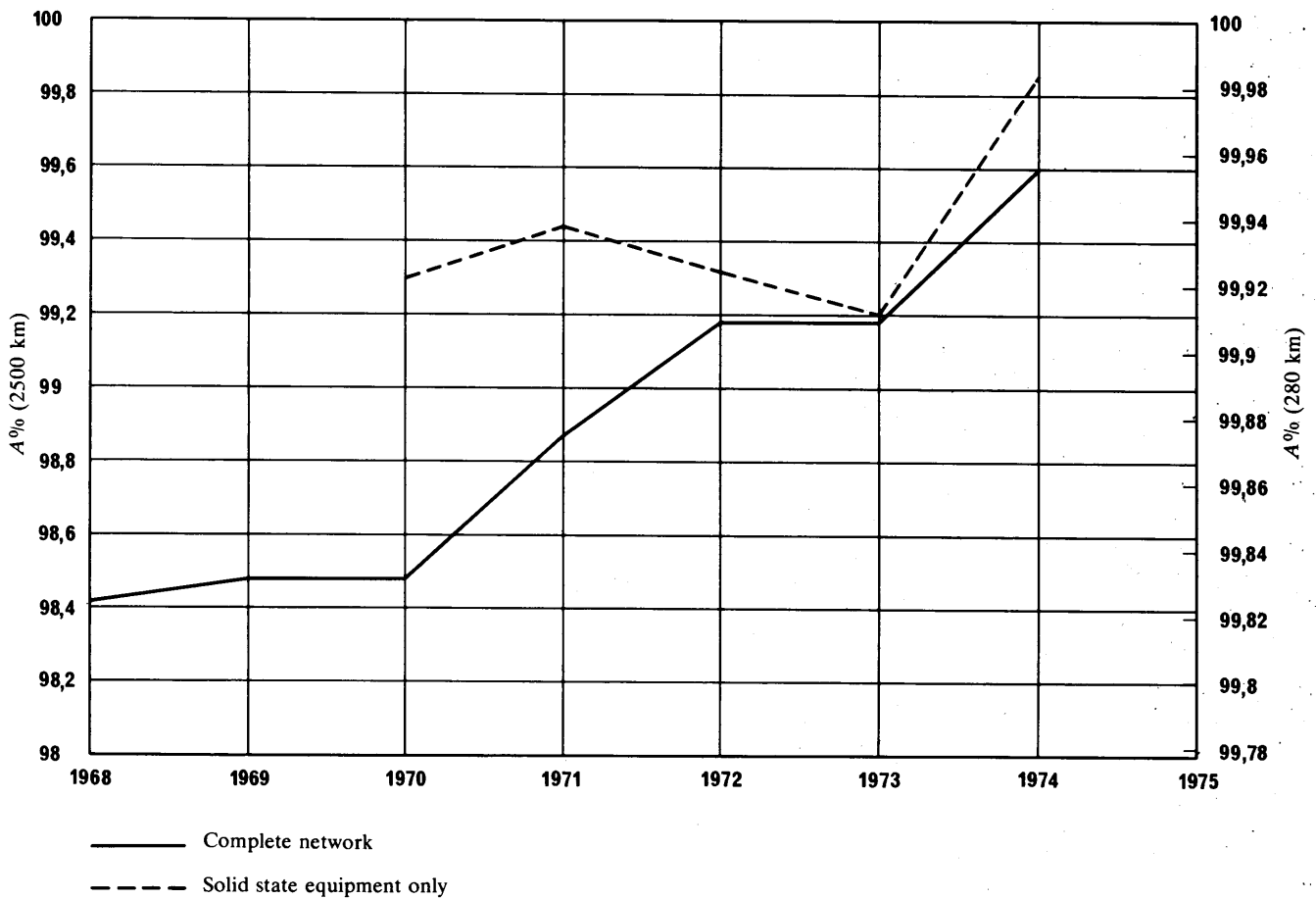


FIGURE 10a – Availability results of the Italian radio-relay system operating in the frequency band 7125 - 7750 MHz

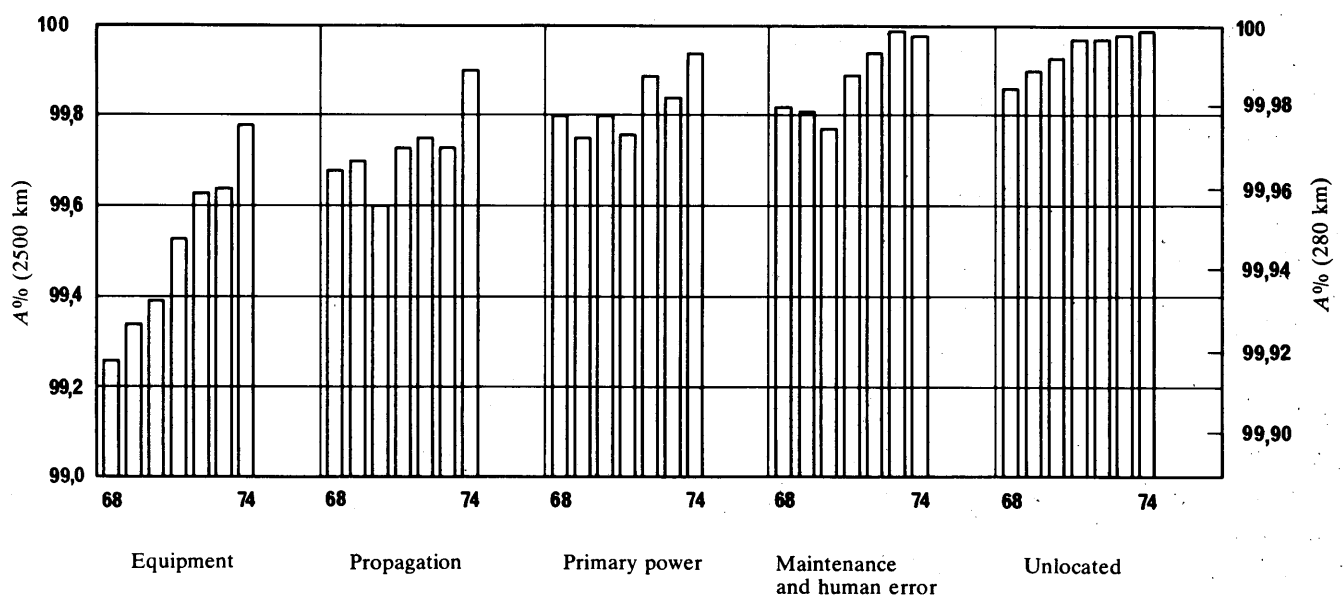


FIGURE 10b – Availability vs. causes of failure for the complete network of the Italian radio-relay system operating in the frequency band 7125 - 7750 MHz

5.4 Results from the Federal Republic of Germany

Since early 1970 the Post and Telecommunications Administration of the Federal Republic of Germany has been monitoring the continuity pilots on all wide-band radio-relay channels and by means of time classification equipment recording all interruptions of the radio-relay channels. All channels are protected by an $n + 1$ switching system. Figure 11 shows the measured data, converted to section lengths of 100 km, of some 100 radio-relay links of a 4 GHz-system (valve equipment). Fig. 12 shows the results of about 15 radio-relay links of a 6 GHz-system (semi-conductor equipment with travelling-wave tube).

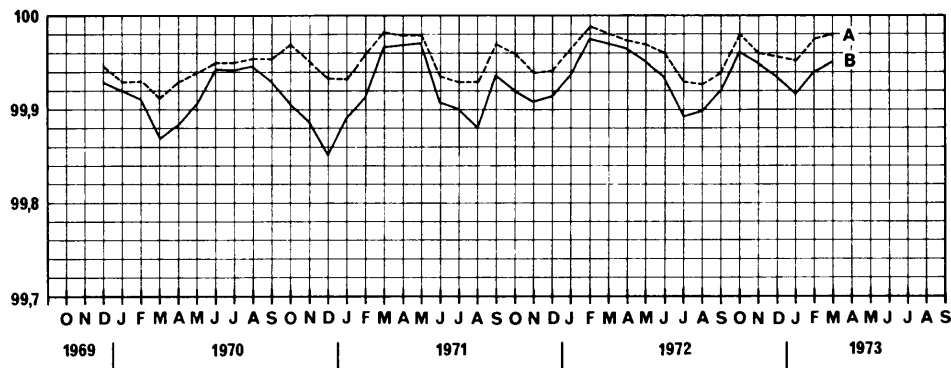


FIGURE 11 – Availability of radio-relay circuits on 4 GHz systems carrying 960 telephone channels or one television channel (valve equipment), converted to section lengths of 100 km

Curve A: without intentional switch-off periods

B: with intentional switch-off periods (for maintenance purpose)

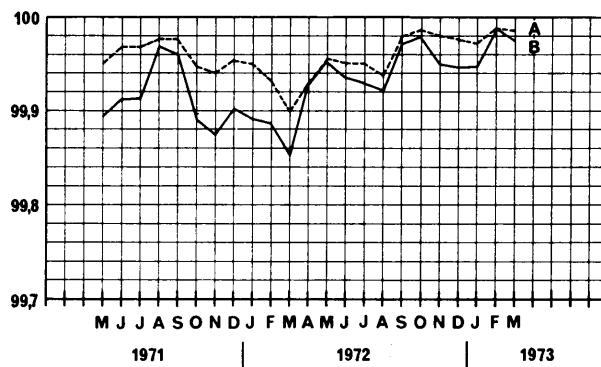


FIGURE 12 – Availability of radio-relay circuits of 6 GHz systems carrying 1800 telephone channels or the equivalent in television channels (semi-conductor equipment), converted to section lengths of 100 km

Curve A: without intentional switch-off periods

B: with intentional switch-off periods (for maintenance purpose)

A calculation of the anticipated availability on the basis of available equipment failure rates and mean times to repair (MTTR) is much more favourable (factor 10-15 for the non-availability) than actually measured on operational circuits. This means that, besides the equipment failure, the factors given in § 2.2 play an important role in the overall availability rate of a system.

5.5 Results from Japan

Table III shows data on interruptions in operating long haul 4 GHz and 6 GHz radio-relay systems. The availability of these systems is more than 99.97%/2500 km per year.

These availability results do not take into account periods of intentional interruptions due to installation or modification of equipment.

TABLE III – Non-availability of (a) 4 GHz tube system (b) 4 GHz and (c) 6 GHz transistorized except for TWT systems (2500 km, both ways) (%)

Fiscal Year	Equipment			Propagation	Human activity	Unlocated	Total
	Radio Equipment		Power Supply Equipment				
	With Stand-by	Without Stand-by					
1971 (a) (b) (c)	0.586×10^{-2}	2.989	0.287	1.152	0.718	0.570	6.302×10^{-2}
	0.062×10^{-2}	0.197	0.016	0	0.012	0.156	0.443×10^{-2}
	0.041×10^{-2}	0.028	0.053	0	0.131	0.110	0.363×10^{-2}
1972 (a) (b) (c)	0.152×10^{-2}	0.426	1.366	0.463	0.193	0.496	3.096×10^{-2}
	0.029×10^{-2}	0.008	0.078	0.004	0.070	0.062	0.251×10^{-2}
	0.065×10^{-2}	0.020	1.296	0.074	0.148	0.148	1.751×10^{-2}
1973 (a) (b) (c)	0.098×10^{-2}	0.074	0.131	0.131	0.111	0.357	0.902×10^{-2}
	2.271×10^{-2}	0.016	0.008	0	0.115	0.238	2.648×10^{-2}
	0.028×10^{-2}	0.139	2.337	0.069	0.250	0.041	2.864×10^{-2}
1974 (a) (b) (c)	0.152×10^{-2}	0.074	0.144	0.045	0.574	0.156	1.145×10^{-2}
	0.078×10^{-2}	0.357	0.021	0	0.242	0.066	0.764×10^{-2}
	0.057×10^{-2}	0.061	0.152	0.041	0.107	0.148	0.566×10^{-2}
Average (a) (b) (c)	0.247×10^{-2}	0.891×10^{-2}	0.482×10^{-2}	0.448×10^{-2}	0.399×10^{-2}	0.395×10^{-2}	2.861×10^{-2}
	0.610×10^{-2}	0.144×10^{-2}	0.031×10^{-2}	0	0.110×10^{-2}	0.131×10^{-2}	1.026×10^{-2}
	0.048×10^{-2}	0.062×10^{-2}	0.960×10^{-2}	0.046×10^{-2}	0.159×10^{-2}	0.112×10^{-2}	1.387×10^{-2}

5.6 Results from France

On the basis of results obtained by the French Administration in 1974 and 1976, the measured mean value of non-availability is approximately 0.4% for links of 2500 km with stand-by protection. Intentional interruptions have not been taken into account.

5.6.1 "Intentional interruptions" are those required for installation or modification of equipment. They are very frequent in a rapidly expanding system, but should not in principle lead to complete interruption of the super groups and master groups transmitted over the link, because different routes are brought into service during these interruptions, which are moreover often arranged during low-traffic hours.

5.6.2 On links without stand-by protection, the total outage time due to the radio-relay equipment is about 15 times longer and the overall non-availability approximately 5 times greater than on links with such protection.

5.6.3 A number of interruptions on links with stand-by protection were caused by the fact that for fairly long periods the stand-by channels were used as a replacement of a cut coaxial cable. Such irregular use of stand-by channels obviously reduces the availability of the corresponding main radio relay route.

5.7 Results from Australia

Maintenance records, referring to 70% of the total radio-relay network (systems of 300 channel capacity or larger), were examined for the year 1976. The network consists of analogue systems operating in the bands between about 2 and 8 GHz. Measured unavailability was categorized according to causes as shown in Table IV.

Systems were also subdivided into two categories: viz. systems using solid state equipment and systems using valve equipment. Two salient points emerge from Table IV, i.e.

- the reliability of modern solid state equipment is significantly better than for the older valve equipment;
- the total measured availability was 99.88%.

TABLE IV – Unavailability of the Australian radio-relay network (1976, system of 300-channel capacity or larger)

Cause of Outage	Solid State equipment (12 656 km - 297 paths)		Valve equipment (3025 km - 56 paths)		All equipment (15 681 km - 353 paths)	
	Outage (hours)	Unavailability per 2500 km (%)	Outage (hours)	Unavailability per 2500 km (%)	Outage (hours)	Unavailability per 2500 km (%)
a. Primary power	9.83	0.022	2.48	0.024	12.31	0.022
b. Radio equipment	11.91	0.027	18.88	0.178	30.79	0.056
c. Fading	19.22	0.043	3.29	0.031	22.51	0.041
d. Human error	0.39	0.001	0.003	—	0.40	0.001
e. Other	1.26	0.003	0.07	0.0006	1.33	0.002
f. Total (a+b+c+d+e)	42.61	0.096	24.72	0.233	67.33	0.123

6. Conclusions

The availability of radio-relay systems can be described in terms of interruption time. Availability objectives should be aimed at providing good service performance and at providing practical guidance to system designers.

REFERENCES

- BOITHIAS, L. and BATTESTI, J. [September-October, 1971] Fiabilité des liaisons par faisceaux hertziens (Reliability of radio-relay systems). *Ann. des Télécomm.*, Vol. 26, 9-10, 381-392.
- DUMMER, G. W. A. and GRIFFITH, N. B. [1966] *Electronics Reliability – Calculation and Design*. Pergamon Press, Oxford, United Kingdom.
- KARAS, W. P. [December, 1967] Reliability and field experience of electronic switching systems. *IEEE Trans. Comm. Tech.*, 736-743.
- SASAKI, M. and HAYASHI, H. [1976] Confidence limits for redundant system availability *IEEE*, R-25, 1.
- WALROUND, J. C. [1971] Assessing equipment reliability for microwave radio-relay systems. *Microelectronics and Reliability*, Vol. 10, 95-103, Pergamon Press, Oxford, United Kingdom.

BIBLIOGRAPHY

- ELKINS, N. A. [October, 1968] The reliability of microwave radio-relay systems. *POEEJ*, Vol. 61, 3, 143-148.

REPORT 932

PROTECTION OF RADIO-RELAY STATIONS AGAINST LIGHTNING DISCHARGES *

(Question 32/9)

(1982)

1. Introduction

Lightning can create a severe protection problem at radio-relay stations with antennas that are higher than nearby structures. In urban areas, the presence of extensive metallic water pipe systems and other well grounded metallic structures reduces the chances of radio station damage. In rural areas, however, radio stations are more susceptible to damage because metallic underground facilities will either not be as extensive as in urban areas, or will be non-existent. Destructive lightning surges can also be conducted into the station through connecting power and communications lines, in addition to direct strikes to the antenna and antenna tower. Consequently, special protection measures are necessary to minimize damage from lightning.

* This Report has been prepared on the basis of information from three administrations and is an information document for transmission to CCITT Study Group V in order that this information can be included in the Handbook entitled "Protection of telecommunication lines and equipment against lightning discharges".

The buildings in which radio-relay stations are installed often house other radiocommunication systems (e.g. broadcasting and mobile facilities) and even non-radio transmission systems and switching centres.

The protection techniques and devices used have to be designed with such multiple applications in view. Relevant information is contained in the CCITT Handbook entitled "Protection of telecommunication lines and equipment against lightning discharges" (1978).

The present Report discusses in particular, aspects of safeguarding radio-relay equipment from the effects of surges caused by atmospheric discharges or by induction and aims to align the techniques and equipment involved with those used for protecting buildings, including towers and personnel.

2. Frequency of discharges and faults in radio-relay stations

2.1 General characteristics

It is generally considered that a telecommunication system can fail as a result of a surge caused by atmospheric discharge or by induction when the breakdown voltage of the equipment is reached or exceeded.

Semiconductor-based equipment is more vulnerable to surges than equipment using only electronic tubes, owing to the fragility of the components and the short distances between conducting parts.

2.2 Breakdown frequency

The number of atmospheric discharges striking a radio-relay station and causing a surge greater than or equal to the breakdown voltage will depend on:

- the number of thunderstorm days per year in the area within which the station is located (keraunic level), the relationship being practically linear;
- the height of the tower;
- the height of the site above sea level and the conditions of the terrain, especially its conductivity. Quantitatively, the former factor could be expressed as a hypothetical increase in the height of the tower;
- the breakdown voltage and transfer impedance of the station's component units, including the tower.

Chapter 7 of the CCITT Handbook contains statistics on the frequency of discharges and a theoretical discussion of the anticipated frequency of breakdowns, together with sample transfer impedance values.

In practice, it is considered preferable to use data from local observations in estimating the breakdown frequency of radio-relay stations.

It may not be economical to provide uniform lightning protection at every radio-relay station. Greater lightning protection should be applied to stations with high lightning damage probability than to those where that probability is smaller.

Annex I gives information on investigations carried out in Japan.

3. Protective techniques and equipment

3.1 General

The basic objective of systems used to protect radio-relay stations from surges caused by atmospheric discharges or by induction should be to ensure that the currents produced are evenly distributed among all the conducting parts of the earthing network and that the current in each branch is as small as possible. To achieve this, special attention should be given to the factors which determine the protection system (e.g. keraunic level, ground conductivity at different depths, height above sea level, etc.), as well as to other characteristics which need to be taken into account when selecting the site of a station (access, power main, topography, etc.).

Radio-relay stations usually take the form of an antenna tower near or on top of the building in which the equipment is housed. It is also common to install the equipment inside the tower.

3.2 Protection of buildings and towers

Under current regulations, buildings and towers must be protected against atmospheric discharges by means of suitable lightning conductors. The systems adopted should be compatible with those used for protecting the equipment. Accordingly, station construction should provide for electrical continuity between all metallic parts of the building to reduce the risk of dangerous voltages between the metallic structural elements and between the structure and the equipment. All lightning conductors and down-leads and the metal structure of the building itself (including the tower) must form an integral part of the station's protective system.

If the tower is erected at some distance from the equipment building, it may be advisable to fit a separate tower earthing system, with a view to subsequent integration into a single system for the station as a whole, including that of the building.

When antennas are mounted on relatively large steel-framed buildings housing other facilities in urban areas, adequate grounding is ordinarily obtained by bonding the antennas and radio equipment to the steel frame of the building. The building frame should be bonded to the power grounding system.

Inductance (self and mutual) is generally more effectively reduced by providing parallel separated connecting paths rather than by increasing conductor diameter.

3.3 *Protection of equipment and antennas*

It may be useful for all the metal parts of the radio and power supply and distribution equipment to be connected to the main system described in § 3.2. To avoid the use of lengthy interconnecting cables which would increase the station's transfer impedance, a metal conductor ring (earth collector) may be fitted inside the building, the different metal parts being connected to it, the ring or earth collector then being connected to the metal structural network of the building. Earthing between the collector and the different items of equipment should be effected by short conductors having as few bends as possible. The best distribution in this respect would be star-shaped with branches (e.g. one for each bank of frames) attached to short conductors running to the earthing terminals on the equipment.

Connection of all the waveguides and the metal housings of coaxial and power cables to this system at their point of entry to the building would reduce the risk of surges affecting the equipment installed inside it.

Up-leads to any equipment installed in the upper part of the tower might require further protection, possibly in the form of screened cable trunking.

In large buildings, it is desirable to supplement the interior perimeter ring bus with supplementary buses to reduce the length of bond paths and to facilitate bonding and grounding of equipment enclosures and other metallic components. Each end of the supplementary buses must be connected to the main interior ring bus to assure multiple bonding and grounding paths. Cables used for bonding and grounding must be bonded together where they cross or are in proximity to each other, to prevent arcing.

Metallic antennas usually are not damaged by direct strokes, but should be bonded to the metallic supporting structure to prevent arcing. Non-metallic antennas such as those made of fibreglass have to be protected by lightning rods if they fall outside the cone of protection created by the tower. Waveguides and the outer conductor of coaxial cables should be bonded to the antenna tower at the top and bottom of the vertical run. Additional bonds may be necessary where the towers are very high (over about 50 m, for example). The bond at the bottom of the waveguide must be run as direct and straight as possible and be bonded to the tower ground ring where it will be accessible at a corner footing. Where the waveguide enters the building, the waveguide hatch is connected to the interior ring bus and over a primary bond to the exterior ring ground.

3.4 *Power line and equipment protection*

Radio station equipment and supply circuits are vulnerable to damage from lightning surges and switching transients originating on the connecting power lines. To prevent such damage, protective devices should be used on power line conductors and, in some cases, on branch circuits within the station.

Primary circuit arrester grounds and the secondary neutral ground of the power system should be interconnected either metallicity or through an isolating gap. This arrangement minimizes large voltage differences between transformer windings as a result of lightning discharges to the antenna tower or the primary power conductor.

Secondary circuit arresters will generally provide adequate protection for the station and tower lighting circuits and most of the heavier duty equipment such as motors. Frequently, however, arresters of this type will not limit surge voltages sufficiently to protect semi-conductor and other sensitive types of electronic equipment. In such cases it is necessary to supplement the secondary arrester with low voltage branch circuit arresters or low pass filter circuits, located as close as possible to the equipment being protected.

All arrester circuitry that is installed indoors should be provided with fuses or circuit breakers so that in the event of a short in the wiring or in the arrester, an electrical fire will be prevented.

3.5 Communications line protection

Telephone lines and cables entering radio stations are especially vulnerable to lightning damage. The shield of aerial cables, the supporting strand, and the attachment at the entrance pole should be bonded together and grounded at the pole. The strand attachment at the building and the cable shield should be bonded to the exterior ground ring. Inside the building, the cable shield, strand extension, and cable entrance terminal should be bonded to the interior ring bus. The shield of buried cables should be bonded to both the exterior ring ground and the interior ring bus.

All conductors, both working and non-working, should be equipped with station protectors. Where aerial or buried branch cable is connected to a main cable, protectors should be provided on all pairs of the branch cable at the junction.

4. Examples of protection systems

Annex II (Figs. 5, 6, 7 and 8) gives examples of the configuration of protection systems against surges caused by atmospheric discharges or by induction in radio-relay stations.

Figures 5 and 6 show grounding systems with the corresponding bonds used in the United States of America, based on the ring configuration described in § 3.

Figures 7 and 8 give examples of the connection of protective devices in power lines and equipment.

Table 1 describes the basic elements of the protection systems used in Japan in relation to the risks and the classification given in Fig. 4. These protection measures were defined on the basis of statistics represented in Figs. 1, 2 and 3, which were derived from stations in which the protection measures had not been applied.

5. Impedance and earth resistance values

Reducing the resistance of the earthing system may not afford effective protection unless the overall impedance is also reduced.

Figure 3 on measurements made in Japan indicates some relationship between the resistance of the earthing system (for values of between 1 and 50 Ω) and the likelihood of discharges causing damage to the station. This probability is much less for resistance values below 1 Ω .

Very low resistance values depend on the ground resistivity at different depths and on the installation and use of earthing electrodes matching the configuration of the layers of least resistivity.

Generally speaking, heavy investment might be required for providing an adequate system of protection (e.g. with a resistance of less than 10 Ω) for stations sited on ground having a resistivity of more than about 500 $\Omega \cdot m$.

The shape, arrangement and number of earthing electrodes to be installed will depend on the ground conductivity, the shape and size of the available plot and the actual reduction effected in the impedance and resistance of the protection system.

6. Conclusions

The design of the system used to protect a radio-relay station from surges caused by atmospheric discharges or by induction may seek to relate the cost to the risk of damage to which the station is exposed.

Further study should be made of the relationship between frequency of breakdowns, the keraunic index of the area, the topographical and structural characteristics of the station, the system of protection adopted and any other possible factors.

Since radio stations may be used for a variety of purposes, care should be taken to ensure that the measures and solutions adopted are consistent with the general plan for the protection of telecommunication installations. The information given in the CCITT Handbook "Protection of telecommunication lines and equipment against lightning discharges" is most useful in this respect.

BIBLIOGRAPHY

- KAMIIKE, K. and EGUCHI, N. [January, 1978] Lightning protection for microwave relay station. *Japan Telecomm. Rev.*, Vol. 20, 1, 63-70.
- MUKASA, K., KAMIIKE, K., FUJIOKA, N. and KIYOTANI, Y. [May-June, 1977] Lightning protection for microwave relay station. *Rev. Elec. Comm. Labs.*, Vol. 25, 5-6, 487-503.

CCIR Documents:

[1978-82]: 9/246 (Japan); 9/258 (United States of America); 9/271 (CTNE — Spain).

ANNEX I

CLASSIFICATION OF LIGHTNING DAMAGE PROBABILITY

419 radio-relay stations throughout Japan were investigated for approximately three years between 1972 to 1974, in order to obtain relations of lightning damage requiring mechanical or electrical repair to KL (keraunic levels), altitudes above sea level and ground resistance.

The results are shown in Figs. 1, 2 and 3, respectively.

Conventional classifications of lightning damage probability are complicated and not suitable for practical use. Therefore, a new classification has been established, based upon the results of investigations.

In this classification (see Fig. 4), radio-relay stations are divided into three ranks according to the KL and altitudes above sea level, out of consideration for their great influence on the damage probability. Ground resistance has little relation to damage probability as shown in Fig. 3.

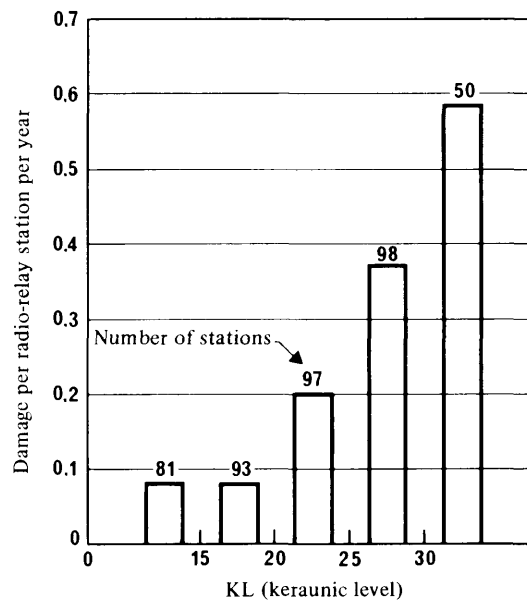


FIGURE 1 — Relation between lightning damage and KL

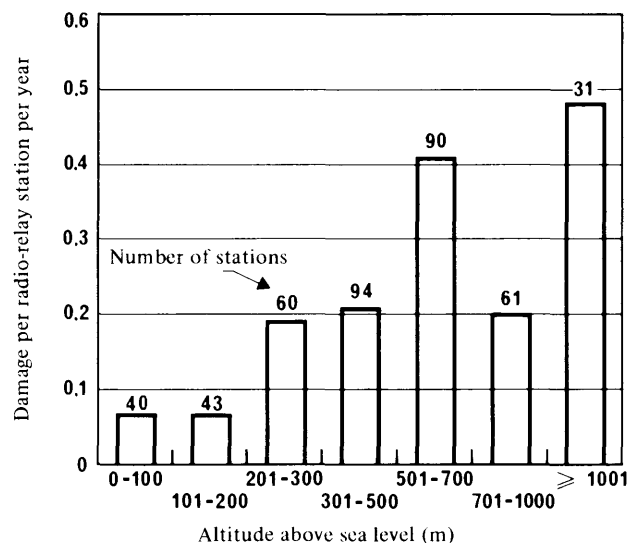


FIGURE 2 — Relation between lightning damage and altitude above sea level

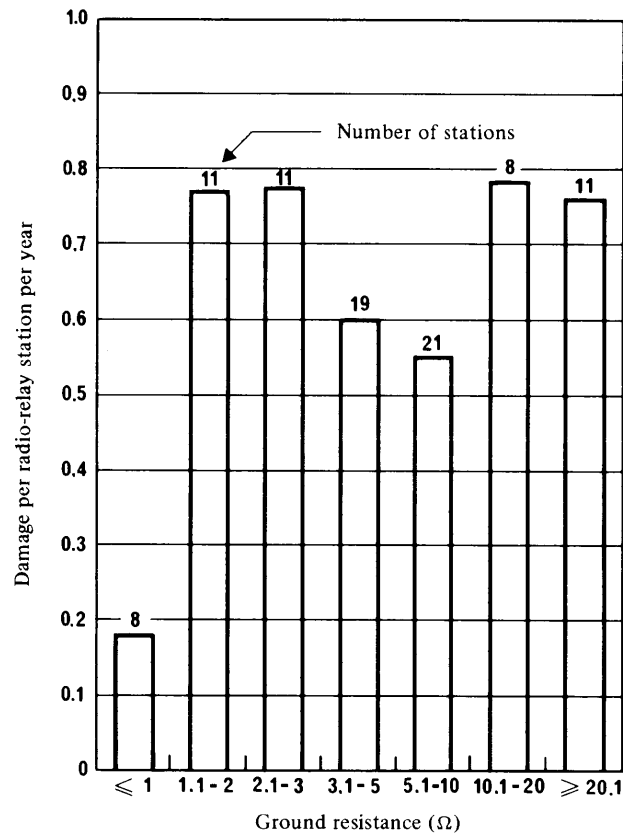


FIGURE 3 — Relation between ground resistance and lightning damage

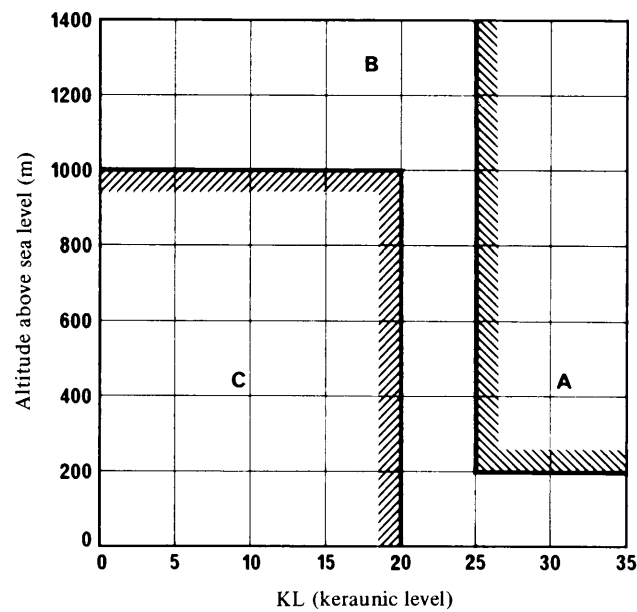


FIGURE 4 — Lightning damage classification

Approximate probability of lightning damage (per station per year)

- A: more than 0.3 (great)
- B: 0.1 to 0.3 (medium)
- C: less than 0.1 (small)

ANNEX II

EXAMPLES OF LIGHTNING PROTECTION SYSTEMS

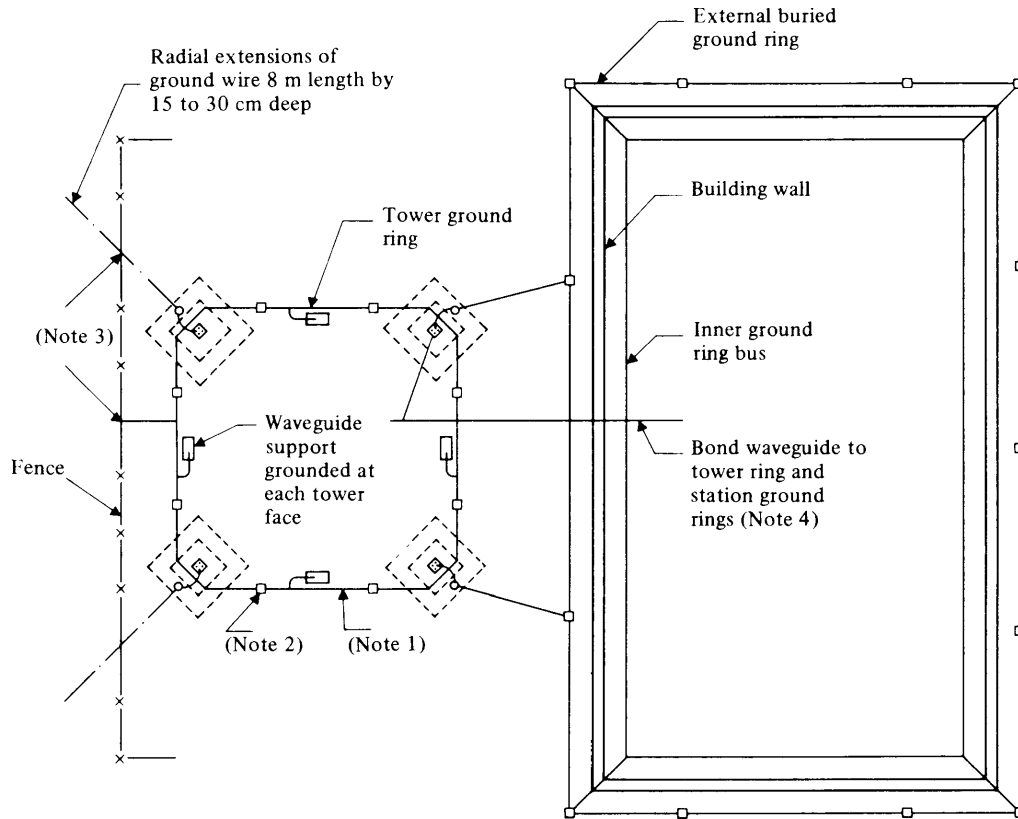


FIGURE 5 — Grounding network for a radio station

Note 1. — Tinned solid copper wire for bonding and grounding.

Note 2. — Ground rods.

Note 3. — Bond fence to ground ring. When radial extensions are used, bond fence to radial conductors. This will preclude the need for intermediate bonds.

Note 4. — Bond waveguide at bottom of vertical run as direct and straight as possible to ground ring connection at a base corner of tower footing.

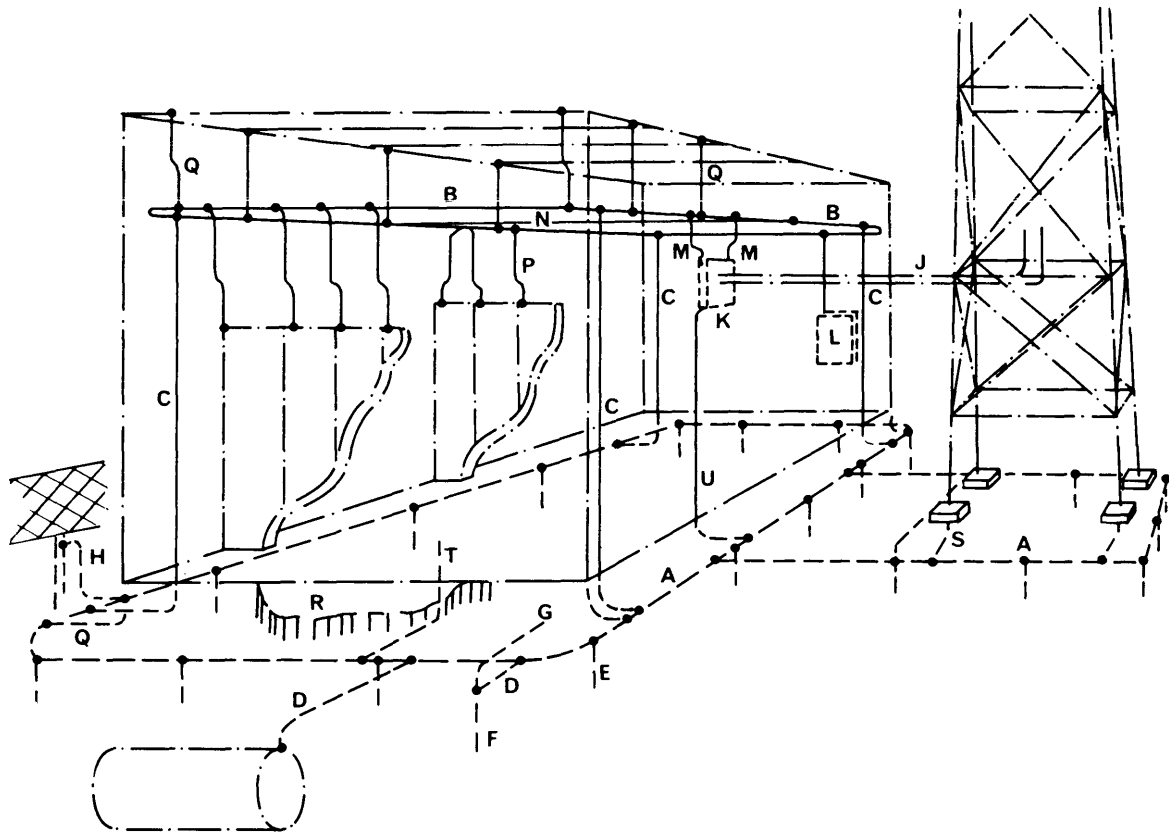


FIGURE 6 — *Radio station ring ground system and principal ground bonds*

A: buried exterior ring bus	L: wall mounted cabinet
B: interior ring bus	M: hatch bond
C: inter-bus bonds	N: supplementary bus
D: bond to buried metallic objects	P: equipment bond
E: ground rod	Q: building steel bond
F: power system ground electrode	R: grade level
G: power system neutral bond	S: tower base bond
H: bond to fence within 2 m	T: bond to metallic object on building exterior
J: waveguide	U: waveguide hatch primary bond
K: waveguide hatch (entry port)	

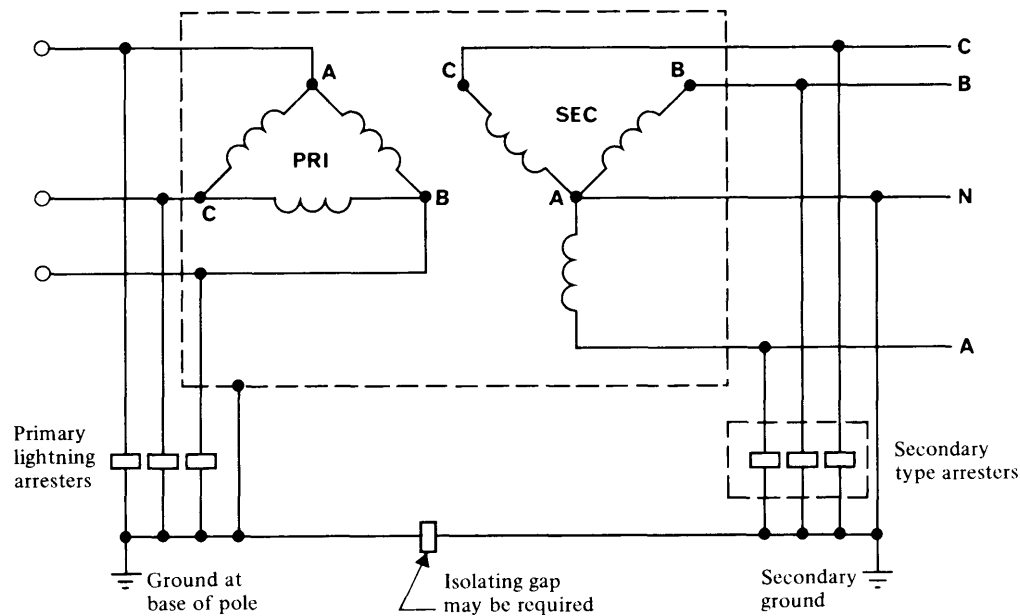


FIGURE 7 — Installation of lightning arresters on power lines

TABLE 1 — Lightning protection system corresponding to risk assessment

Risk assessment	Standard grounding method	Connection point at high voltage arresters		Common items
A (Great)	1. Connect grounding rods with buried ground ring 2. Grounding rod metal type 14 mm (diameter) × 1500 mm 3. Number of rods: 50 4. Space: about 3 m 5. Ground ring 38 mm ² bare copper standard wire	Incoming pole	10 kA	1. Install circular grounding bus in power and repeater room 2. Connect the ground terminal of each power equipment with the grounding bus, using 14 mm ² wire 3. Connect switch board frame with 14 mm ² wire 4. Attach Zn0 varistor to transistor type voltage relay 5. Connect low voltage arresters to all power equipment
B (Medium)		Power source receiving board	10 kA	
		Incoming pole	2.5 kA	
		Power source receiving board	10 kA	
C (Small)		Incoming pole	2.5 kA	
	Power source receiving board	2.5 kA		

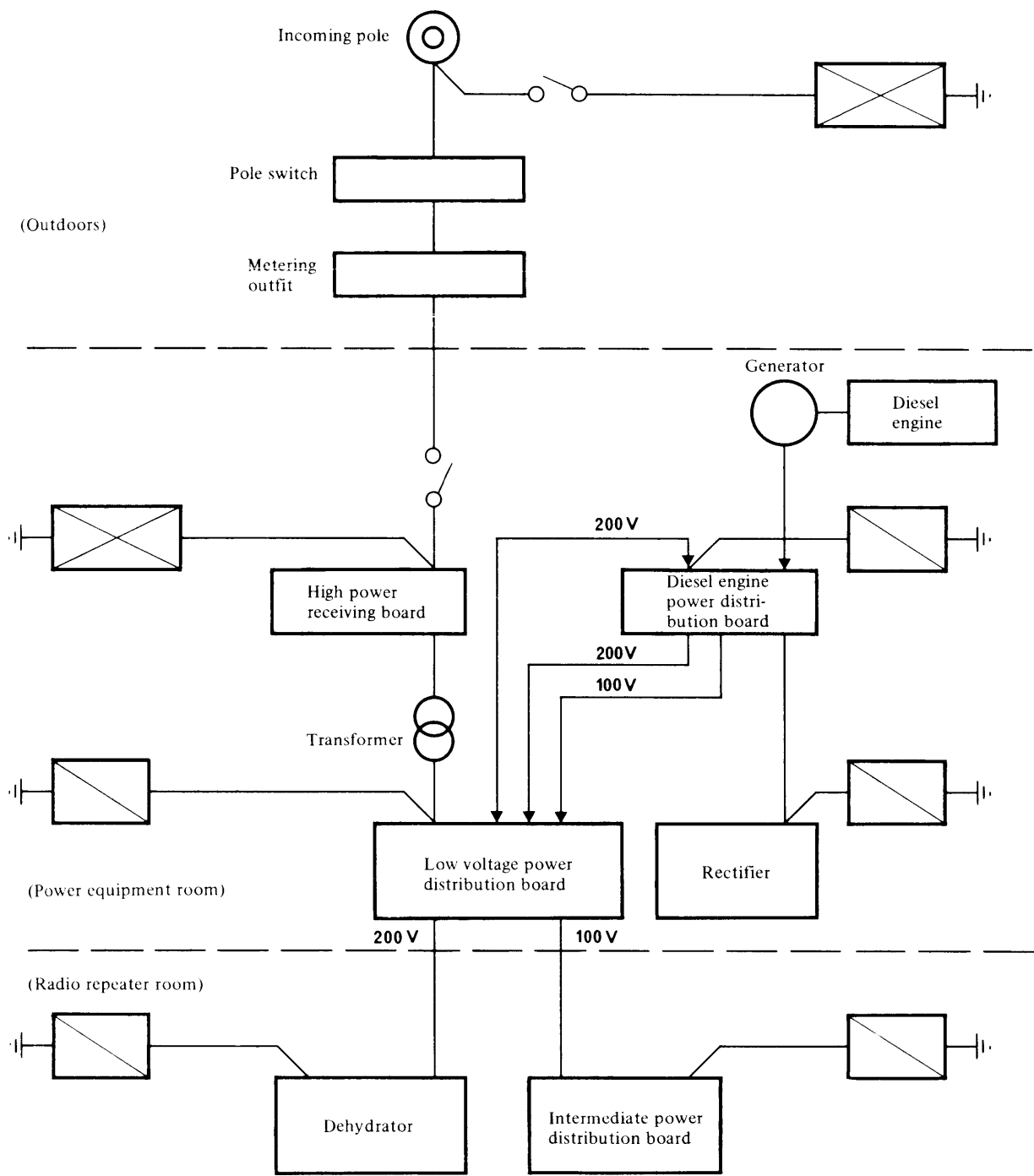
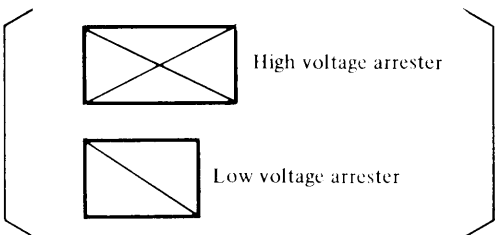


FIGURE 8 — An example of arrester connection for power line and equipment at a radio-relay station



PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

SECTION 9B: RADIO-FREQUENCY CHANNEL ARRANGEMENTS AND SPECTRUM UTILIZATION

Recommendations and Reports

RECOMMENDATION 283-4 *

**RADIO-FREQUENCY CHANNEL ARRANGEMENT FOR ANALOGUE RADIO-RELAY SYSTEMS
WITH A CAPACITY OF 60, 120, 300 AND UP TO 960 ** TELEPHONE CHANNELS
OR LOW AND MEDIUM CAPACITY DIGITAL SYSTEMS OF EQUIVALENT RF
BANDWIDTH OPERATING IN THE 2 GHz BAND**

(Questions 1/9 and 12/9)

(1959-1966-1970-1978-1982)

The CCIR,

CONSIDERING

- (a) that it is sometimes desirable to be able to interconnect radio-relay systems of 60, 120, 300 and up to 960 ** telephone channel capacity, or low and medium capacity digital systems of equivalent bandwidth, on international circuits using radio frequencies in the 2 GHz band;
- (b) that, in a frequency band 200 MHz wide, it may be desirable to interconnect up to six go and six return radio-frequency channels;
- (c) that economy may be achieved, if at least three go and three return channels can be interconnected between systems each of which uses a common transmit-receive antenna;
- (d) that for systems up to 300 telephony channels many interfering effects can be substantially reduced by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;
- (e) that for systems up to 300 telephony channels it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;
- (f) that it is desirable for the values of the mid-frequencies of the radio-frequency channels to be the same for 60, 120, 300 and up to 960 channel telephony systems, as well as for digital systems;
- (g) that the spacing between the mid-frequencies of the radio-frequency channels should be such that the systems can work with the maximum frequency deviation given in Recommendation 404 for systems up to 600 telephone channels, while for 960 telephone channel systems a lower frequency deviation should be used in order to improve the spectrum utilization,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to six go and six return channels, each accommodating 60, 120, 300 or a maximum of 960 ** telephone channels or digital systems of equivalent RF bandwidth, and operating within the frequency bands listed under § 6, should be as shown in Fig. 1, which is derived as follows:

Let f_0 be the frequency of the centre of a 200 MHz band of frequencies occupied (MHz);

f_n be the centre frequency of one radio-frequency channel in the lower half of this band (MHz);

f'_n be the centre frequency of one radio-frequency channel in the upper half of this band (MHz);

then the frequencies in MHz of individual channels are expressed by the following relationships:

lower half of band: $f_n = f_0 - 108.5 + 14 n$,

upper half of band: $f'_n = f_0 + 10.5 + 14 n$,

where

$n = 1, 2, 3, 4, 5$ or 6 ;

2. that, in a section over which the international connection is arranged, all the go channels should be in one half of the band, and all the return channels should be in the other half of the band;

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

** The provision of this Recommendation for 960 channels applies only in the frequency band 2500 to 2700 MHz.

3. that for adjacent radio-frequency channels in the same half of the band, different polarizations should preferably be used alternately; *
4. that, when common transmit-receive antennas are used and three radio-frequency channels are accommodated on a single antenna, it is preferable that the channel frequencies be selected by either making $n = 1, 3$ and 5 in both halves of the band or making $n = 2, 4$ and 6 in both halves of the band;
5. that, when additional radio-frequency channels, interleaved between those of the main patterns, are required, the values of the centre frequencies of these radio-frequency channels should be 7 MHz above those of the corresponding main channel frequencies; **
6. that the centre frequencies should preferably be those shown below:

$f_0 = 1808$ MHz for the band 1700 to 1900 MHz;
 $f_0 = 2000$ MHz for the band 1900 to 2100 MHz;
 $f_0 = 2203$ MHz for the band 2100 to 2300 MHz (see Note 3);
 $f_0 = 2586$ MHz for the band 2500 to 2700 MHz ***.

Other centre frequencies may be used by agreement between the administrations concerned.

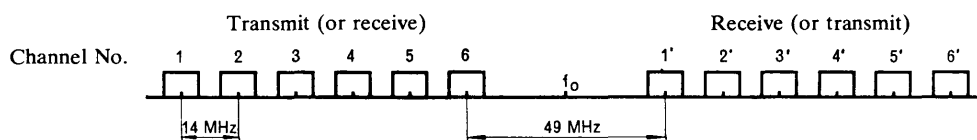


FIGURE 1 – Radio-frequency channel arrangement for international connection of radio-relay systems operating in the 2 GHz band

Note 1. – When the frequency band 1900 to 2300 MHz or 1700 to 2100 MHz is used for large capacity radio-relay systems and a 60 , a 120 or a 300 channel system is used on the same route, the possibility of introducing mutual interference is greatly reduced if separate antennas are used for the two systems.

Note 2. – In systems for up to 300 telephony channels, operational difficulties may be experienced along a route, due to over-reach and similar problems. In such cases, additional frequencies, spaced 3.5 MHz from the allocations given above, are available for use as stagger frequencies.

Note 3. – In certain countries, particularly in Region 2, it may be preferable to have the frequencies in MHz of individual channels as expressed by the following relationships:

$$\begin{aligned}
 \text{lower half of band: } f_n &= f_0 - 94.5 + 14n, \\
 \text{upper half of band: } f'_n &= f_0 - 3.5 + 14n,
 \end{aligned}$$

where

$$n = 1, 2, 3, 4, 5 \text{ or } 6.$$

Interleaved channels should be 7 MHz below those of the corresponding main channels.

* The same polarization for adjacent channels can also be used for low capacity digital systems.

** In systems for 960 telephone channels in the band 2500 to 2700 MHz, or digital systems of equivalent RF bandwidth, it may not be practicable to use interleaved frequencies, because of the wide bandwidth occupied by the modulated carrier.

*** Attention is drawn to the fact that the lowest main channel frequency is below 2500 MHz and that in accordance with Article 8 of the Radio Regulations, all emissions are prohibited in the band 2690 - 2700 MHz except in the countries mentioned in Nos. 767 and 769 and for equipment in operation by 1 January 1985 .

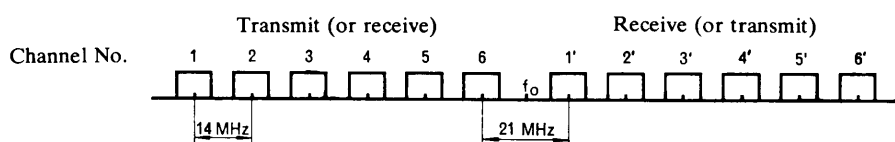


FIGURE 2 – Radio-frequency channel arrangement referred to in Note 3

Note 4. — When using a 960 * telephone channel system, in accordance with this Recommendation, the following preferred values should be used:

- r.m.s. deviation per channel: 140 kHz,
- frequency of continuity pilot: 4715 kHz,
- r.m.s. deviation for the continuity pilot: 100 kHz.

REPORT 933

**RADIO-FREQUENCY CHANNEL ARRANGEMENT FOR ANALOGUE
RADIO-RELAY SYSTEMS WITH A CAPACITY UP TO 300
TELEPHONE-TYPE CHANNELS OR DIGITAL SYSTEMS
OF EQUIVALENT RF BANDWIDTH OPERATING IN
THE 2.3 TO 2.5 GHz BAND ****

(Questions 1/9 and 12/9)

(1982)

1. Introduction

Radio-frequency channel arrangements for systems with a capacity of up to 300 FDM-FM telephone channels or digital systems of equivalent radio-frequency bandwidths operating in the bands 1.7 to 2.3, and 2.5 to 2.7 GHz are given in Recommendation 283.

This Report presents a radio-frequency channel arrangement in the radio-frequency band 2.3 to 2.5 GHz, a band which has been allocated by the WARC-79 to the fixed service. This radio-frequency band could be used for various applications such as trunk connections in rural areas, medium-capacity radio circuits etc.

2. Frequency-band utilization

Independent of its application, it has been found useful to have only one basic radio-frequency channel arrangement. This would allow the application of radio-relay systems of various capacities, within a certain area, minimizing the risk of mutual, harmful interference.

3. Frequency pattern

3.1 The radio-frequency channel arrangement for the above radio-relay systems is based on an adjacent-channel spacing of 1 MHz, and is derived as follows:

Let f_0 be the reference frequency (in MHz) of the frequency pattern;

f_n be the centre frequency (in MHz) of one radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (in MHz) of one radio-frequency channel in the upper half of the band;

then the centre frequencies of the individual channels can be expressed by the following relationships:

lower half of the band: $f_n = f_0 - 87 + n$,

upper half of the band: $f'_n = f_0 + 7 + n$,

where

$n = 1, 2, 3, \dots, 80$

* The provision of this Recommendation for 960 channels applies only in the frequency band 2500 to 2700 MHz.

** This radio-frequency channel arrangement applies only to line-of-sight and near line-of-sight radio-relay systems.

This is illustrated in Fig. 1.

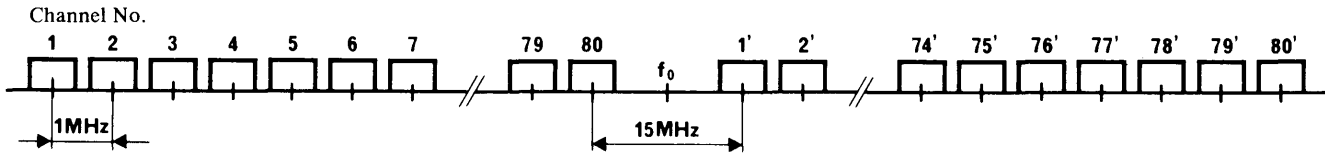


FIGURE 1 — Radio-frequency channel arrangement for up to 300 telephone channels radio-relay systems operating in the 2.3 to 2.5 GHz band

- 3.2 The reference frequency should preferably be $f_0 = 2394$ MHz.
- 3.3 In a section over which an international or rural connection is arranged, as well as in a network node, all the go channels should be in one half of the radio-frequency band, and all the return channels in the other half.
- 3.4 The preferred adjacent co-polar channel separations for various channel capacities are listed in Table I.

TABLE I

Channel capacity	RF channel separation (MHz)	$n =$
12 FDM	1	1, 2, 3, 4, ...
24 FDM	2	1, 3, 5, 7, ...
60 FDM	4	1, 5, 9, 13, ...
120 FDM	14	1, 15, 29, 43, ...
300 FDM	28	1, 29, 57
24 PCM	2	1, 3, 5, 7, ...
30 PCM	2	1, 3, 5, 7, ...
48 PCM	4	1, 5, 9, 13, ...
60 PCM	4	1, 5, 9, 13, ...

- 3.5 When, for example, either at a nodal point or within an artery (using cross-polar discrimination), and for capacities of 24 telephone channels or more, additional radio-frequency channels are required, the channel numbers should be as follows:
- 24 telephone channels $n = 2, 4, 6, 8, \dots (n \leq 80)$
- 60 telephone channels $n = 3, 7, 11, 15, \dots (n \leq 79)$
- 120 telephone channels $n = 8, 22, 36, 50, \dots (n \leq 78)$
- 300 telephone channels $n = 15, 43, 71$.

Note 1. — The band 2400 to 2500 MHz (centre frequency 2450 MHz) is designated for industrial, scientific and medical (ISM) applications. Radio services operating within this band must accept harmful interference which may be caused by these applications.

Note 2. — For capacities of 60 telephone channels or more, additional frequencies with channel number:

- $n = 2, 4, 6, 8$, etc. for 60 telephone channels
- $n = 5, 12, 19, 26$, etc. for 120 telephone channels
- $n = 8, 22, 36, 50$, etc. for 300 telephone channels

are available for use as offset frequencies. These frequencies may be of help to reduce interference along a route due to over-reach, or to reduce the requirements for the antenna discrimination in a network node.

Note 3. — Further studies are required to evaluate interference problems caused by intermodulation products between different systems working on the same route.

RECOMMENDATION 382-3 *

**RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR RADIO-RELAY SYSTEMS
FOR TELEVISION AND TELEPHONY FOR 600 TO 1800 TELEPHONE CHANNELS,
OR THE EQUIVALENT, OPERATING IN THE 2 AND 4 GHz BANDS
OR FOR MEDIUM-CAPACITY DIGITAL RADIO-RELAY SYSTEMS
OPERATING IN THE 4 GHz BAND**

(Questions 1/9 and 12/9)

(1956-1959-1963-1966-1970-1982)

The CCIR,

CONSIDERING

- (a) that it is sometimes desirable to be able to interconnect radio-relay systems on international circuits at radio frequencies in the 2 and 4 GHz bands;
- (b) that, in a frequency band 400 MHz wide, it may be desirable to interconnect up to six go and six return radio-frequency channels;
- (c) that economy may be achieved if at least three go and three return channels can be interconnected between systems each of which uses common transmit-receive antennas;
- (d) that many interfering effects can be substantially reduced by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;
- (e) that it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;
- (f) that the use of bit rates of 2×34 Mbit/s or 2×45 Mbit/s is possible in the 4 GHz band,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to six go and six return channels, each accommodating 600 to 1800 telephone channels, or the equivalent, and operating at frequencies in the 2 and 4 GHz bands, should be as shown in Fig. 3 and should be derived as follows:

Let f_0 be the frequency of the centre of the band of frequencies occupied (MHz);

f_n be the centre frequency of one radio-frequency channel in the lower half of the band (MHz);

f'_n be the centre frequency of one radio-frequency channel in the upper half of the band (MHz);

then the frequencies in MHz of individual channels are expressed by the following relationships:

lower half of band: $f_n = f_0 - 208 + 29 n$,

upper half of band: $f'_n = f_0 + 5 + 29 n$,

where

$n = 1, 2, 3, 4, 5$ or 6 ;

2. that in a section over which the international connection is arranged all the go channels should be in one half of the band, and all the return channels should be in the other half of the band;
3. that for adjacent radio-frequency channels in the same half of the band, different polarizations should preferably be used alternately; i.e. the odd numbered channels in both directions of transmission on a given section should use H(V) polarization, and the even numbered channels should use V(H) polarization, as shown in Fig. 1 below:

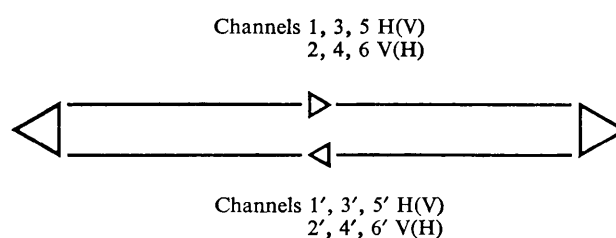


FIGURE 1

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

Note. — When antennas for double polarization are used, the arrangement of channels shown in Fig. 2 may be used by agreement between administrations:

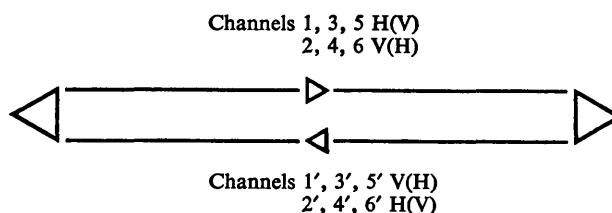


FIGURE 2

4. that, when common transmit-receive antennas are used, and not more than three radio-frequency channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by either making $n = 1, 3$ and 5 in both halves of the band or making $n = 2, 4$ and 6 in both halves of the band;

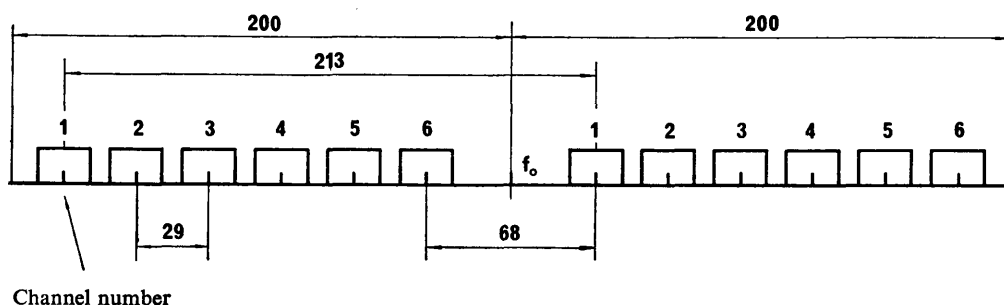


FIGURE 3

Radio-frequency channel arrangement for radio-relay systems with capacities from 600 to 1800 telephone channels, or the equivalent, operating in the 2 and 4 GHz bands, for use in international connections
(All frequencies are in MHz)

5. that when additional radio-frequency channels, interleaved between those of the main pattern, are required, the values of the centre frequencies of these radio-frequency channels should be 14.5 MHz below those of the corresponding main channel frequencies *;
6. that to minimize interference within a system, the centre frequency f_0 should preferably be as given below:
in the 2 GHz band, $f_0 = 1903$ or 2101 MHz (see Note 1);
in the 4 GHz band, $f_0 = 4003.5$ MHz.
Other centre frequencies may be used by agreement between the administrations concerned **;
7. that due regard be taken of the fact that in some countries, mostly in a large part of Region 2 and in certain other areas, another radio-frequency channel arrangement for 4 GHz systems is used. A description of this radio-frequency channel arrangement is given in Annex I. Attention is drawn to the problem of interconnection.

* In analogue radio-relay systems for 1800 telephone channels, or the equivalent, and in radio-relay systems with digital modulation using a bit rate of 2×34 Mbit/s or 2×45 Mbit/s, it may not be practicable to use interleaved frequencies, because of the wide bandwidth occupied by the modulated carrier.

** Interference due to certain harmonics of the shift frequency, which may fall near radio-frequency channel frequencies f_n (MHz) in radio-frequency repeaters, or may fall near $(f_n \pm 70)$ MHz in repeaters using an intermediate frequency of 70 MHz, may in certain cases be serious. Such interference may be reduced by choosing a suitable value for f_0 , such as those given in § 6.

8. that if a digital transmission at 2×34 Mbit/s or 2×45 Mbit/s is established in the existing 4 GHz arrangement, there exist modulation systems which ensure compatibility on the same artery between digital and analogue radio-frequency circuits with up to 1260 analogue telephone channels, provided that the analogue and digital radio-frequency circuits are cross-polarized.

Note 1. — In certain countries, particularly in Region 2, it may be preferable to use as centre frequency:

$f_0 = 1932$ MHz instead of 1903 MHz, and

$f_0 = 2086.5$ MHz instead of 2101 MHz.

Note 2. — In the U.S.S.R., a radio-frequency channel arrangement conforming to the scheme in Fig. 1 of Recommendation 497 is used in the frequency band 3700 to 4200 MHz and for systems with a capacity of 1800 telephone channels or the equivalent. The reference frequency f_0 is then 3947.5 MHz.

ANNEX I

DESCRIPTION OF THE RADIO-FREQUENCY CHANNEL ARRANGEMENT REFERRED TO IN § 7

1. The radio-frequency channel arrangement for a band 500 MHz wide and for up to six go and six return channels (Group 1) and an interleaved pattern of six go and six return channels (Group 2), each accommodating up to 1260 telephone channels, or the equivalent, operating in the 4 GHz band, is as shown in Fig. 4 and is derived as follows:

Let f_r be the frequency of the lower edge of the band of frequencies occupied (MHz);

f_n be the centre frequency of one radio-frequency channel in the go (return) channel of the band (MHz);

f'_n be the centre frequency of one radio-frequency channel in the return (go) channel of the band (MHz);

then the frequencies in MHz of individual channels are expressed by the following relationships:

Group 1

go (return) channel, $f_n = f_r - 50 + 80 n$,

return (go) channel, $f'_n = f_r - 10 + 80 n$,

where

$n = 1, 2, 3, 4, 5$ and 6 .

Group 2

go (return) channel, $f_n = f_r - 70 + 80 (n - 6)$,

return (go) channel, $f'_n = f_r - 30 + 80 (n - 6)$,

where

$n = 7, 8, 9, 10, 11$ and 12 .

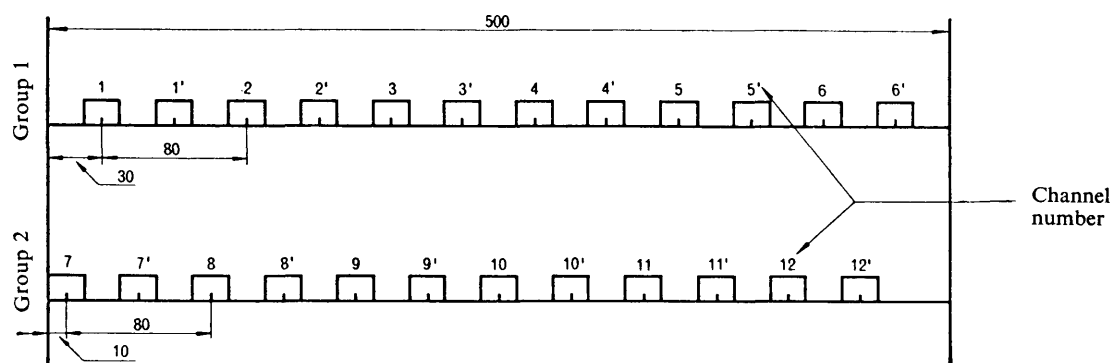


FIGURE 4

Radio-frequency channel arrangements described in the Annex I
(All frequencies are in MHz)

2. In a section over which international connections are arranged, the go and return channels are in the same group and are adjacent channels in that group.
3. In any section, both the go and return channels of any one group are of one polarization.
4. In any section, the channels of each group are of different polarizations.
5. In general, the value of f_r is 3700 MHz.

Note. — Subject to agreement between administrations concerned, 1800 telephone channels may be accommodated on each radio-frequency channel using either Group 1 or Group 2 frequencies.

REPORT 934

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR HIGH AND MEDIUM-HIGH CAPACITY DIGITAL RADIO-RELAY SYSTEMS OPERATING IN THE FREQUENCY BANDS BELOW ABOUT 10 GHz

(Study Programmes 12E/9 and 12F/9)

(1982)

1. Introduction

The purpose of this Report is to present the basic criteria for the determination of preferred RF channel arrangements for digital systems operating in the frequency bands below about 10 GHz. By taking into account the different hierarchical levels and the fact that the transmission capacity per radio channel should be equal to, or a multiple of, one of these hierarchical levels. This Report considers, as medium-high and high-capacity systems the gross bit rates of 2×34 Mbit/s (70 Mbit/s), 2×45 Mbit/s (90 Mbit/s), 140 Mbit/s, and 200 Mbit/s.

A related text is Report 782 dealing specifically with the 11 GHz band.

The use of frequency bands below about 12 GHz (Study Programme 12E/9) for digital radio-relays may be envisaged in two ways:

- either by the re-use of the channel arrangements recommended for analogue radio-relays, which enables analogue and digital systems to co-exist on the same artery and at nodal points and, in particular, is consistent with gradual digitization;
- or by the formulation of new channel arrangements specifically designed for digital transmission, sacrificing, if need be, compatibility with existing channel arrangements.

The first alternative has been followed in the 4 GHz band (see Recommendation 382) for systems with a bit rate of 2×34 and 2×45 Mbit/s and in the upper 6 GHz band (see Recommendation 384) for systems with a bit ratio of the order of 140 Mbit/s. Further examples of the use of frequency bands, as proposed by some administrations, are presented in Annexes I, II, III, IV and V.

2. System design considerations

The determination of channel arrangements is a complex subject which depends on the following interrelated factors:

- the digital modulation method;
- the parameters defining the RF channel disposition (X , Y , Z and S parameters as defined in Report 378);
- the behaviour of the propagation medium.

These factors are discussed in the sub-sections which follow. In addition, consideration is given to the problems of compatibility in situations where digital and analogue systems may need to co-exist; in particular the problems of compatibility with 1800, 2700 and 3600 channel FDM-FM systems.

2.1 *Modulation methods*

The main characteristics which determine the suitability of a modulation method for use in the frequency bands below 10 GHz are:

- tolerance to interference and distortions;
- the efficiency of use of the spectrum (see Report 662);
- the number of information bits per transmitted symbol.

Modulation methods are described in Report 378.

2.2 *Efficiency considerations*

The definitions of efficiency and compatibility need to be further investigated from the point of view of implementing digital systems in the bands below 10 GHz.

There can be various degrees of coexistence of analogue and digital transmission systems, depending on the present use of the frequency bands in the areas concerned. Administrations are asked to submit further contributions on this matter.

2.3 *Channel disposition*

The channel disposition is completely defined when the frequencies and the polarizations associated with each channel are given. Such values are expressed by the parameters X , Y and Z , which are normalized with respect to the symbol rate S .

The values of X , Y and Z depend on the modulation method adopted and on the degree of bandwidth reduction of which the equipment concerned is intended to be capable, and also on the complex balance that has to be struck by the system designer between the various interferences that can arise and other sources of system degradations.

The values of the normalized parameters are given in the Annexes for each frequency plan presented.

2.4 *Effects of anomalous propagation*

This topic is covered by Report 784. In this paragraph only the propagation effects which influence the planning of channel arrangements for digital systems are presented. Recent investigations have shown that systems employing high speed digital modulation are considerably more susceptible to propagation induced distortion than are existing analogue FM transmissions. Consequently, it may be concluded from the studies that the use of space diversity reception and/or adaptive equalization might be necessary on difficult paths.

Another effect of propagation is a reduction of cross-polarization decoupling (XPD). Such a reduction results in a degradation of the carrier-to-interference ratio and thus affects the performance of the digital system. It is important to consider the effects of XPD variations for both co-channel dual-polarized plans and interleaved plans. Good cross-polarization performance of antennas is essential. This discrimination is a conclusive factor in determining digital channel arrangements.

There is insufficient data available on decoupling in practical systems for it to be possible to be certain that the performance and availability objectives would be met for either type of plan on all paths. If decoupling turns out to be inadequate in some circumstances, various measures are available, including, for example, the following:

- use of antennas chosen and aligned for good on- and off-axis XPD;
- use of space diversity;
- use of adaptive cross-polar interference cancellation techniques;
- use of higher selectivity filters in interleaved channel arrangements.

The improvement obtained by the above techniques needs to be carefully investigated.

3. *Use of existing channel arrangements*

Many existing CCIR RF channel arrangements below 10 GHz make use of two typical cross-polarized adjacent channel spacings: 29 to 29.65 MHz and 40 MHz.

As it is summarized in Annex I, digital systems having bit rates of 2×34 or 2×45 Mbit/s can be applied to 29 to 29.65 MHz cross-polarized adjacent channel spacing. Digital systems having a capacity of 140 Mbit/s can be applied to 40 MHz cross-polarized adjacent channel spacing (e.g. Recommendation 384).

A bit rate of the order of 140 Mbit/s could also possibly be inserted in the future in a 29 to 29.65 MHz spacing, although this operation seems to be very difficult at the present moment.

A number of different modulation methods are suitable for this operation and allow a gradual introduction of digital systems into existing networks.

For example, 8-level PSK at 70 Mbit/s or 16-level QAM at 90 Mbit/s and 1800 channel FDM-FM systems can operate compatibly on the same route with adjacent channel spacing of 29 to 29.65 MHz with low and acceptable impairments on analogue systems as well as 16 QAM at 140 Mbit/s with adjacent channel spacing of 40 MHz [CCIR, 1978-82a].

Practical experience gained in the United States with 16 QAM-90 Mbit/s digital and 1800 voice circuit FDM-FM analogue systems using the 6 GHz radio-frequency channel arrangement of Recommendation 383 is presented in Annex V.

4. Use of new channel arrangements specifically designed for digital systems

Plans proposed by two administrations [CCIR, 1978-82b and c] for the 6 and 8 GHz bands are presented in Annexes II and III, respectively.

REFERENCES

CCIR Documents

[1978-82]: **a.** 9/109 (Italy); **b.** 9/26 (United Kingdom); **c.** 9/30 (Canada).

ANNEX I

USE OF CCIR CHANNEL ARRANGEMENTS FOR HIGH AND MEDIUM-HIGH CAPACITY DIGITAL SYSTEMS

For high order modulation methods (e.g. 8 and 16-level) good spectrum efficiency may be obtained with interleaved frequency plans. Only the existing CCIR RF channel arrangements are considered and some of the characteristics, when these arrangements are used for high capacity digital systems, are summarized in Tables I and II.

TABLE I

Modulation 8-level PSK 2×34 Mbit/s (70 Mbit/s)				
Frequency band (GHz)	1.9-2.3	3.8-4.2	5.925-6.425	7.725-8.275
Type of arrangement	Recommendation 382	Recommendation 382	Recommendation 383	Annex I to Recommendation 386
Number of channels	6	6	8	7
Guard band ZS (MHz) Z	20 0.87	17.5 0.76	20.2 0.88	22.7 0.99
Mid-band separation YS (MHz) Y	68 2.96	68 2.96	44.5 1.93	133.42 5.8
Cross-polarized channel spacing XS/2 (MHz) X	29 2.52	29 2.52	29.65 2.58	29.65 2.58
Efficiency of spectrum utilization (bits/Hz)	2.1	2.1	2.24	1.78

Note. — It is not intended to prevent the use of higher modulation methods, if technically and economically advantageous.

TABLE II

Modulation 16-level QAM 2 × 45 Mbit/s (90 Mbit/s)				
Frequency band (GHz)	1.9-2.3	3.8-4.2	5.925-6.425	7.725-8.275
Type of arrangement	Recommendation 382	Recommendation 382	Recommendation 383	Annex I to Recommendation 386
Number of channels	6	6	8	7
Guard band ZS (MHz) Z	20 0.89	17.5 0.78	20.2 0.9	22.7 1
Mid-band separation YS (MHz) Y	68 3.02	68 3.02	44.5 1.98	133.42 5.9
Cross-polarized channel spacing XS/2 (MHz) X	29 2.58	29 2.58	29.65 2.64	29.65 2.64
Efficiency of spectrum utilization (bits/Hz)	2.7	2.7	2.88	2.3

Note. — Other modulation methods (e.g. 8-level PSK) can also be used.

1. Analogue/digital compatibility

1.1 On the same route

8 PSK at 70 Mbit/s or 16 QAM at 90 Mbit/s and 1800 channel FDM-FM systems can operate compatibly with acceptable impairments over common routes using existing radio frequency plans with spacing of 29 to 29.65 MHz taking into account the possible shaping of digital spectrum and a difference in transmitted power between analogue and digital systems of the order of 4 to 5 dB. With 16-level QAM modulation, the spacing between a 2700 channel system and a 140 Mbit/s digital channel must not be less than 60 MHz, whereas taking into account a difference in transmitted power of the order of 3 dB between analogue and digital systems a 40 MHz spacing between a 1800 channel system and a 140 Mbit/s digital channel can be possible with very low impairments.

1.2 Systems converging at the same station

The same carrier frequencies can be used on two converging routes, one being analogue modulated and the other digital modulated. With orthogonally polarized emissions the protection between the two routes may be sufficient to allow relatively low convergence angles, but this benefit may be offset by the higher interference sensitivity of 16-level QAM compared with other types of modulation. These matters are further considered in Report 610.

ANNEX II

A RADIO-FREQUENCY CHANNELLING ARRANGEMENT FOR THE 6 GHz BAND

This Annex describes a radio-frequency channelling arrangement for the 6 GHz band which is based on the use of reduced bandwidth quaternary phase shift keying (RBQPSK) techniques [Chamberlain *et al.*, 1980]. In designing the plan, consideration has been given to the existing channelling plan of Recommendation 383 for analogue systems operating with up to 1800 telephony channels.

The proposed plan is shown in Fig. 1 and is based on a channel spacing of 60 MHz; other parameters are shown in Table III. It can be seen from Fig. 1 and Table III that both polarizations are used for transmission at each channel frequency. From theoretical and practical studies in the United Kingdom it seems possible that cross-polar operation is feasible for RBQPSK systems provided that adequate measures (such as the use of space diversity techniques) are used to minimize the effects of cross-polar decoupling on system performance.

The 60 MHz spacing of the plan of Fig. 1 is comparable with the 59.3 MHz co-polar channel spacing of the plan of Recommendation 383 and the channels of the new plan have been chosen to enable some degree of consistency between analogue and digital systems in the 6 GHz band to be achieved on the same route.

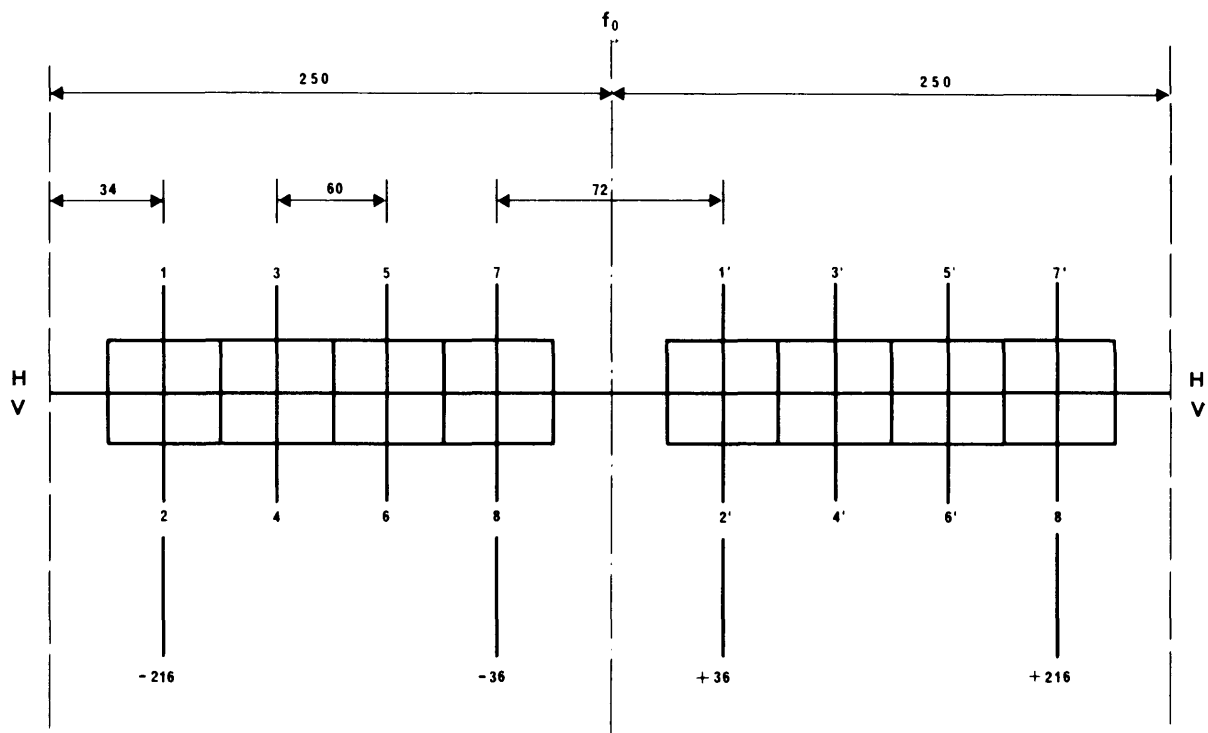


FIGURE 1 — Suggested radio-frequency channel arrangements for the lower 6 GHz bands

(All frequencies are in MHz)

f_0 : centre frequency (MHz) = 6175 MHz

H: horizontal polarization of emission

V: vertical polarization of emission

TABLE III — Parameters of proposed channelling arrangement

Modulation	RBQPSK 140 Mbit/s
Number of channels	8
Guard band ZS (MHz) Z	34 0.49
Mid-band separation YS (MHz) Y	72 1.02
Cross-polarized channel spacing XS (MHz) X	60 0.86
Efficiency of spectrum utilization (bits/Hz)	4.5

REFERENCE

CHAMBERLAIN, J. K., CLAYTON, F. M. and COLLINS, P. V. [4 March, 1980] Reduced bandwidth quaternary phase-shift-keying (RBQPSK) — an evolutionary approach to bandwidth efficient digital microwave transmission. Proc. IEEE International Zurich Seminar on Digital Communications, Switzerland, A3.1-A3.6.

ANNEX III

A RADIO-FREQUENCY CHANNELLING ARRANGEMENT FOR THE 8 GHz BAND

This Annex describes a radio-frequency channelling arrangement for the 8 GHz band. The arrangement provides for up to 6 go and 6 return channels each accommodating about 90 Mbit/s.

1. The radio-frequency channel arrangement is as shown in Fig. 2 of this Annex and is derived as follows:
Let f_0 be the frequency at the centre of the band:

$$f_0 = 8000 \text{ MHz}$$

f_n is the centre frequency of one radio-frequency channel in the lower half of the band (MHz);

f'_n is the centre frequency of one radio-frequency channel in the upper half of the band (MHz);

then the frequencies in MHz of the individual channels are expressed by the following relationships:

lower half of the band: $f_n = f_0 - 295.37 + 40.74 n$,

upper half of the band: $f'_n = f_0 + 10.19 + 40.74 n$,

where

$n = 1, 2, 3, 4, 5, 6$.

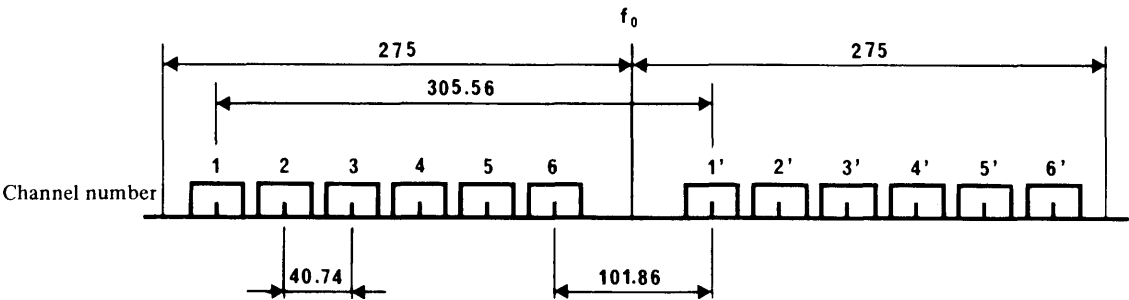


FIGURE 2 — Radio-frequency channel arrangement, described in Annex III

(All frequencies are in MHz)

2. All the go channels should be in one half of the band and all the return channels should be in the other half of the band.
3. For growth to 6 go and 6 return channels orthogonal polarizations may be used alternately for adjacent radio-frequency channels in the same half of the band.

ANNEX IV

A RADIO-FREQUENCY CHANNELLING ARRANGEMENT FOR THE 4 GHz BAND

This Annex describes, as an example, a radio-frequency channel arrangement in the frequency band 3600 to 4200 MHz for 16-QAM 200 Mbit/s high capacity digital radio systems developed in Japan.

The radio-frequency channel arrangement is shown in Fig. 3, where X , Y and Z are 1.6, 1.2 and 0.6 respectively. The feasibility of a 200 Mbit/s 16-QAM system using this channel arrangement has been confirmed in a field experiment [Murase *et al.*, 1981]. In order to attain the high channel spectrum utilization efficiency of 5 bit/s/Hz and to co-exist with existing FDM-FM systems an "out-of-phase" combiner [Komaki *et al.*, 1980], an adaptive equalizer [Murase *et al.*, 1981] and separate antennas for transmission and reception, with good cross-polarization characteristics, were used in the experimental equipment.

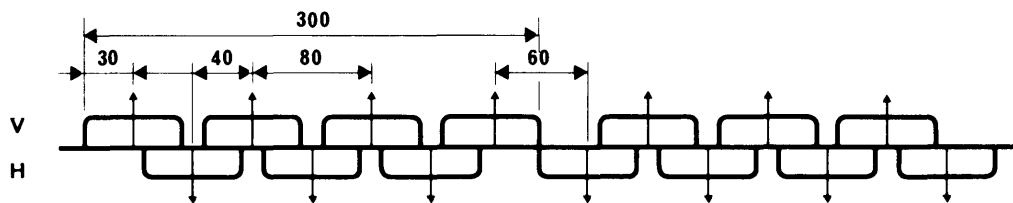


FIGURE 3 — 200 Mbit/s 16-QAM digital radio system channel arrangement

(All frequencies are in MHz)

REFERENCES

- KOMAKI, S., OKAMOTO, Y. and TAJIMA, K. [11 June, 1980] Performance of 16-QAM digital radio system using new space diversity. IEEE International Conference on Communications (ICC '80), Seattle, Wa., USA, Conf. Record, Vol. 3, Session 52: Digital radio buffet, 52.2.1-52.2.6.
- MURASE, T., MORITA, K. and KOMAKI, S. [17 June, 1981] 200 Mbit/s 16-QAM digital radio system with new countermeasure techniques for multipath fading. IEEE International Conference on Communications (ICC '81), Denver, Col., USA, Conf. Record, Vol. 3, Session 46: Advanced technology for digital radio on multipath fading, 46.1.1-46.1.5.

ANNEX V

COMPATIBILITY BETWEEN ANALOGUE AND DIGITAL HIGH CAPACITY SYSTEMS IN THE 6 GHz BAND

Practical experience gained in the United States with 16-QAM 90 Mbit/s digital and 1800 voice circuit FDM-FM analogue systems using the existing CCIR RF channel arrangement in the 5.925 to 6.425 GHz band has confirmed the practicality of coexistence on the same route and permitted the better definition of the criteria for compatible operation [Kenny, 1980]. Figure 4 shows the spectra and pertinent data for the two systems, and Table IV lists the critical co-channel and adjacent channel interference characteristics. The following comments and data are helpful in establishing compatibility criteria for similar applications.

Figure 4 also shows the limiting requirement for the emitted digital spectrum that has been imposed in the United States by the Federal Communications Commission (FCC). If Nyquist filtering is divided approximately equally between transmitter and receiver, as was the case in the 16-QAM system of Fig. 4, then digital spectra that fall below this "FCC mask" will allow trouble-free adjacent channel operation of similar digital systems. If adjacent operation of digital and analogue channels is desired, the requirements for the digital spectrum normally have to be tightened.

The FCC also requires that no discrete spectral components be emitted by the radio transmitter resulting from repetitive patterns in the bit stream. This is greatly helped by scrambling of the bit stream except that certain tones due to carrier leak ($f_c = 70$ MHz), harmonics of the clock signal ($f_s = 22.63$ MHz), and tones at $f_c \pm f_s$ have to be controlled by separate means. Some of these tones (see Fig. 4) could cause serious interference into co-channel and adjacent channel analogue systems.

This means that tones within the 29.65 MHz digital channel bandwidth should be kept below the power level of the continuous digital spectrum, as measured in a 4 kHz bandwidth. Tones outside the channel bandwidth have to be at least 76 dB below the total digital power or conform to the FCC mask in Fig. 4 for acceptable interference into the adjacent 1800 FM system.

System characteristics	16 QAM	1800 FM
Capacity	90 Mbit/s	1800 circuits
Transmitter power	1.0 W	10.0 W
Noise figure	4 dB	9 dB
Flat fade margin	40 dB	40 dB
At BER	10^{-6}	
At 9 MHz noise		316 000 pW0p
r.m.s per channel deviation		117.9 kHz

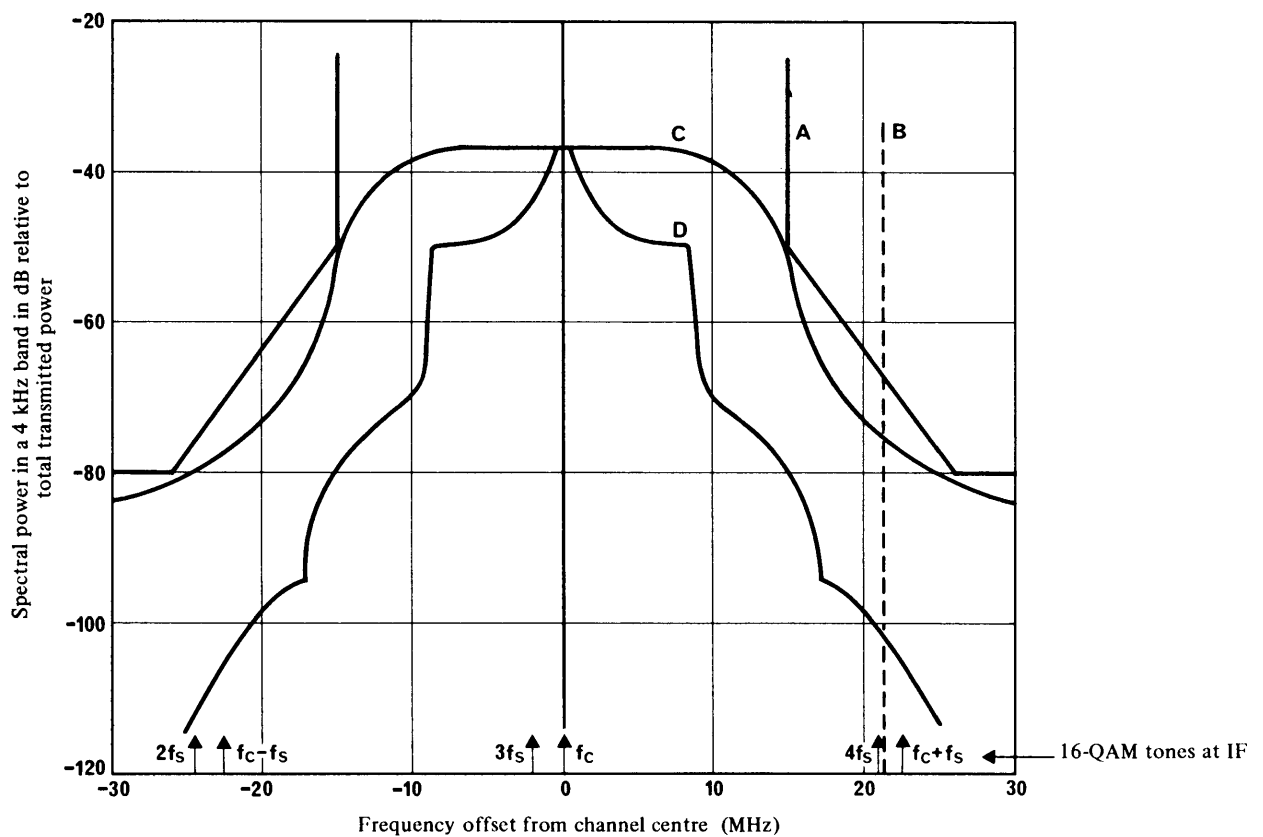


FIGURE 4 — Spectra of 16-QAM and 1800 FM systems operating jointly in the 6 GHz band (Recommendation 385)

- A: FCC digital emission limitation, §21.106
- B: top baseband circuit of adjacent 1800 FM channel
- C: 16 QAM
- D: 1800 FM

Table IV lists only the critical elements in the interference matrix. Interference cases not shown can be assumed to be negligible. Co-channel and adjacent channel interferences affect digital radio only during periods of fading, and it has been an unofficial objective to keep this effect limited to a 1.0 dB reduction in flat fade margin. The most important exposure here is the co-channel interference from the 10 W 1800 FM system into the 1 W 16-QAM system. Because of the 10 dB power difference, an isolation of 77 dB $C/I + 10$ is generally required to keep the reduction of flat fade margin limited to 1.0 dB. Since "net" fade margins (see Report 784) of high capacity digital radio systems are only around 30 dB, not too much harm is done with this degradation in flat (40 dB) fade margin.

TABLE IV — Matrix of critical interference in a 6 GHz arrangement (Recommendation 383) using 16-QAM and 1800 FM systems

		Interfering system			
		Co-channel		Adjacent channel	
		1800 FM	16 QAM	1800 FM	16 QAM
Interfered-with system	1800 FM (unfaded)	$N_i = 1.25$ for $C/I = 69$	$N_i = 2.2$ for $C/I = 79$	$N_i = 0.13$ for $XPD = 30$	$P_i = 27$ $N_i = 0.6$ for $XPD = 30$
	16 QAM (flat-faded)	$\delta_m = 1.0$ for $C/I = 67$	$\delta_m = 1.0$ for $C/I = 67$		$\delta_m = 0.66$ for $XPD = 0$ $D_f = 32$

P_i : transmitter power (dBm)
 N_i : worst interference power (pW0p)
 C/I : carrier-to-interference ratio (dB)
 XPD : cross-polarization discrimination (dB)
 δ_m : degradation in flat fade margin (dB)
 D_f : filter discrimination (dB), 16 QAM into 16 QAM

Co-channel and adjacent channel interferences into analogue FM systems is mostly a consideration during non-fading periods and objectives of 2.5 pW0p are being used for each type of interference.

Finally, tertiary interference in analogue FM systems is an important source of degradation not shown in Table IV. It is assumed that when the 16-QAM system is operated adjacent (a 29.65 MHz separation) to an analogue FM system, its contribution to tertiary interference should not exceed the levels caused by an 1800 channel FM system. This requires that the power of the 16-QAM transmitter be reduced to 0.5 W whenever the digital system operates adjacent to an 1800 channel FM system.

REFERENCE

KENNY, J. J. [2 December, 1980] Impact of interference on 16 QAM system requirements. IEEE National Telecommunications Conference (NTC '80), Houston, Texas, USA, Conf. Record, Vol. 2, Session 43: A montage of radio communication topics, 43.4-43.6.

REPORT 935

**FREQUENCY CHANNEL ARRANGEMENTS BASED ON A HOMOGENEOUS
PATTERN FOR DIGITAL RADIO-RELAY SYSTEMS WITH A CAPACITY
OF UP TO 200 Mbit/s IN THE 4 GHz BAND ***

(Study Programme 12E/9)

(1982)

1. Introduction

This Report is concerned with a basic channel arrangement for digital radio-relay systems in the 4 GHz band with a capacity of up to 200 Mbit/s.

Consideration is given to the fact that the upper limit of the frequency band assigned to the fixed service is uniform 4200 MHz throughout the world according to the Radio Regulations whilst the lower band limits are non-uniform and vary internationally from 3400 to 3800 MHz. This presents a difficulty from a standardization point of view. For future optimum digital application it is recognized that the recommended pattern in Recommendation 382 is not suitable for extension into lower band limits.

For these reasons a homogeneous frequency pattern is proposed to be the uniform basis for individual channel arrangements for the application of digital systems. These arrangements can be chosen by selecting wanted channel frequency positions from the basic pattern.

2. Characteristics of a frequency channel arrangement selected from a homogeneous pattern

In the frequency channel arrangement for digital radio-relay systems selected from a homogeneous pattern the centre gap will be an integral multiple of the spacing of the basic pattern so that in the case of different limits of the allocated frequency band it is possible to move the centre gap. The desired centre gap can be chosen by non-occupancy of a suitable number of RF channel positions.

The channel spacing for high-capacity digital radio-relay systems depends on many factors, such as bit rate, modulation method, filtering, polarization discrimination, propagation effects. Consideration of the above factors leads to specific solutions.

As far as the value of the basic spacing is concerned a 20 MHz pattern will fulfil the following different requirements for high-capacity digital systems in the 4 GHz range:

(a) An interleaved plan based on:

- a 40 MHz spacing, to be used cross-polarized, and
- a 80 MHz spacing, to be used co-polarized.

(b) A co-channel plan based on:

- a 0 MHz spacing, to be used cross-polarized, and
- a 60 MHz spacing, to be used co-polarized.

Besides the fact that the 20 MHz pattern may serve as a compromise for 40/80 and 0/60 MHz plans, as mentioned above, the 20 MHz spacing is regarded as the smallest practicable subdivision for high capacity systems from a standardization point of view. In comparison with larger spacings however the 20 MHz spacing allows an appropriate and economic choice of centre gaps and guard frequency bands at the edges of the available 4 GHz band. An example which conforms to a 20 MHz pattern is shown in Annex IV of Report 934. With this arrangement, 5 bit/s/Hz spectrum utilization efficiency and a high capacity of 200 Mbit/s can be achieved using 16-QAM modulation and adequate counter measures for fading.

3. Conclusion

In order to achieve an optimum utilization of the 4 GHz band, a homogeneous pattern is proposed with the following characteristics:

Centre frequency of one radio frequency channel

$$f_n = f_h - 20 m \quad \text{MHz}$$

where:

m : integral number depending on available frequency band,

f_h : the highest frequency of the homogeneous pattern.

* General principles for RF channel arrangements for digital systems below about 10 GHz are given in Report 934.

It is necessary to determine a value for f_h .

Centre gap: internal multiple of the 20 MHz spacing within the homogeneous pattern.

Although this proposal is based on consideration of existing modulation methods and filtering techniques, further study of the proposal, and in particular the preferred value of f_h , is necessary before a Recommendation can be established.

A proposed Recommendation is shown in Annex I of this Report.

BIBLIOGRAPHY

CCIR Documents

[1978-82]: 9/53 (Germany (Federal Republic of)).

ANNEX I

(PROPOSED RECOMMENDATION)

DIGITAL RADIO-RELAY SYSTEMS

FREQUENCY CHANNEL ARRANGEMENTS BASED ON A HOMOGENEOUS PATTERN FOR DIGITAL RADIO-RELAY SYSTEMS WITH A CAPACITY OF THE ORDER OF 140 Mbit/s, OPERATING IN THE 4 GHz BAND

(Question 12/9 and Study Programme 12E/9)

The CCIR,

CONSIDERING

- (a) that high-capacity digital radio-relay systems of the order of 140 Mbit/s are required in the 4 GHz radio-frequency bands;
- (b) that the lower band limits of the 4 GHz radio-frequency bands are not uniform and vary internationally from 3400 to 3800 MHz;
- (c) that efficient use of bands of different width can be achieved by radio-frequency channel arrangements matched to the width of the band available;
- (d) that a high degree of compatibility between RF channels of different arrangements can be achieved by selecting all channel centre frequencies from a uniform basic pattern;
- (e) that the centre gaps of the individual channel arrangements and the guard spacing at the edges of the band can be chosen by non-occupancy of a suitable number of RF-channel positions in a homogeneous basic pattern;
- (f) that the uniform basic pattern spacing should not be unjustifiably small (i.e. the number of RF-channel positions too high) from a standardization point of view;
- (g) that the absolute frequencies of the basic pattern should be defined by a single reference frequency,

RECOMMENDS

1. that the preferred radio-frequency channel arrangement for high-capacity digital radio-relay systems in the order of 140 Mbit/s, operating in the 4 GHz band, should be selected from a homogeneous pattern with the following characteristics:

Centre frequencies f_n of the radio-frequency channels within the basic pattern

$$f_n = f_r - m \cdot 20 \quad \text{MHz} \quad (1)$$

m : integral number depending on available frequency band; 0, 1, 2, 3 ...

f_r : reference frequency of the basic pattern.

2. that for international connections the reference frequency should preferably be $f_r = 4170$ MHz (see Note);

3. that all the go channels should be in one half of the band and all the return channels should be in the other half of the band;
4. that the channel spacing XS , the centre gap YS , the guard spaces Z_1S and Z_2S at the edges of the band and the antenna polarization should be agreed between the administrations concerned;
5. that one of the two principal channel arrangement plans shown in Fig. 1 should be used.

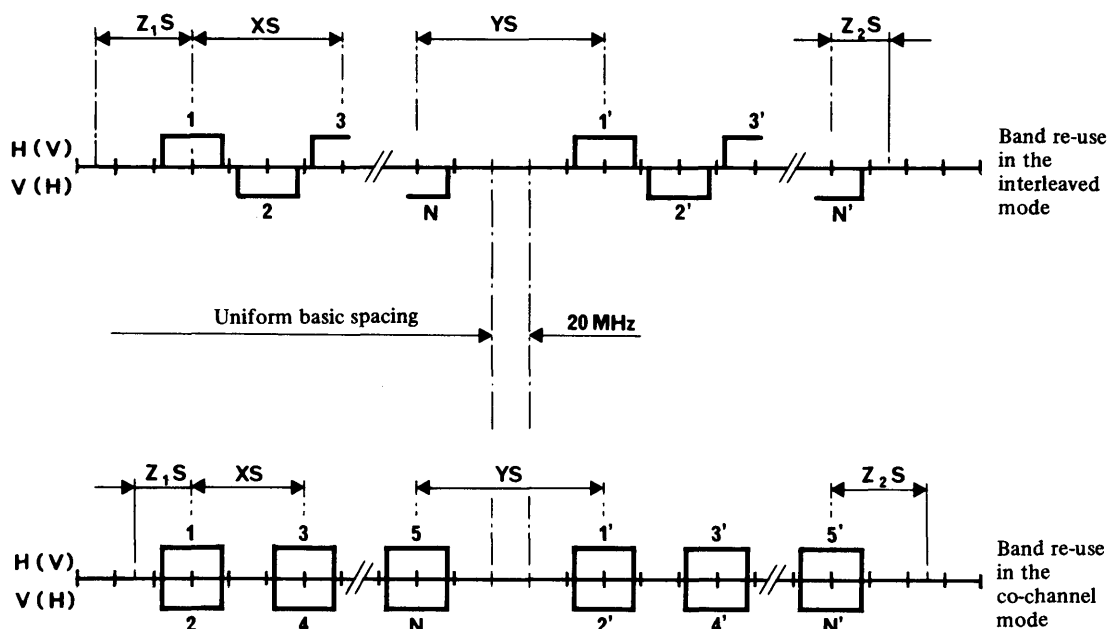


FIGURE 1 — The two principal channel arrangements based on § 1 to 3

(For definitions see Report 378)

Note. — The reference frequency is the highest frequency of the homogeneous basic pattern, which is sufficiently apart from the uniformly allocated upper band limit 4200 MHz of the considered 4 GHz band.

RECOMMENDATION 383-2 *

RADIO-FREQUENCY CHANNEL ARRANGEMENTS, FOR SYSTEMS HAVING A CAPACITY OF 1800 TELEPHONE CHANNELS, OR THE EQUIVALENT, OPERATING IN THE 6 GHz BAND

(Question 1/9)

(1959–1963–1966–1982)

The CCIR,

CONSIDERING

- (a) that it is sometimes desirable to be able to interconnect radio-relay systems on international circuits in the 6 GHz band at radio frequencies;
- (b) that, in a frequency band 500 MHz wide, it may be desirable to interconnect up to eight go and eight return channels;
- (c) that economy may be achieved if at least four go and four return channels can be interconnected between systems, each of which uses common transmit-receive antennas;

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

- (d) that many interfering effects can be substantially reduced by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;
- (e) that it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;
- (f) that there may be a desire to interconnect more than eight go and eight return radio-frequency channels, each with a capacity significantly lower than 1800 telephone channels,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to eight go and eight return channels, each accommodating 1800 telephone channels, or the equivalent, and operating at frequencies in the 6 GHz band, should be as shown in Fig. 1 and should be derived as follows:

Let f_0 be the frequency (MHz) of the centre of the band of frequencies occupied;

f_n be the centre frequency (MHz) of one radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (MHz) of one radio-frequency channel in the upper half of the band;

then the frequencies (MHz) of individual channels are expressed by the following relationships:

lower half of the band: $f_n = f_0 - 259.45 + 29.65 n$,

upper half of the band: $f'_n = f_0 - 7.41 + 29.65 n$,

where

$n = 1, 2, 3, 4, 5, 6, 7$ or 8 ;

2. that, in a section over which the international connection is arranged, all the go channels should be in one half of the band, and all the return channels should be in the other half of the band;
3. that the go and return channels on a given section should preferably use polarizations as shown below:

	<i>Go</i>				<i>Return</i>				
H(V)	1	3	5	7		2'	4'	6'	8'
V(H)		2	4	6	8	1'	3'	5'	7'

The following alternative arrangement of polarization may be used by agreement between the administrations concerned:

	<i>Go</i>				<i>Return</i>				
H(V)	1	3	5	7	1'	3'	5'	7'	
V(H)		2	4	6	8	2'	4'	6'	8'

4. that, when common transmit-receive antennas for double polarization are used and not more than four channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by either making $n = 1, 3, 5$ and 7 in both halves of the band or making $n = 2, 4, 6$ and 8 in both halves of the band (see Note 2);
5. that, when additional radio-frequency channels, interleaved between those of the main pattern, are required, the values of the centre frequencies of these radio-frequency channels should be 14.825 MHz below those of the corresponding main channel frequencies; in systems for 1800 channels, or the equivalent, it may not be practical, because of the bandwidth of the modulated carrier, to use interleaved frequencies;
6. that up to 16 go and 16 return radio-frequency channels, each with a capacity of up to 600 telephone channels, may be obtained on the same route if the additional radio-frequency channels are used simultaneously, with those of the main pattern. Different polarizations should be used alternately for adjacent radio-frequency channels in the same half of the band (see Note 3);
7. that the preferred centre frequency is 6175.0 MHz; other centre frequencies may be used by agreement between the administrations concerned.

Note 1. — The radio-frequency arrangement shown in Fig. 1 is suitable for use with the preferred intermediate frequency of 70 MHz (see Recommendation 403). It is also suitable for use with an intermediate frequency of 74.13 MHz, which enables a common oscillator (14.82 MHz) to be used for generating all the local oscillations for the system, if desired.

Note 2. — When common transmit-receive antennas are used and not more than four channels are accommodated on a single antenna, channel frequencies may be selected, by agreement between administrations, by making $n = 1, 3, 5$ and 7 in the lower half of the band, and $n = 2, 4, 6$ and 8 in the upper half of the band. If a second

similar antenna is used for four further channels, the channel frequencies may be selected by making $n = 2, 4, 6$ and 8 in the lower half of the band and $n = 1, 3, 5$ and 7 in the upper half of the band, but if only three further channels are required, the channel frequencies may be selected by making $n = 2, 4$ and 6 in the lower half of the band and $n = 3, 5$ and 7 in the upper half of the band to avoid the difficulty of separating frequencies 8 and $1'$.

Note 3. — The primary purpose of this Recommendation is to facilitate the international interconnection of high-capacity radio-relay systems. It should therefore be noted, that the use of both the main and interleaved arrangements of radio frequencies on a route would limit the provision of systems with a capacity of 1800 telephone channels, or the equivalent, on that route.

Note 4. — In the U.S.S.R., a radio-frequency channel arrangement conforming to the scheme in Fig. 1 of Recommendation 497 is used in the frequency band 5925 to 6425 MHz and for systems with a capacity of 1800 telephone channels, or the equivalent. The reference frequency f_0 is then 6172 MHz.

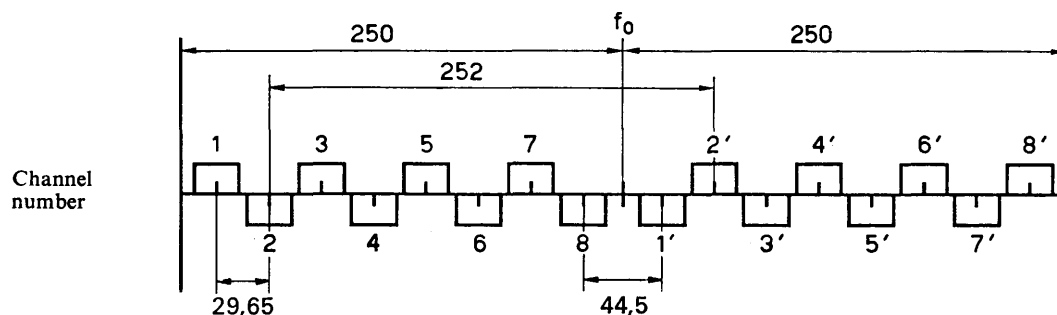


FIGURE 1

Radio-frequency channel arrangement for radio-relay systems operating in the 6 GHz band for use in international connections (the frequencies shown are approximate)

(All frequencies are in MHz)

RECOMMENDATION 384-3 *

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR ANALOGUE RADIO-RELAY SYSTEMS WITH A CAPACITY OF 2700 TELEPHONE CHANNELS OR UP TO 1260 TELEPHONE CHANNELS, OR THE EQUIVALENT, AND DIGITAL RADIO-RELAY SYSTEMS WITH A CAPACITY OF THE ORDER OF 140 Mbit/s, OPERATING IN THE 6 GHz BAND

(Study Programme 1A/9 and Question 12/9)

(1963–1966–1974–1982)

The CCIR,

CONSIDERING

- that radio-relay systems with a capacity of 2700 telephone channels should prove to be feasible in the 6 GHz band, if due care is exercised in the planning of radio paths to reduce multipath effects;
- that it is sometimes desirable to be able to interconnect, at radio frequencies, radio-relay systems on international circuits in the 6 GHz band;
- that it may be desirable to interconnect up to eight go and eight return channels in a frequency band 680 MHz wide;
- that economy may be achieved if at least four go and four return channels can be interconnected between radio-relay systems, each of which uses common transmit-receive antennas;

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

- (e) that a common radio-frequency channel arrangement for both up to 1260 and 2700 telephone channel radio-relay systems offers considerable advantages;
- (f) that the use of certain types of digital modulation (e.g. 16-level QAM) permits the use of the radio-frequency channel arrangement defined for 2700 telephone channel systems for the transmission of digital channels with a bit rate of the order of 140 Mbit/s;
- (g) that many interfering effects can be reduced substantially by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;
- (h) that the radio-frequency channels should be so arranged that an intermediate frequency of 70 MHz may be used for up to 1260 channel systems;
- (j) that the radio-frequency channels should be so arranged that an intermediate frequency of 140 MHz may be employed for 2700 channel systems,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to eight go and eight return channels, each accommodating 2700 telephone channels, or the bit rate of the order of 140 Mbit/s, or the equivalent, and operating at frequencies in the 6 GHz band, should be derived as follows:

Let f_0 be the frequency (MHz) of the centre of the band of frequencies occupied;

f_n be the centre frequency (MHz) of one radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (MHz) of one radio-frequency channel in the upper half of the band;

then the frequencies (MHz) of individual channels are expressed by the following relationships:

lower half of the band: $f_n = f_0 - 350 + 40n$,

upper half of the band: $f'_n = f_0 - 10 + 40n$,

where

$n = 1, 2, 3, 4, 5, 6, 7$ or 8 ;

2. that, in the section over which the international connection is arranged, all the go channels should be in one half of the band, and all the return channels should be in the other half of the band;

3. that different polarizations should be used alternately for adjacent radio-frequency channels in the same half of the band;

4. that, when common transmit-receive antennas are used, and not more than four channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by making either:

$n = 1, 3, 5$ and 7 in both halves of the band

or

$n = 2, 4, 6$ and 8 in both halves of the band;

5. that the preferred arrangement of radio-frequency polarization should be one of those shown in Fig. 1, depending upon whether antennas for single or double polarization are used;

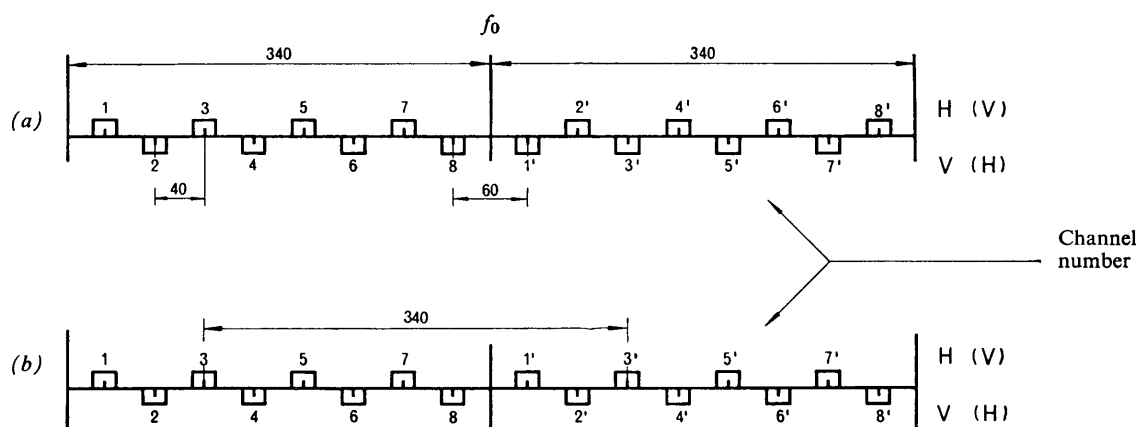


FIGURE 1

(a) Channel arrangement for antennae with double polarization
 (b) Channel arrangement for antennae with single polarization
 (All frequencies are in MHz)

6. that the preferred radio-frequency channel arrangement for up to 16 go and 16 return channels, each accommodating up to 1260 telephone channels, or the equivalent, should be obtained by interleaving additional channels between those of the main pattern and should be expressed by the following relationship:

$$\text{lower half of the band: } f_N = f_0 - 350 + 20 N,$$

$$\text{upper half of the band: } f'_N = f_0 - 10 + 20 N,$$

where

$$N = 1, 2, 3, \dots 15, 16;$$

7. that, in the section over which international connection is arranged, all the go channels should be in one half of the band and all the return channels in the other half of the band;

8. that different polarizations should be used alternately for adjacent radio-frequency channels in the same half of the band;

9. that when common transmit-receive antennas are used, and not more than four radio-frequency channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by making either:

$$N = 1, 5, 9, 13 \text{ or}$$

$$N = 2, 6, 10, 14 \text{ or}$$

$$N = 3, 7, 11, 15 \text{ or}$$

$$N = 4, 8, 12, 16,$$

in both halves of the bands and the preferred arrangement of radio-frequency polarization is as shown in Fig. 2;

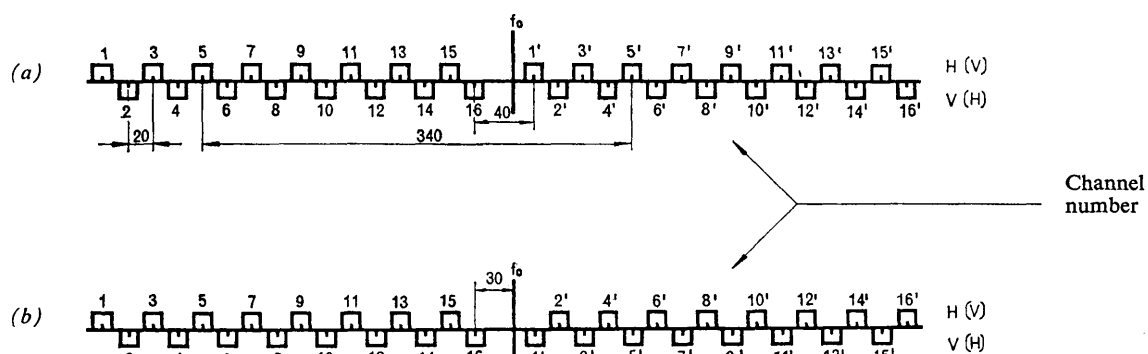


FIGURE 2

(a) Channel arrangement for antennae with single polarization
(b) Channel arrangement for antennae with double polarization

(All frequencies are in MHz)

10. that the preferred centre frequency (f_0) is 6770 MHz; other centre frequencies may be used by agreement between the administrations concerned.

Note 1. — This radio-frequency channel arrangement permits all local oscillator frequencies to be derived from a common oscillator, if desired.

Note 2. — The radio-frequency channel arrangements for systems of up to 1260-channel capacity and of 2700-channel capacity may be used on intersecting routes, as long as adequate antenna discrimination is provided.

REPORT 287-4

ANALOGUE RADIO-RELAY SYSTEMS OF CAPACITY GREATER THAN 1800 TELEPHONE CHANNELS, OR THEIR EQUIVALENT

(Study Programme 1A/9)

(1963-1970-1974-1978-1982)

1. Introduction

Radio-frequency channel arrangements for systems with a capacity of 2700 telephone channels operating in the upper 6 GHz band are given in Recommendation 384. Recommendation 387 refers to the use of the 11 GHz band for 2700 channel transmission. This Report presents additional information concerning radio-relay systems with capacities greater than 1800 telephone channels.

2. Use of the frequency band 4400 to 5000 MHz for 2700 telephone channel transmission *

In Japan, a radio-relay system with a capacity of 2700 telephone channels operating in the 5 GHz band (4400 to 5000 MHz) has been extensively used since 1972 [Matsushashi, 1972]. High quality and high availability have been achieved. The parameters, such as intermediate frequency and r.m.s. test tone deviation are based on the CCIR Recommendations concerned. The radio-frequency channel arrangement is similar to Fig. 1 in Recommendation 384 with the difference that a 600 MHz wide frequency band is available, thus enabling seven go and seven return channels to be provided. The radio-frequency channel arrangement is based on a centre frequency of 4700 MHz, and on adjacent channel separation of 40 MHz. The spacing between adjacent transmitter and receiver is 60 MHz.

3. Systems with increased frequency band utilization

In Japan, the average cross-polarization discrimination (*XPD*) on paths using horn-reflector or parabolic antennas has been improved to more than 38 dB in the 5 and 6 GHz bands, by employing an improved technique for adjusting the antenna direction. No significant *XPD* variation as a function of time has been observed [Ohi *et al.*, 1977].

On the basis of these results, a radio-relay system with a capacity of 2700 telephone channels operating in the 6 GHz band (5925 to 6425 MHz) with a carrier separation of 29.65 MHz was brought into service in 1977 and two types of radio relays with a capacity of 3600 telephone channels, one operating in the 4 GHz band (3600 to 4200 MHz) and the other in the 5 GHz band (4400 to 5000 MHz) with a carrier separation of 40 MHz, were brought into service in 1979. All these systems have since maintained a satisfactory circuit quality [Nishino *et al.*, 1976; Matsumoto *et al.*, 1980].

These systems have improved frequency use 1.3 to 1.5 times over conventional systems. It should be noted, however, that the design and operation of these high-capacity systems calls for numerous precautions. Among the many factors to be considered, the following are particularly important:

- A path *XPD* of 38 dB corresponds to an aggregate adjacent channel interference noise of about 1000 pW0p in a hypothetical reference circuit, which must be included in the total noise contribution.
- The choice of path is significant in ensuring that a satisfactory path *XPD* can be maintained; in particular, over-water paths will probably cause difficulties in meeting the path *XPD* objective.
- The rigidity of the towers required to support the antennas should be sufficient to cause minimum tilt and twist of the antennas. For a horn-reflector antenna, a deflection of less than 0.05° will typically cause a deterioration of the path *XPD* below 38 dB.
- The installation of such a high-capacity transmission system must be preceded by a thorough study of the propagation conditions.

An r.m.s. frequency deviation of 100 kHz per channel with a pre-emphasis factor of 10 dB seems to be optimum for a 3600 channel radio-relay system.

* In many countries there are restrictions on the use of this frequency band for high-capacity radio-relay systems.

4. Auxiliary channels

It is customary, in devising radio-frequency channel arrangements for broadband systems, to provide for two pairs of auxiliary channel frequencies and some preliminary examination has been given to this problem. In the case of the radio-relay system operating in the upper 6 GHz band, it seems likely that the values $f_0 \pm 3$ and $f_0 \pm 337$ MHz will prove to be the most suitable, although, in certain of the polarization arrangements, great difficulty may be experienced in filtering the two inner auxiliary channel frequencies. The proposed arrangement is included in Fig. 1.

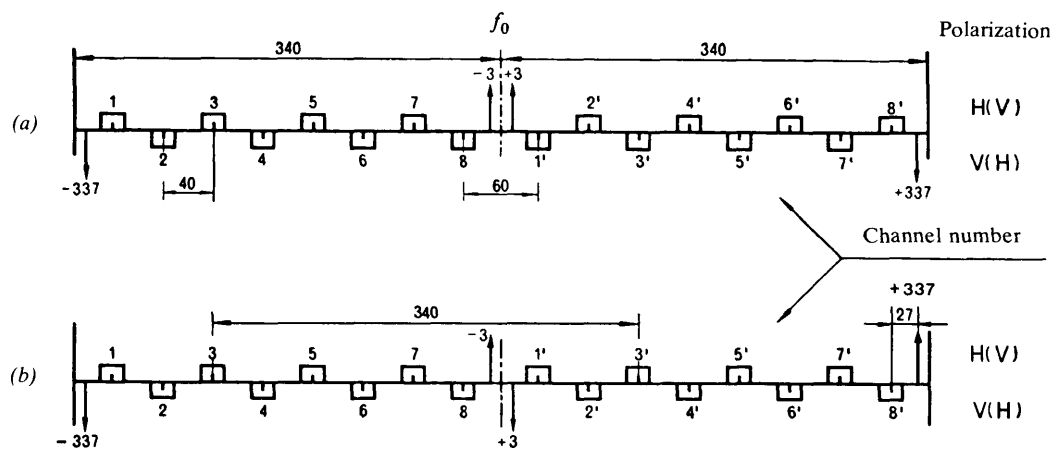


FIGURE 1

(a) Arrangement proposed for antenna with double polarization

(b) Arrangement proposed for antenna with single polarization

(All frequencies are in MHz)

REFERENCES

- MATSUHASHI, S. [1972] 2700 channel radio-relay system operating in the 5 GHz band — SF-E1. *Japan Telecomm. Rev.*, Vol. 14, 3, 159-164.
- MATSUMOTO, S., HASHIMOTO, A. and FUTATSUGI, H. [11 June, 1980] FDM/FM 3600 channel radio-relay systems in 4 GHz and 5 GHz bands. IEEE International Conference on Communications (ICC '80), Seattle, Wa., USA, Conf. Record, Session 41: Line of sight radio systems, Vol. 3, 41-1-1 — 41-1-5.
- NISHINO, K., YAMADA, Y., HASHIMOTO, A. and SANGO, J. [July, 1976] 6 GHz 2700-channel radio-relay system — SF-U4. *Japan Telecomm. Rev.*, Vol. 18, 3, 156-162.
- OHI, J., SANGO, J. and KOYAMA, K. [15 June, 1977] High capacity FDM/FM microwave system with increased efficiency of frequency utilization. IEEE International Conference on Communications (ICC '77), Chicago, Ill., USA, Conf. Record, Session 40: High capacity microwave systems; Vol. 3, 40.2, 83-87.

REPORT 781-1

RADIO-RELAY SYSTEMS FOR TELEPHONY USING SINGLE-SIDEBAND AMPLITUDE MODULATION (SSB-AM)

(Study Programme 1A/9)

(1978-1982)

1. Introduction

This Report deals with the use of single-sideband, suppressed-carrier, amplitude modulation transmission for high-capacity FDM line-of-sight, radio-relay systems for telephony. The systems described have been developed in the United States and Japan for use in the lower 6 GHz band.

The use of SSB modulation allows for a much greater efficiency of spectrum utilization than does the use of current low-index, angle-modulation systems. This is accomplished at the cost of stricter linearity requirements upon repeater amplification for acceptable intermodulation performance. Recent improvements in the state of the art in linear amplification have enabled the spectrum efficiencies of SSB to be exploited.

The utilization of this system will be a conversion of existing FM systems, as an addition to present 4 GHz routes, or as new routes. Since the existing terrestrial network is already densely populated, the SSB system must coexist with FM systems and it must grow within the FM network.

2. System characteristics

2.1 System parameters

Principal system parameters are shown in Table I.

TABLE I — *Principal system parameters*

Items	United States system	Japanese system
Radio-frequency band	5925–6425 MHz	
RF channel separation	29.65 MHz	
Capacity per RF channel	6000 channels	5400 channels
Average radiated power	0.5 W	0.36 W
Noise objective	1.39 pW0p/km	2.00 pW0p/km
Baseband signal spectrum	flat	with 3 dB pre-emphasis

2.2 Modulated spectrum

2.2.1 The United States system

The modulated RF spectrum appears as shown in Fig. 1. There are 10 blocks, each containing 600 voice channels, five on each side of the channel centre frequency as well as a total of eight pilot tones. The gap at the band centre is created to ease co-channel interference problems with FM systems, most of whose energy is near the band centre.

The possibility of using this band gap for the transmission of a digital signal is also being considered. The eight pilot tones are used for equalization, protection switching, and demodulation.

2.2.2 The Japanese system

The modulated RF spectrum appears as shown in Fig. 2. There are 6 blocks, each representing a super-master group (which contains 900 voice channels based on the CCITT FDM hierarchy), three on each side of the channel centre frequency as well as a total of seven pilot tones. A comparatively wide gap is created at the band centre and the sidebands near the centre are slightly raised by pre-emphasis, so as to be applicable to the more severe interference conditions from FM systems.

3. Interference coordination

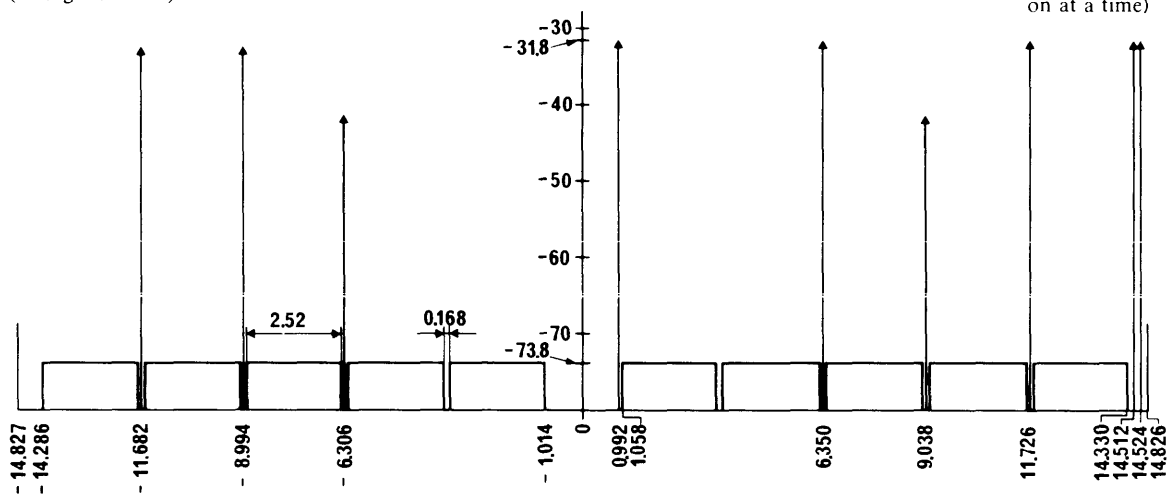
3.1 Interference coordination with terrestrial systems

Interference coordination objectives at present limit the interference power in each baseband voice channel of long-haul, 6 GHz systems to 2.5 pW0p or less, per interference exposure. Table II shows calculated values of the required wanted signal-to-interfering signal discrimination (in dB) necessary to meet this objective for cases involving SSB and typical FM systems (6 GHz FM with 1800 or 2700 channel loading) for co-channel interference.

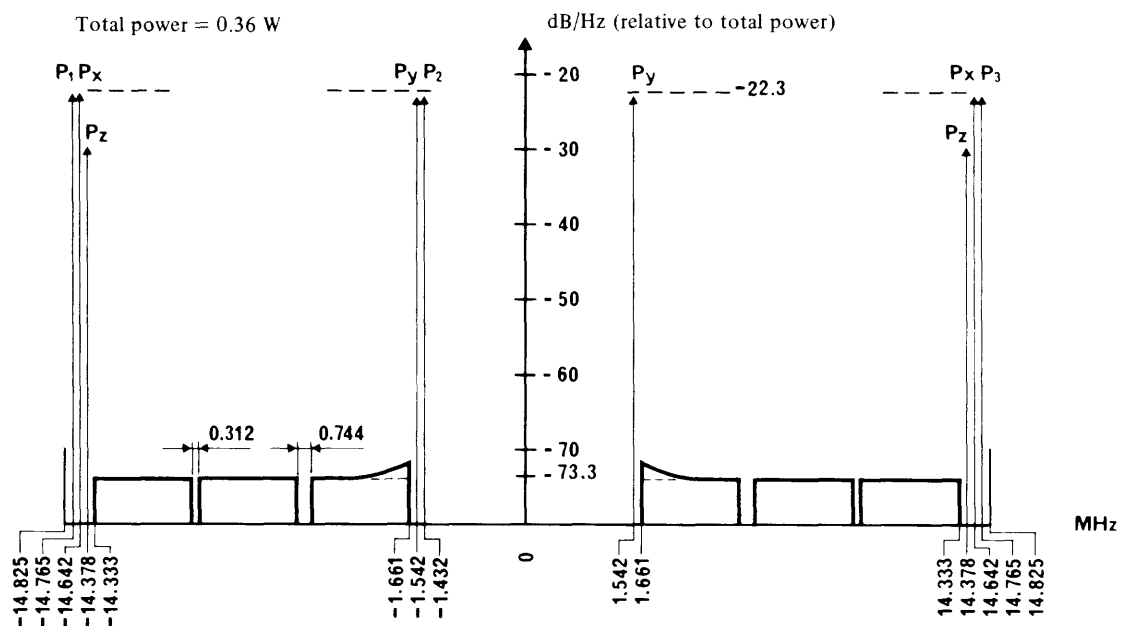
The effect of the difference in average radiated power of the two FM systems (10 W for the 1800 channel or 16 W for the 2700 channel system) on the associated SSB systems has been included in the Table II entries.

Spectrum 6 GHz

dB/Hz (relative to total power)

total power = 0.5 W
(average full load)Signalling tones
(one or other is
on at a time)FIGURE 1 — *Signal arrangement of the United States system*

(Frequency in MHz relative to centre of RF channel assignment)

FIGURE 2 — *Signal arrangement of the Japanese system*

(Frequency in MHz relative to centre of RF channel assignment)

- $P_{1,2,3}$: pilots for detecting in-band level variation
- P_x : continuity pilot for regular channels
- P_y : continuity pilot for a protection channel
- P_z : line regulating pilot

TABLE II — *Required wanted-signal to interfering-signal discrimination (in dB) in order to meet co-channel interference objective*

			Interference signal			
			United States systems		Japanese systems	
			6 GHz (10 W) FM (1800)	SSB (6000)	6 GHz (16 W) FM (2700)	SSB (5400)
Wanted signal	United States systems	6 GHz (10 W) FM (1800)	69	65	—	—
		SSB (6000)	76	68	—	—
	Japanese systems	6 GHz (16 W) FM (2700)	—	—	67.5	61
		SSB (5400)	—	—	71	67.5

3.1.1 *Interference from SSB*

The top row of Table II indicates that the 6 GHz FM system requires 69 dB of isolation from an interfering co-channel 6 GHz FM system and 65 dB from an interfering co-channel SSB system and the third row indicates similar values. The exact value of isolation required may be slightly different with 6 GHz FM systems having different capacities; but, in general, SSB will cause no more interference than other long-haul FM systems.

Since the co-channel interference between two low-index FM systems is directly proportional to the first order sideband energy of both systems, this is not unexpected. The total average SSB power, 0.5 W, or 0.35 W, is not significantly different from the sideband energy of the low-index FM systems. For example the 6 GHz FM system (1800) has about 9.4 of its 10 W of power in the carrier, leaving only about 0.6 W in the sidebands. The carrier beat interference from another 6 GHz system falls below the baseband and is therefore not of concern.

3.1.2 *Interference into SSB*

The first column of Table II indicates that the SSB system requires 76 dB isolation from an interfering co-channel 6 GHz FM system compared to the 69 dB required by a 6 GHz FM system from another interfering 6 GHz FM system. On the other hand, the third column indicates that the required isolation from FM system interference can be reduced in the SSB system with pre-emphasized sidebands and wider centre gap. This comparison is also somewhat dependent upon the FM systems examined, and FM systems with higher capacities will generate less interference. However, it shows that in some cases SSB is moderately more susceptible to interference from FM systems than other 6 GHz FM systems.

3.2 *Interference coordination with satellites*

Since a satellite system uses a high index FM modulation, interference effects will be directly related to the total power of the interfering signal. Therefore, SSB, with a total average radiated power 13 to 17 dB lower than that of FM systems, will cause 13 to 17 dB less interference to a satellite system.

3.2.1 Interference into SSB from satellite systems

Calculations have indicated that the impact of satellite interference upon SSB will be very nearly the same as its impact upon other 6 GHz FM long-haul systems. Once again this effect is due to the similarity of the power in the FM sidebands to the total SSB power. This similarity can be heuristically demonstrated by using the 1800 channel 6 GHz FM system shown in Table II. The interference susceptibility of both terrestrial systems is dependent upon the wanted signal power in the 4 kHz voice channel of interest. From Fig. 1, we see that the distribution of SSB power over all voice channels is uniform, but the distribution of the first order sideband power of an FM system is not. The 6 GHz FDM system with 1800 channel loading has a variation of almost 20 dB.

A direct comparison can be made assuming that the channel with the greatest interference is known. The location of the greatest interference within the baseband of FM systems is dependent upon the spectral density of the interfering and wanted signals (see Report 388). From calculations of many examples of systems in the fixed-satellite service which interfere with terrestrial systems, it has been found that the worst interference occurs near the middle of the baseband. The worst interference from a system of the fixed-satellite service into a SSB system occurs at the lower end of the baseband. However, a comparison at the middle of the baseband will be made under the hypothesis that the interfering signal is frequency modulated with a high modulating index and thus, that the rate of fall of its spectral density is low within the occupied bandwidth.

If a typical FM, 6 GHz spectrum (normalized to the same average transmitter power) were compared to a SSB system spectrum (Fig. 1), the SSB system would be seen to enjoy about 17 dB advantage near the middle of the first order sidebands. Since the 6 GHz, FM system has the same interference susceptibility as a double sided AM signal, it has a 3 dB advantage with respect to the SSB system, due to the redundancy obtained from the other sideband. On the other hand, the FM system typically uses 10 W of transmitted power. In that case, it enjoys a 13 dB advantage on the basis that the received signal level is greater than that of the SSB system by this amount. Therefore, satellite interference should be 1 dB higher in the 6 GHz, FM system and it can be concluded that the impact of satellite interference on SSB will be similar to that of high-capacity terrestrial FM systems.

4. Summary

The use of linear modulation in terrestrial radio-relay systems represents one of the most efficient methods of frequency utilization. Moreover, an SSB system can be placed in an existing FM network and it can equally share a band with satellites in the fixed service, using sharing criteria that were developed for low-index FM systems. The development of this system will enable a large expansion of the capacity of present networks to be made.

BIBLIOGRAPHY

- MARKLE, R. E. [15 June, 1977] The AR 6A single sideband long-haul radio system. IEEE International Conference on Communications (ICC '77), Chicago, Ill., USA, Conf. Record, Vol. 3, Session 40: High capacity microwave systems, 40.1-78—40.1-82.
- MATSUMOTO, S., OKAMOTO, Y., HASHIMOTO, A. and NOJIMA, T. [October, 1981] 6 GHz SSB AM radio relay system. *Japan Telecomm. Rev.*, Vol. 23, 4, 361-368.
-

RECOMMENDATION 385-2 *

**RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR 60, 120 AND 300-CHANNEL
RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION
MULTIPLEX AND OPERATING IN THE 7 GHz BAND ****

(Question 1/9)

(1959-1963-1978-1982)

The CCIR,

CONSIDERING

- (a) that it is desirable to be able to interconnect 60, 120 and 300-channel radio-relay systems on international circuits at radio frequencies in the 7 GHz band;
- (b) that frequency bands 300 MHz wide may be available for such systems;
- (c) that economy may be achieved, if several go and return channels are connected to one common transmit-receive antenna;
- (d) that many interfering effects can be minimized by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;
- (e) that, for reasons of frequency economy, it is desirable to interleave additional radio-frequency channels between those of the main pattern;
- (f) that it is desirable that the values of the mid-frequencies of the radio-frequency channels be the same for 60, 120 and 300-channel systems;
- (g) that the spacing between the mid-frequencies of the radio-frequency channels should be such, that the systems can work with the maximum frequency deviation given in Recommendation 404 for such systems,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for several radio-relay systems, each accommodating 60, 120 or 300 telephone channels and operating in the 7 GHz band, should be derived as follows (see Fig. 1):

Let f_0 be the frequency of the centre of the band of frequencies occupied (MHz);
 f_n be the centre frequency of one radio-frequency channel in the lower half of this band (MHz);
 f'_n be the centre frequency of one radio-frequency channel in the upper half of this band (MHz);

then the frequencies (MHz) of the individual channels are expressed by the following relationships:

lower half of band: $f_n = f_0 - 154 + 7n$ (see Note),

upper half of band: $f'_n = f_0 + 7 + 7n$ (see Note),

where:

$n = 1, 2, 3 \dots 20$;

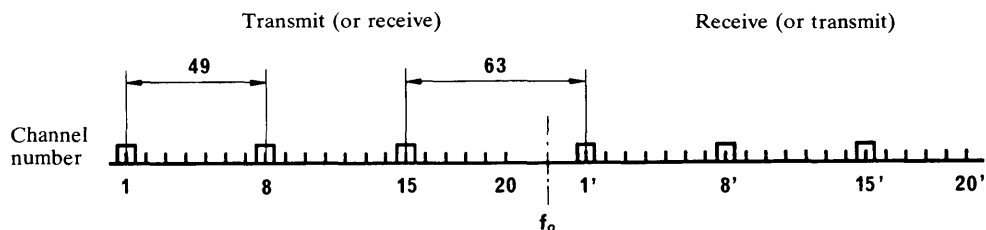


FIGURE 1 – Radio-frequency channel arrangement for international connection of radio-relay systems for 60, 120 or 300 channels operating in the 7 GHz band
(All frequencies are in MHz)

* This Recommendation applies only to line-of-sight and near line-of-sight radio-relay systems.

** Subject to agreement between the administrations concerned, other higher-capacity systems using the radio-frequency channel arrangement pattern defined in this Recommendation may be accepted if necessary.

2. that, in a section over which the international connection is arranged, all the go channels should be in one half of the band and all the return channels should be in the other half of the band;
3. that, when common transmit-receive antennas are used and three radio-frequency channels are accommodated on a single antenna, it is preferable that the channel frequencies be selected by making:
- $n = 1, 8$ and 15, or
 - $n = 2, 9$ and 16, or
 - $n = 3, 10$ and 17, or
 - $n = 4, 11$ and 18, or
 - $n = 5, 12$ and 19, or
 - $n = 6, 13$ and 20,
- in both halves of the band;

4. that for international connections, the centre frequency should preferably be:
- $f_0 = 7575$ MHz for the band 7425 to 7725 MHz (see Note);
- other centre frequencies may be used in certain geographical areas by agreement between the administrations concerned, e.g.:
- $f_0 = 7275, 7400$ or 7700 MHz (see Note);

5. that the channel arrangement and antenna polarization should be agreed between the administrations concerned;

6. that, when systems with 300 telephone channels are operated in a radio-frequency band, channel combinations which result in differences between channel frequencies of less than 14 MHz, should in general be avoided. If sufficient antenna discrimination is available, this precaution may be disregarded.

Note. — The formulae for f_n and f'_n and the values for f_0 differ from those given in Recommendation 284 (Los Angeles, 1959). This change has been made so that the "centre frequency" f_0 falls, in reality, in the centre of the band of frequencies occupied.

RECOMMENDATION 386-2

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR SYSTEMS WITH A CAPACITY OF 960 TELEPHONE CHANNELS, OR THE EQUIVALENT, OPERATING IN THE 8 GHz BAND

(Question 1/9)

(1963-1966-1982)

The CCIR,

CONSIDERING

- (a) that it may be desirable to be able to interconnect radio-relay systems on international circuits at radio frequencies in the 8 GHz band;
- (b) that, for some administrations, a frequency band, 300 MHz wide, may be available in the 8 GHz range for such systems;
- (c) that it may be desirable to interconnect in such a band up to six systems with a capacity of 960 channels, or the equivalent;
- (d) that such a frequency arrangement should also be suitable for 300-channel systems;
- (e) that for reasons of frequency economy, it is desirable to interleave additional radio-frequency channels between those of the main pattern;

- (f) that economy may be achieved, if at least three go and three return channels can be interconnected between systems using common transmit-receive antennas;
- (g) that many interfering effects can be minimized by a carefully planned frequency arrangement for systems employing several radio-frequency channels,

UNANIMOUSLY RECOMMENDS

- that the preferred radio-frequency channel arrangement in the 8 GHz band should be derived as follows:
let f_0 be the frequency of the centre of the band of frequencies occupied (MHz);
 f_n be the centre frequency of one radio-frequency channel in the lower half of this band (MHz);
 f'_n be the centre frequency of one radio-frequency channel in the upper half of this band (MHz);
then the frequencies of the individual channels are expressed by the following relationships:
lower half of band: $f_n = f_0 - 151.614 + 11.662 n$,
upper half of band: $f'_n = f_0 + 11.662 n$,
where for systems with a capacity of 960 telephone channels, or the equivalent:
 $n = 1, 3, 5, 7, 9$ and 11 ;
for systems with a capacity of 300 telephone channels:
 $n = 1, 2, 3, 4, 5 \dots 12$;
- that, in a section over which the international connection is arranged, all the go channels should be in one half of the band, and all the return channels should be in the other half of the band;
- that, for adjacent radio-frequency channels in the same half of the band, horizontal and vertical polarization shall be used alternately;
- that, when common transmit-receive antennas are used and three radio-frequency channels are accommodated on a single antenna, it is preferable that for systems with a capacity of 960 telephone channels, or the equivalent, channel frequencies be selected by making:

$$\text{or } \left. \begin{array}{l} n = 1, 5 \text{ and } 9 \\ n = 3, 7 \text{ and } 11 \end{array} \right\} \text{ in both halves of the band;}$$

when using systems with a capacity of 300 telephone channels it is preferable to select:

$$\left. \begin{array}{l} n = 1, 5 \text{ and } 9 \text{ or} \\ n = 2, 6 \text{ and } 10 \text{ or} \\ n = 3, 7 \text{ and } 11 \text{ or} \\ n = 4, 8 \text{ and } 12 \end{array} \right\} \text{ in both halves of the band;}$$

- that, when additional radio-frequency channels are required for 960-channel systems, or the equivalent, interleaved between those of the main pattern, the frequencies of the individual channels shall be obtained by making:
 $n = 2, 4, 6, 8, 10$ and 12 ;
- that for international connections the centre frequency should preferably be:
 $f_0 = 8350 \text{ MHz}$,

this value corresponds to the band 8200-8500 MHz. Other values may be taken by agreement between the administrations concerned;

- that due regard be taken of the fact that, in some countries, another radio-frequency channel arrangement for systems with capacities of up to 1800 telephone channels, or the equivalent, is used. A description of this radio-frequency channel arrangement is given in Annex I.

Note 1. — The radio-frequency channel arrangement described in § 1 to 6 permits all local oscillator frequencies to be derived from the common oscillator frequency 11.662 MHz. The frequency pattern allows for economical use of the frequency band, but since the intermediate frequency of 70 MHz is a multiple of the channel spacing, adequate system selectivity will have to be provided to avoid undue interference.

Note 2. — Due regard should be taken of the fact that in parts of Region 2 a different radio-frequency channel arrangement is in use for digital systems with a capacity of about 90 Mbit/s. This arrangement is described in Annex III of Report 934.

ANNEX I

DESCRIPTION OF THE RADIO-FREQUENCY CHANNEL ARRANGEMENT
REFERRED TO IN § 7

1. The radio-frequency channel arrangement, in a frequency band 250 MHz below 7975 MHz and 250 MHz above 8025 MHz for up to eight go and eight return channels, each accommodating up to 1800 telephone channels, or the equivalent, operating in the 8 GHz band, is as shown in Fig. 1 and is derived as follows:

Let f_0 be the frequency of the centre of the band of frequencies occupied (MHz);

f_n be the centre frequency of one radio-frequency channel in the lower half of this band (MHz);

f'_n be the centre frequency of one radio-frequency channel in the upper half of this band (MHz);

then the frequencies of the individual channels are expressed by the following relationships:

lower half of band: $f_n = f_0 - 281.95 + 29.65 n$,

upper half of band: $f'_n = f_0 + 29.37 + 29.65 n$,

where:

$n = 1, 2, 3, 4, 5, 6, 7$ or 8 .

2. That, in a section over which the international interconnection is arranged, all the go channels should be in one half of the band, and all the return channels should be in the other half of the band.

3. That the go and return channels on a given section should preferably use the polarizations shown below:

	<i>Go</i>					<i>Return</i>				
H(V)	1	3	5	7		1'	3'	5'	7'	
V(H)		2	4	6	8		2'	4'	6'	8'

4. That, when additional radio-frequency channels, interleaved between those of the main pattern, are required, the values of the centre frequencies of these radio-frequency channels should be 14.825 MHz below those of the corresponding main channel frequencies; in systems for 1800 channels, or the equivalent, it may not be practical, because of the bandwidth of the modulated carrier, to use interleaved frequencies.

5. That, for international connections, the centre frequency should be:

$f_0 = 8000$ MHz.

This value corresponds to the band 7725-7975 MHz in the lower half and 8025-8275 MHz in the upper half.

Note 1. — The radio-frequency channel arrangement for eight go and eight return channels, shown in Fig. 1, is suitable for use with the preferred intermediate frequency of 70 MHz (see Recommendation 403). It is also suitable for use with an intermediate frequency of 74.13 MHz, which enables a common oscillator (14.82 MHz) to be used for generating all the local oscillations for the system, if desired.

Note 2. — The radio-frequency channel arrangement shown in Fig. 1 overlaps that of Recommendation 386 by 75 MHz, between 8200 MHz and 8275 MHz, and that mentioned in Recommendation 385, for a centre frequency of 7700 MHz, by 125 MHz between 7725 MHz and 7850 MHz. All due precautions to avoid mutual interference must be taken by radio-relay systems using these channel arrangements.

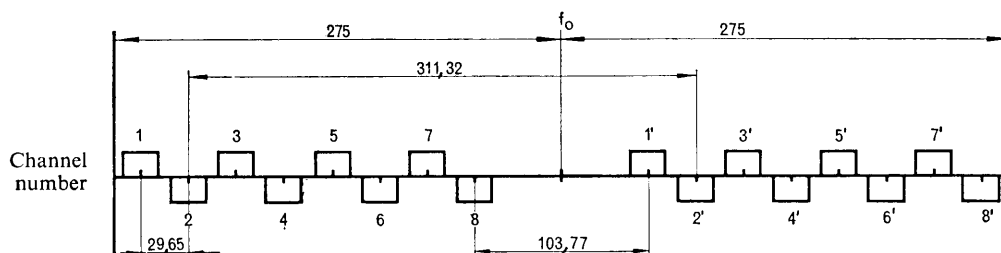


FIGURE 1

Radio-frequency channel arrangement, described in the Annex I
(All frequencies are in MHz)

RECOMMENDATION 387-3

**RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR ANALOGUE TELEVISION
AND TELEPHONY RADIO-RELAY SYSTEMS WITH A CAPACITY
OF 600 TO 1800 TELEPHONE CHANNELS, OR THE EQUIVALENT, OR LOW
AND MEDIUM-CAPACITY DIGITAL SYSTEMS OF EQUIVALENT BANDWIDTH,
OPERATING IN THE 11 GHz BAND ***

(Questions 1/9 and 12/9)

(1963-1970-1974-1978)

The CCIR,

CONSIDERING

- (a) that, at 11 GHz, analogue radio-relay systems with a capacity of up to 1800 telephone channels, or the equivalent, or low and medium capacity digital systems of equivalent bandwidth, seem to be feasible, subject to rainfall conditions;
- (b) that repeater spacing as well as other aspects of system design in this frequency range must take due cognizance of significant meteorological factors;
- (c) that it is desirable to interconnect such systems at radio frequencies on international circuits;
- (d) that for analogue systems a uniform radio-frequency channel arrangement for both smaller and larger capacities offers considerable advantages;
- (e) that, in a frequency band 1000 MHz wide, it may be desirable to interconnect up to twelve go and twelve return analogue channels, or up to twenty-two go and twenty-two return digital channels;
- (f) that economy may be achieved if at least three go and three return analogue channels, or if at least six go and six return digital channels can be accommodated on a common antenna;
- (g) that it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;
- (h) that the channels should be so arranged as to enable an intermediate frequency of 70 MHz to be used,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for analogue radio-relay systems with a maximum capacity of 1800 telephone channels, or the equivalent, and operating in the 11 GHz band should be derived as follows:

Let f_0 be the frequency (MHz) of the centre of the band of frequencies occupied;
 f_n be the centre frequency (MHz) of one radio-frequency channel in the lower half of the band;
 f'_n be the centre frequency (MHz) of one radio-frequency channel in the upper half of the band;

then the frequencies (MHz) of individual channels are expressed by the following relationship:

$$\begin{aligned} \text{lower half of the band: } f_n &= f_0 - 525 + 40n, \\ \text{upper half of the band: } f'_n &= f_0 + 5 + 40n, \end{aligned}$$

where:

$$n = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 \text{ or } 12.$$

The frequency arrangement is illustrated in Fig. 1;

2. that, when additional analogue radio-frequency channels, interleaved between those of the main pattern are required, the values of the centre frequencies of these radio-frequency channels should be 20 MHz below those of the corresponding main channel frequencies;

Note. — Channel 1 of the interleaved pattern in the lower half of the band is beyond the lower extremity of a 1000 MHz band and may therefore not be available for use.

* Subject to agreement between the administrations concerned, 2700 telephone channel systems employing an intermediate frequency of 140 MHz and following the main pattern of the radio frequency plan of this Recommendation, may be accommodated in the 11 GHz band when required for special cases.

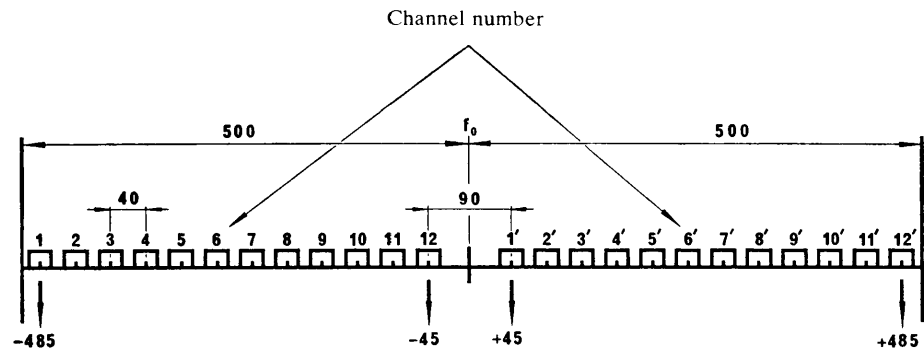


FIGURE 1 – Radio-frequency channel arrangement for radio-relay systems operating in the 11 GHz band
(Main pattern)
(All frequencies in MHz)

3. that, when analogue radio-frequency channels are also required for auxiliary radio-relay systems, the preferred frequencies for eleven go and eleven return channels, including two pairs of auxiliary channels in both the main and interleaved patterns should be derived by making:

- $n = 2, 3, 4 \dots 12$ in the lower half of the band,
- $n = 1, 2, 3 \dots 11$ in the upper half of the band.

The radio frequencies (MHz) for the auxiliary systems should be chosen as shown below:

	Main pattern	Interleaved pattern
lower half of the band	$f_0 - 485$ $f_0 - 15$	$f_0 - 495$ $f_0 - 25$
upper half of the band	$f_0 + 15$ $f_0 + 485$	$f_0 + 2.5$ $f_0 + 465$

The radio-frequency arrangement is illustrated in Fig. 2, which also shows a possible polarization arrangement;

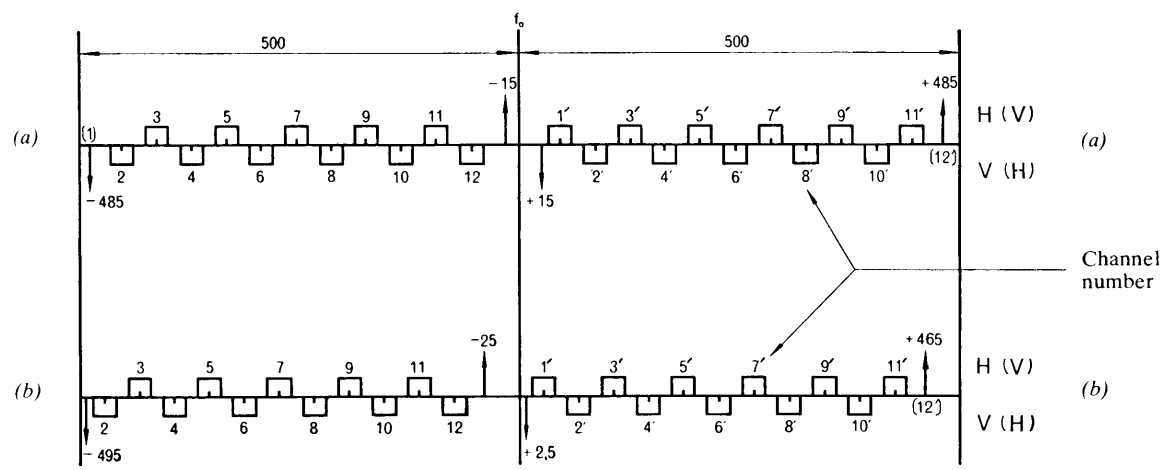


FIGURE 2 – Radio-frequency channel arrangement for main and auxiliary radio-relay systems operating in the 11 GHz band
(All frequencies in MHz)

- (a) Main pattern
- (b) Interleaved pattern

4. that, in a section over which the international connection is arranged, all the go channels should be in one half of the band and all the return channels should be in the other half of the band;
5. that if, for example, only three go and three return channels are accommodated on a common transmit-receive antenna, it is preferable that the channel frequencies (MHz) be selected by making:

$$\left. \begin{array}{l} n = 1, 5, 9 \text{ or} \\ n = 2, 6, 10 \text{ or} \\ n = 3, 7, 11 \text{ or} \\ n = 4, 8, 12 \end{array} \right\} \text{ in both halves of the band;}$$

6. that for adjacent analogue radio-frequency channels in the same half of the band different polarizations should preferably be used alternately;
7. that the preferred centre frequency is 11 200 MHz; other centre frequencies may be used by agreement between the administrations concerned;
8. that when digital radio-relay systems of low or medium capacity are to be used in the 11 GHz band, the radio-frequency channel arrangement should be in accordance with § 1 and 2 above. A description of these channel arrangements is given in Annex I.

ANNEX I

DESCRIPTION OF THE RADIO-FREQUENCY CHANNEL ARRANGEMENT REFERRED TO IN § 8

1. Suitable channel arrangements for low and medium-capacity digital radio-relay systems requiring channel spacings of 40 MHz can be provided by this Recommendation if co-channel assignments are made for both polarizations.

2. The preferred radio-frequency channel arrangement for digital radio-relay systems provides eleven go and eleven return channels derived as follows:

Let f_0 be the frequency (MHz) of the centre of the band of frequencies occupied;

f_n be the centre frequency (MHz) of one radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (MHz) of one radio-frequency channel in the upper half of the band;

then the frequencies (MHz) of the co-channel pairs are expressed by the following relationship:

$$\begin{array}{l} \text{lower half of the band: } f_n = f_0 - 545 + 40 n, \\ \text{upper half of the band: } f'_n = f_0 - 15 + 40 n, \end{array}$$

where:

$$n = 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 \text{ or } 12.$$

3. When digital radio channels are to be added to an existing analogue system that is not fully developed, the digital channels should preferably use the interleaved plan of § 2 of the RECOMMENDS if the analogue channels are using the main pattern of § 1 and vice versa (Fig. 3 is included as an example).

However, it is recognized that in some cases it may be possible to add digital channels in the unused portions of an existing analogue system.

Note 1. — The general principles of compatibility between analogue and digital radio-relay systems are dealt with in Report 610.

Note 2. — It is recognized that some administrations are considering the use of the 11 GHz band for high-capacity digital systems and that an alternative channel arrangement for such use is the subject of study within the CCIR.

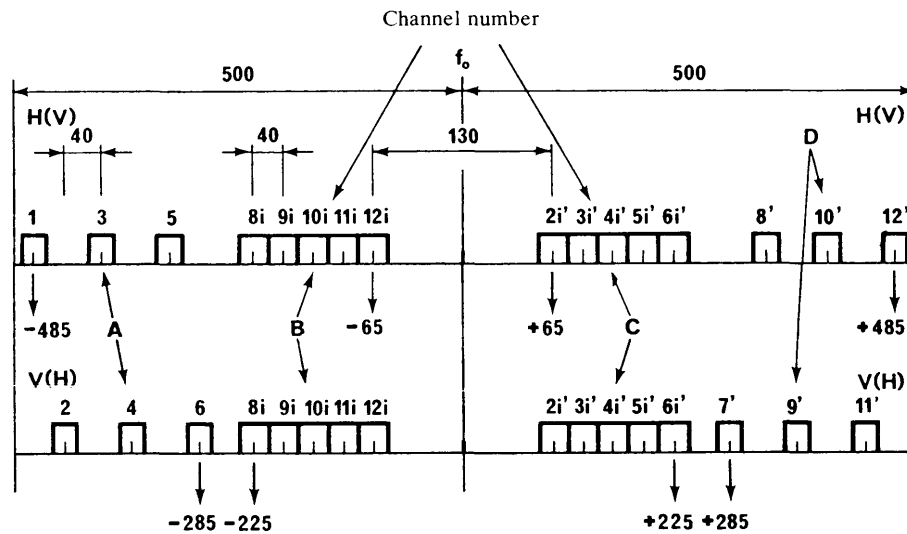


FIGURE 3 – Example of a mixed analogue and digital radio-frequency channel arrangement for radio-relay systems operating in the 11 GHz band
(All frequencies in MHz)

A: analogue

B: digital

C: interleaved pattern

D: main pattern

RECOMMENDATION 389-2

PREFERRED CHARACTERISTICS OF AUXILIARY RADIO-RELAY SYSTEMS OPERATING IN THE 2, 4, 6 OR 11 GHz BANDS

(Study Programme 4A/9)

(1959–1963–1970–1974)

The CCIR,

CONSIDERING

- (a) that an auxiliary radio-relay system may be required for the provision of service channels for the maintenance, supervision and control of radio-relay links, using either the radio-frequency channel arrangements of Recommendations 382, 383 or 387;
- (b) that, sometimes, the auxiliary radio-relay system may be required to operate with frequencies in or near the band of the main radio-relay system, and may, for reasons of economy, share the same antennas;
- (c) that occasionally, a different frequency band from that of the main radio-relay system may be preferred for the auxiliary radio-relay system (Study Programme 4A/9);
- (d) that the characteristics of an auxiliary radio-relay system, sharing the same frequency band as the main radio-relay system and, in particular, the radio-frequency channel arrangement, should be such as not to cause mutual interference;
- (e) that the auxiliary radio channels may employ either frequency or amplitude modulation;

(f) that two pairs of frequency allocations may be needed for the auxiliary radio-relay system, to provide either two normal service channels in each direction, or a normal service channel and a stand-by service channel in each direction, and to allow for the use of frequency diversity where this is essential and other forms of diversity are not practicable;

(g) that the numbers of the service channels to be provided and their functions have been defined in Recommendation 400,

UNANIMOUSLY RECOMMENDS

1. that, for an auxiliary radio-relay system sharing the same frequency band as the main radio-relay system, operating in the 2 or 4 GHz bands (Recommendation 382), the preferred frequencies (MHz) of the radio-frequency channels of the auxiliary system should be related to the centre frequency f_0 of the normal pattern of the main system as shown below:

Normal:

lower half of band: $f_0 - 204.5$ and $f_0 - 12$

upper half of band: $f_0 + 8.5$ and $f_0 + 199$

Interleaved:

lower half of band: $f_0 - 213.5$ and $f_0 - 23$

upper half of band: $f_0 - 2.5$ and $f_0 + 190$

The arrangement of the radio-frequency channels and the preferred polarizations are shown in Fig. 1. Other radio-frequency channel arrangements for the auxiliary radio-relay systems may be used by agreement between the administrations concerned; *

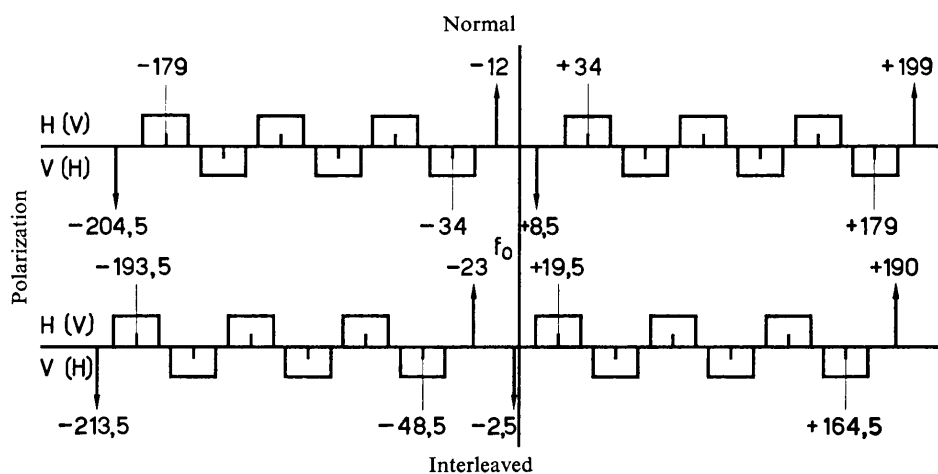


FIGURE 1

*Radio-frequency channel arrangement for main and auxiliary radio-relay systems
operating in the 2 and 4 GHz bands
(All frequencies are in MHz)*

* The use of the frequency $f_0 + 199$ MHz (f_0 being 4003.5 MHz) may not be in accordance with Article 8 of the Radio Regulations. A special agreement of the administrations concerned to use this frequency is necessary, and interference must not be caused to users of the frequency in accordance with the Radio Regulations.

2. that, for an auxiliary radio-relay system sharing the frequency band of the main radio-relay system, operating in the 6 GHz band (Recommendation 383), the preferred frequencies (in MHz) of the radio-frequency channels of this auxiliary system should be related to the centre frequency f_0 of the normal pattern of the main system, as shown below:

2.1 *For frequency-modulation systems **

lower half of band: $f_0 - 248.9$ and $f_0 - 3.1$
 upper half of band: $f_0 + 3.1$ and $f_0 + 248.9$

2.2 *For amplitude-modulation or frequency-modulation systems **

lower half of band: $f_0 - 249.5$ and $f_0 - 2.5$
 upper half of band: $f_0 + 2.5$ and $f_0 + 249.5$

The arrangement of the radio-frequency channels and the preferred polarizations are shown in Fig. 2.

If the radio-frequency channel arrangement of the main system follows the interleaved pattern of Recommendation 383, § 5, the lowest channel in each half of the band of that interleaved pattern should be left free, if the two lowest auxiliary radio-frequency channels are to be accommodated;

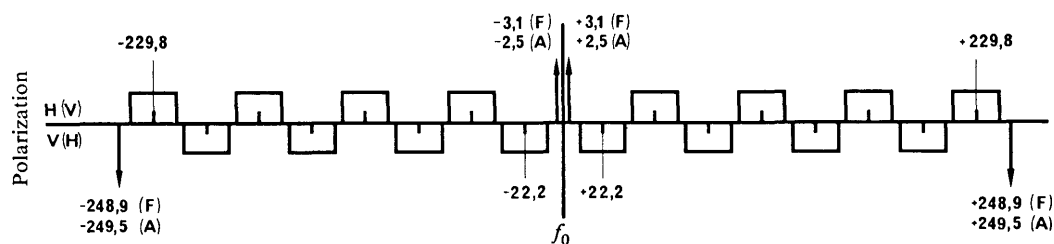


FIGURE 2

*Radio-frequency channel arrangement for main and auxiliary radio-relay systems
 operating in the 6 GHz band
 (All frequencies are in MHz)*

↑ or ↓ indicate the radio-frequency channels of the auxiliary radio-relay system

A: amplitude modulation

F: frequency modulation

3. that, for an auxiliary radio-relay system sharing the frequency band of the main radio-relay system, operating in the 11 GHz band (Recommendation 387), the preferred provisions to that end, set out in § 3 of that Recommendation, should be observed;

4. that the other characteristics of the auxiliary radio-relay system should be the subject of further study and, for the present, be subject to agreement between the administrations directly concerned.

* Apart from the type of modulation, certain other characteristics (e.g. load on main channels, frequency stability, frequency allocation plan of the adjacent bands) should be taken into account, in accordance with Study Programme 4A/9.

REPORT 782-1

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR HIGH-CAPACITY DIGITAL SYSTEMS IN THE 10.7 TO 11.7 GHz FREQUENCY BAND

(Study Programme 12E/9)

(1978-1982)

1. Introduction

This Report discusses the RF channel arrangements for digital radio-relay systems having a bit rate B , of the order of 140 Mbit/s.

In adopting a channelling arrangement, consideration needs to be given to the following factors:

- efficiency of spectrum utilization;
- compatibility with existing RF channel arrangements;
- compatibility with the location of existing radio-relay stations.

The relative importance attached to these factors by each administration may be different, and could lead to different proposals for frequency plans when considering the 11 GHz frequency band. Plans proposed by three administrations are presented as examples in Annexes I, II and III to this Report.

In § 2, other aspects, which should be considered when determining a channelling arrangement, are discussed.

It is not the intention of this Report to discuss problems which form the subjects of other Reports. The following are relevant texts:

- Report 779 where interferences between digital systems are considered.
- Report 378 where the general principles of RF channel arrangements are discussed.
- Report 610 dealing with the problems of compatibility between analogue and digital transmissions.
- Report 784 dealing with the propagation effects on radio-relay systems.

2. System design considerations

The determination of channel arrangements is a complex subject which depends on the following interrelated factors:

- the digital modulation method;
- the parameters defining the RF channel disposition (X , Y , Z and S parameters as defined in Report 378);
- the behaviour of the propagation medium.

These factors are discussed in the sub-sections which follow. In addition, consideration is given to the problems of compatibility in situations where digital and analogue systems may need to co-exist; in particular the problems of compatibility with an 1800 channel FDM-FM system.

2.1 Modulation methods

The main characteristics which determine the suitability of a modulation method for use in the 11 GHz band, are:

- tolerance to waveform distortions resulting from channel filtering and multipath fading;
- tolerance to co-channel and adjacent channel interference and noise;
- the number of information bits per transmitted symbol.

Three methods are considered in this Report, but other modulation methods are possible; 4-level PSK, 8-level PSK, and 16-level QAM (obtained by two quadrature carriers, each modulated with 4 amplitude levels).

2.2 Channel disposition

The channel disposition is completely defined when the frequencies and the polarizations associated with each channel are given. Such values depend on the parameters X , Y and Z , which are normalized with respect to the symbol rate S . For a bit rate of the order of 140 Mbit/s, and for the three modulation methods listed in § 2.1, S has the values of 70, 47 and 35 Mbaud respectively. In practice however, these values may be increased by the introduction of supervisory and signalling bits.

Report 378 considers the values of X , Y , and Z , but does not take into account the effects of the modulation methods on these values.

Co-channel frequency plans may be usable and desirable for low order modulation methods. For higher level (e.g. 8 and 16) modulation methods, good spectrum efficiency can be obtained even with interleaved frequency plans. Therefore, only the channel arrangements and modulation methods shown in Table I are considered.

TABLE I — *Channel arrangement*

Modulation	Four-level PSK, $S = 70$ Mbaud			Eight-level PSK $S = 47$ Mbaud		Sixteen-level QAM $S = 35$ Mbaud	
Type of arrangement	Interleaved	Interleaved	Co-channel	Interleaved	Interleaved	Interleaved	Interleaved
Number of channel arrangements	6	7	8 ⁽¹⁾	8	9	10	11 ⁽²⁾
Guard band ZS (MHz) Z	75 1.07	70 1.00	55 0.79	35 0.74	47 1.0	32 0.91	55 1.57
Mid-band separation YS (MHz) Y	180 2.57	173 2.47	230 3.3	90 1.9	122 2.6	72 2.05	90 2.57
Cross-polarized channel spacing $XS/2$ (MHz) X	67 1.91	57 1.63	0 1.57	60 2.55	49 2.09	48 2.74	40 2.29
Efficiency of band utilization (bits/Hz)	1.68	1.96	2.24	2.24	2.52	2.80	3.08

⁽¹⁾ Arrangement deduced on the basis of $\frac{1}{2}$ of the co-channel arrangement suggested for the 17.7 to 19.7 GHz band (see Recommendation 595).

⁽²⁾ The interleaved frequencies of the CCIR arrangement suggested for 1800 channel systems ($ZS = 35$ MHz, $YS = 130$ MHz) might also be used. The number of channels has to be reduced from 12 to 11 because of the difficulty in limiting the power at the edge of the band.

Note. - No allowance has been made for additional bits that may be required for supervisory purposes.

Table I summarizes some of the characteristics of the channel-plan choices. A comparison of the practical merits of the various solutions from the point-of-view of the power requirements and compatibility requirements is difficult at the present time. However, some consideration of the problems of compatibility is given in the following section.

2.3 *Analogue/digital compatibility*

2.3.1 *On the same route*

1800-channel systems and 140 Mbit/s digital channels can be conveniently combined only in channel arrangements using 8-level PSK and 16-level QAM modulation.

With 8-level PSK modulation, the spacing between a 1800-channel system and a 140 Mbit/s channel should not be less than 80 MHz. Thus the combined use of 3 digital and 7 analogue channels or 5 digital and 4 analogue channels may be envisaged. With 16-level QAM modulation, the spacing between a 1800-channel system and a 140 Mbit/s channel must not be less than 60 MHz [CCIR, 1974-78].

2.3.2 *Systems converging at the same station*

With an 11-channel arrangement and 16-level QAM, the same carrier frequencies can be used on two converging routes, one being analogue modulated and the other digital modulated. With orthogonally polarized emissions the protection between the two routes may be sufficient to allow relatively low convergence angles but this benefit is partially offset by the higher interference sensitivity of 16-level QAM compared with other types of modulation. These matters are further considered in Report 610.

2.4 Cross-polarization decoupling

A reduction in cross-polarization decoupling results in a degradation of the carrier-to-interference ratio in a digital channel and thus affects the quality of the digital system. Coupling between cross-polarized channels depends on the combined effects of antenna cross-polarization coupling characteristics and the cross-polarization coupling caused by the path propagation characteristics.

Factors to be considered are:

- water or snow on the antenna reflector or on the feed aperture;
- performance of the antenna both on axis and off axis;
- propagation aspects.

In the 11 GHz frequency band propagation anomalies attributable to multipath propagation conditions and to precipitation effects (snow and rain) should be taken into consideration. Propagation effects are studied in Report 784, and are discussed in detail in Section C (Effects of the atmosphere (Radiometeorology)) of Volume V, to which reference should be made. Report 722 is of particular importance.

REFERENCES

CCIR Documents

[1974-78]: 9/253 (France).

ANNEX I

APPLICATION OF DESIGN CRITERIA TO A PRACTICAL CHANNEL ARRANGEMENT

1. Introduction

This Annex describes the way in which the design criteria of § 1 and 2 have been applied to the production of a practical channel arrangement. This channel arrangement is shown in Fig. 1 and will be used in the United Kingdom for a system, based on 4-level PSK modulation, intended for use over existing radio-relay routes which incorporate hop lengths of up to 65 km. Close attention has, therefore, been paid to the need for compatibility with the existing network infra-structure, particularly:

- the need for sufficient margin to counteract fading due to precipitation at 11 GHz over hops of up to 65 km;
- the need to minimize the interference between systems on routes converging at nodal points in the network;
- the need to provide height diversity reception on the longer hops to counteract any distortion due to multipath propagation activity.

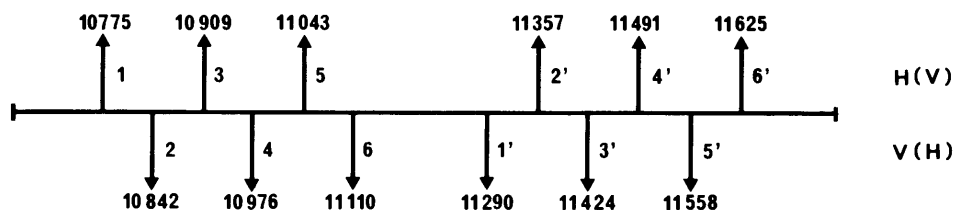


FIGURE 1 – RF channel plan
(All frequencies in MHz)

2. Radio channelling plan and system parameters

The interleaved channelling plan shown in Fig. 1 is based on the general principles of channelling arrangements discussed in Report 378. The RF multiplexing arrangement is shown in Fig. 2. The design of the channelling plan and RF multiplexing has been influenced by other system parameters, the principal ones being:

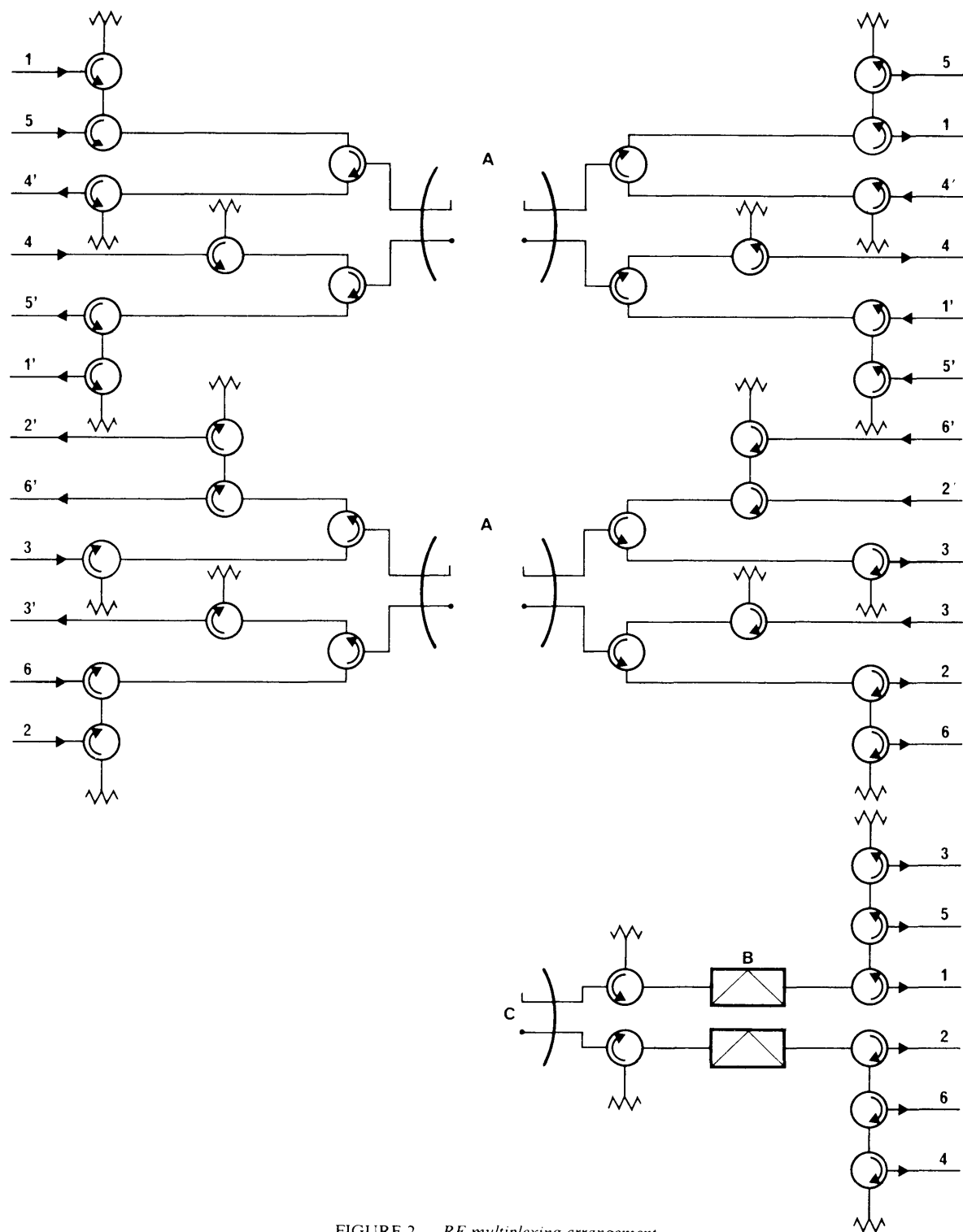
Maximum transmitter power	10 dBW
Nominal receive level	− 60 dBW
Receiver thermal noise (for a noise figure of 8 dB)	− 117 dBW
Receive level for effective * BER of 10^{-3}	− 102 dBW
Fade margin for effective * BER of 10^{-3}	42 dB
Modulation	4 level PSK
Demodulation	Coherent detection
Intermediate frequency of receiver	140 MHz
Transmit and receive RF filter	Levy (linear phase) 8 pole, 0.001 dB passband ripple with a 3 dB bandwidth of 1.82 S
Receive IF filter	quasi-Bessell 2 pole with a 1.5 dB bandwidth of S
Post demodulation filter	Gaussian 6 pole with a 1.5 dB cut-off frequency of 0.5 S

A complete description of the system is given in Hyamson *et al.* [1979].

3. Practical evaluation of the channelling plan

A fully equipped prototype system based on the channelling plan of Fig. 1 and the above parameters has been under evaluation for more than a year over a 53 km hop between Birmingham and Charwelton in the United Kingdom. A second hop between Bredon Hill and Birmingham has also been equipped with one channel to provide an assessment of the nodal interference at Birmingham. The evaluation exercise has shown that the channelling plan is robust and enables the performance objectives of Recommendation 594 to be met. The interim results of the exercise are discussed in Muir and de Belin [1981].

* Effective BER refers to the bit error ratio at the output digital interface of the complete radio system; this differs from the BER measured at the detector output because of the effects of post-detection processing (descrambling) and differential decoding.



A : main antennas
 B : phase modulators
 C : diversity antenna

REFERENCES

- HYAMSON, H. D., MUIR, A. W. and ROBINSON, J. M. [December, 1979] An 11 GHz high capacity digital radio system for overlaying existing microwave routes. *IEEE Trans. Comm.*, Vol. COM-27, 12, 1928-1937.
- MUIR, A. W. and de BELIN, M. J. [17-20 March, 1981] The field evaluation of a 140 Mbit/s digital radio-relay system in the 11 GHz band. IEE Conf. Publ. No. 193, 106-109. IEE Second International Conference on Telecommunication Transmission – Into the Digital Era, London, UK.

ANNEX II

DIGITAL RADIO-RELAY SYSTEM AT 140 Mbit/s IN THE 11 GHz BAND

1. Definition of the system ; choice of type of modulation

To determine a suitable type of modulation, account should be taken of the following main parameters:

- the introduction of 140 Mbit/s per channel digital radio-relay systems in the French network has to make maximum re-use of existing infra-structures, with radio hop lengths of about 50 km, which is an important feature, especially at 11 GHz, while maintaining good spectral efficiency and, in particular, optimizing the nodal capacity of the system;
- climatic conditions should also be taken into account; at 11 GHz some hops are mainly disturbed by rain and others by multipath propagation.

In the light of these constraints, 8-level PSK modulation has been adopted in preference to 16-level QAM, with the 8-channel frequency plan defined below.

It should be noted that for a given system gain, 8-level PSK permits an 8 dB lower saturated power limit for a TWT amplifier, than is required for 16-level QAM.

It is thus possible to ensure high net margins for fading due to rain. The improvement in quality resulting from space diversity in the case of multipath systems is used, not to increase the capacity of the artery, but to solve the problem of long hops ($L > 50$ km).

Furthermore, 8-level PSK modulation is better protected than 16-level QAM modulation against the disturbance due to adjacent arteries leaving the same nodal point. Since the angular decoupling thereby necessitated is smaller, it is possible to increase the number of outgoing links and overall to obtain a slightly better nodal capacity than can be obtained with systems using 16-level QAM modulation.

2. Arrangement of radio-frequency channels and branching

The channel arrangement is shown in Fig. 3 and that of the RF multiplexing in Fig. 4.

The centre frequencies of this channel arrangement are defined on the basis of those referred to in Recommendation 387, and the 60 MHz spacing between adjacent channels is obtained by choosing alternately a centre frequency from the interleaved plan (channels 1, 3, 5 and 7) and a centre frequency from the main plan (channels 2, 4, 6 and 8).

With the branching system adopted, it is possible to use a single antenna for sending and receiving the first four channels installed.

3. Definition of parameters X, Y, Z and S

Allowing for the additional bits used for the error detection and the service channels, the modulation speed S is 46.811 Mbaud. The coefficients X , Y and Z are thus defined with the following values:

$$\begin{aligned} X &= 2.56 \\ Y &= 1.92 \\ Z &= 0.747 \end{aligned}$$

By using appropriate filters, there would seem to be no difficulty about lowering the lower limit of Y and the value of Z .

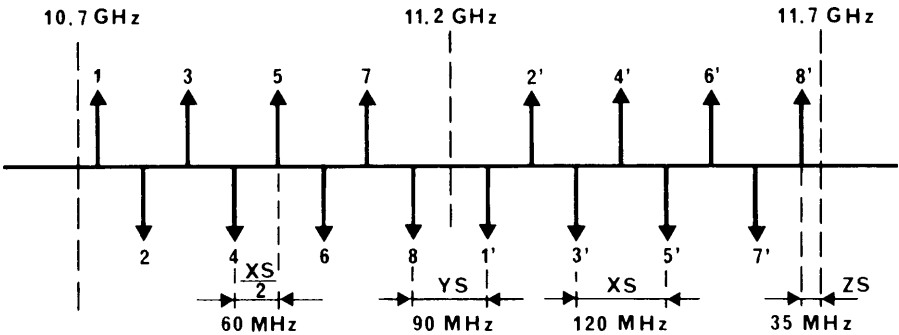


FIGURE 3 — Radio-frequency channel arrangement for a 140 Mbit/s radio-relay system operating in the 10.7-11.7 GHz band

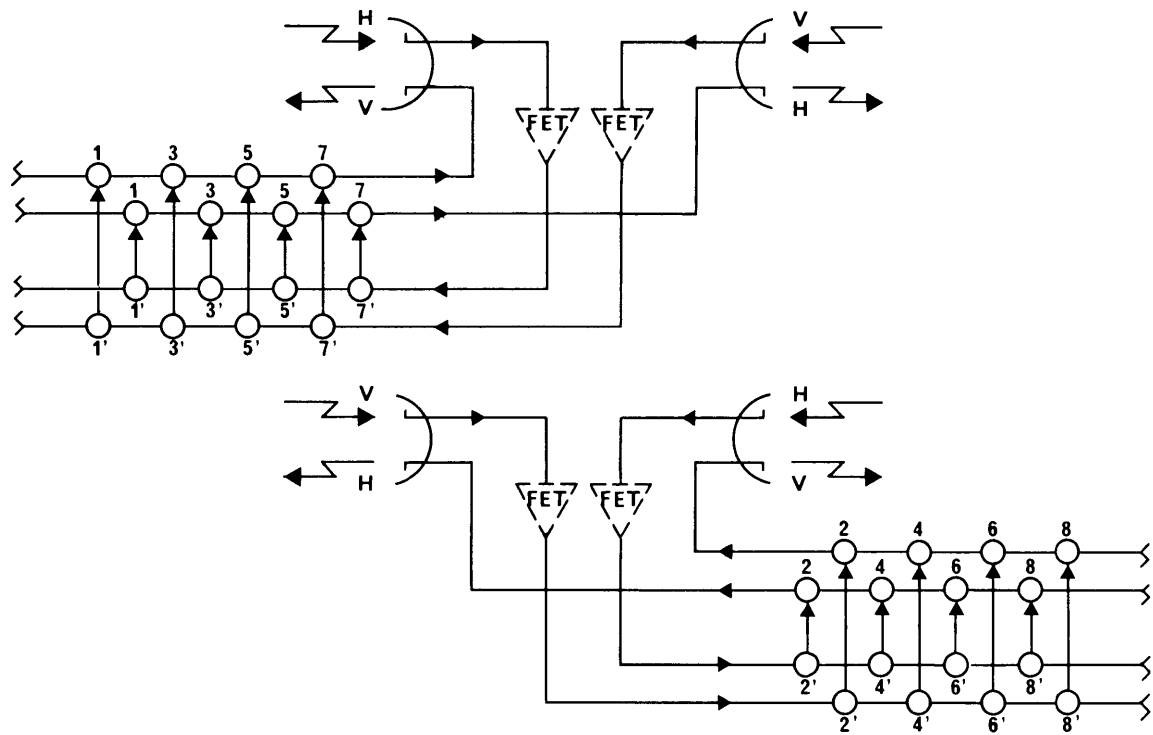


FIGURE 4 — Antenna and multiplexing systems suitable for the channel arrangement in Figure 3
FET: optional “low noise amplifier” (Field Effect Transistor)

4. Main system characteristics

– Transmitter power	$P_E = 41$ dBm taking into account 2 dB backoff for TWT
– Normal receive level	$P_R = -21$ dBm
– Receiver thermal noise	$N = -89$ dBm
– Noise factor	$F = 8$ dB
– Flat fade margin for BER of 10^{-3}	46 dB
– C/I ratio in the adjacent channels for $XPD = 0$	$C/I = 19.5$ dB
– Transmitted bit rate B (including additional bits for quality measurement and service channels)	140 434 kbit/s
– Modulation	8-level PSK
– Demodulation	Coherent detection
– Intermediate frequency	140 MHz
– IF send and receive filter	anti-Chebyshev, 3 pole, corrected at sending by $x/\sin x$, with a 3 dB bandwidth of 1 S
– RF before TWT	Chebyshev, 6 pole, equal ripple band 70 MHz (1.5 S)
– RF branching send and receive	Chebyshev, 5 pole, equal ripple band 70 MHz (1.5 S)

ANNEX III

RADIO-FREQUENCY CHANNEL ARRANGEMENT FOR MEDIUM-HIGH AND HIGH CAPACITY DIGITAL SYSTEMS IN THE 11 GHz FREQUENCY BAND

This Annex describes the use of the 11 GHz frequency band for medium-high and high capacity digital radio-relay systems as proposed by the Italian Administration [CCIR, 1978-82]. The Italian Administration is also going to make experimental tests on the long haul network, by using available 140 Mbit/s radio equipments with modulation method and channel arrangement as per Annex I.

Two capacities are considered:

- 70 Mbit/s (2×34 Mbit/s) to be employed in medium haul connections;
- 140 Mbit/s to be employed in long haul connections.

The Italian Administration considers primarily important the RF spectrum efficiency and the possibility of introducing such digital systems in such a way as to have both compatibility with existing analogue systems and utilization of existing radio-relay stations.

The existing 11 GHz channel arrangement (see Recommendation 387) provides a 40 MHz channel spacing for which development and experiments are starting for the two above capacities with the following modulation methods:

- 8-level PSK for gross bit rate of 70 Mbit/s (2×34 Mbit/s);
- 16-level QAM for gross bit rate of 140 Mbit/s.

The use of these modulation methods permits, over common routes, compatibility (with acceptable impairments) between existing 1800 FM channel systems and 70 or 140 Mbit/s digital systems.

Table II summarizes some of the characteristics of the existing CCIR channel arrangement and of the above digital systems.

Experiments are also starting on the evaluation of improvements due to crossband diversity using the 11 GHz band for stand-by channels for the lower frequency bands.

The purpose of all the above experiments is to obtain experimental data as yet unavailable in adequate quantity and form.

TABLE II

Gross bit rate	70 Mbit/s	140 Mbit/s
Modulation method	PSK 8	QAM 16
Type of arrangement	Rec. 387	
Number of channels	12	11 ⁽¹⁾
Guard band ZS (MHz) Z	15 0.64	55 1.57
Mid-band separation YS (MHz) Y	90 3.86	90 2.57
Cross-polarized channel XS/2 (MHz) X	40 3.43	40 2.29
Efficiency of band utilization (bit/s/Hz)	1.68	3.08

(¹) The interleaved frequencies of the CCIR arrangement suggested for 1800 channel systems (ZS = 35 MHz, YS = 130 MHz) might also be used. The number of channels has to be reduced from 12 to 11 because of the difficulty in limiting the power at the edge of the band.

Note. — No allowance has been made for additional bits that may be required for supervisory purposes.

REFERENCES

CCIR Documents

[1978-82]: 9/109 (Italy).

REPORT 607-2

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR RADIO-RELAY SYSTEMS IN THE RANGES 10.5 TO 10.68 GHz AND 11.7 TO 15.35 GHz

(Question 16/9)

(1974-1978-1982)

1. Spectrum availability

In the frequency range 10.5 to 15.35 GHz, according to Article 8 of the Radio Regulations, the frequency bands 10.5 to 10.68 GHz, 11.7 to 12.5 GHz, 14.4 to 14.5 GHz and 14.5 to 15.35 GHz are allocated on a world-wide basis. It would appear that a study might be undertaken of the entire range with a view to specifying channel arrangements which might be fitted into an international pattern as has already been done in this part of the spectrum for the frequency bands 10.7 to 11.7 GHz (see Recommendation 387) and 12.75 to 13.25 GHz (see Recommendation 497).

2. Suitability of the frequency range for radio-relay systems

The frequency range which is the subject of this Report is already in use in certain areas of the world and practical experience is available describing both the potentials and limitations of this frequency range. In some instances precautionary measures (e.g., short paths, route diversity operation) are employed. In many areas, not noted for heavy rainfall, technical, economic and physical characteristics of operating systems resemble radio-relay systems operating in lower frequency ranges. In other cases, the careful matching of transmission requirements with system design has facilitated effective use of these bands to relieve frequency congestion in the lower bands. Such requirements include educational television (where in temperate zones heavy rainfalls often occur in the months corresponding to lowest transmission needs) short feeders to larger systems (often in metropolitan locations), loop systems delivering area type service, etc.

In other areas, the relatively broad availability of this frequency range is giving rise to the planning of new systems employing emerging technology (e.g. broadband digital).

Certain administrations are not, at present, using this frequency range extensively and might wish to develop this band for digital systems. In some cases such systems may also extend into frequency bands outside the range considered in this Report, but always with regard to the Radio Regulations.

3. Specific channel arrangements

3.1 General

Recommendation 497 provides for medium-capacity analogue and digital systems using the 12.75 to 13.25 GHz band and also mentions low-capacity systems using this same band.

The channel frequencies are chosen to facilitate frequency coordination, the use of branching circuits and of smaller capacity systems. They also permit the utilization of cross-polarization for frequency coordination or possibly, in the case of digital transmission, for co-channel operation *.

3.2 14/28 MHz plan

For many purposes the use of a homogeneous frequency pattern based on an interval of 14 MHz is possible.

The radio-channel centre frequencies of the basic pattern are derived from a formula such as:

$$f_n = f_r + 14n \quad (n = \dots 0, 1, 2, \dots), \text{ MHz}$$

where f_r is a reference frequency and n is the channel number.

The preferred reference frequency f_r is 11 701 MHz.

In very small frequency bands, it may be preferable to use a basic interval of 14 MHz but staggered by 7 MHz with respect to the above formula.

Recommendation 497 shows a preferred channel arrangement in the band 12.75 to 13.25 GHz using the basic pattern.

Annex I to this Report shows a preferred channel arrangement in the band 10.5 to 10.68 GHz using the same basic pattern. **

In the band 11.7 to 12.5 GHz, certain countries propose to use radio-relay systems with SSB modulation for the simultaneous transmission of several television and sound-broadcasting signals by one or more transmitters to a number of receiving stations. The frequencies indicating the channel to be used for an individual television plus sound signal should correspond to the centre of the modulating band of this individual signal.

* A letter relating to this subject has been addressed to the Chairman of Study Group 5.

** In certain countries and for certain applications other arrangements may be used.

3.3 12.5/25 MHz plan

In the United States of America, extensive use is being made of the 12.7 to 12.95 GHz range primarily for television transmission to feed wired distribution systems (cable television). These systems, often traversing distances of 100 to 500 km are typically unidirectional, hence a frequency pattern without a guard band is used utilizing a 25 MHz spaced main channel plan and a mid-spaced interstitial plan for coordination purposes (e.g., branch routes).

This frequency range is also available for multiple television channel transmission – both vestigial sideband/SSB and VSB/FM. These are typically of a short-haul type (5-15 km) and feed multiple receiving points. The rest of the band (12.95 to 13.25 GHz) uses a similar channelling pattern, but the prime use here is to feed television broadcasting systems, both in fixed, as well as in mobile configurations. In Japan, the entire frequency range of 12.7 to 13.25 GHz is used for television pick-up and studio transmitter links with the same 25 MHz channel separations.

3.4 20 MHz plan

In the United States of America and Japan, the 12.2 to 12.7 GHz range is used for both television and telephony data transmission. The channelling arrangement is based on a 20 MHz pattern. These channels are used for FDM telephony (to 1200 channels) or for 7.876 Mbit/s 4-phase PSK digital data streams. Users of this band include utilities, educational entities, civil government and commerce.

3.5 19.18 MHz spacing plan in the band 11.7 to 12.5 GHz *

The development of a channel arrangement in the 11.7 to 12.5 GHz band will need to take into account the requirements of the broadcasting-satellite (BS) service to which the band or parts thereof are also allocated, in accordance with the decisions of the World Administrative Radio Conference, Geneva, 1977 (WARC-BS-77) and WARC-79. For Regions 1 and 3, studies [CCIR, 1974-78] indicate that a channel arrangement should have the following basic characteristics in order to facilitate sharing between the two services:

- adjacent channel spacing should be the same as, or a multiple of, the spacing agreed for the BS service (19.18 MHz);
- channel frequencies should coincide or be interleaved with the BS service frequencies, that is

$$f = (11\,708.3 + 19.18\,n) \quad \text{MHz}$$

$$\text{or} \quad f = (11\,717.89 + 19.18\,n) \quad \text{MHz}$$

where $n = 1, 2, 3 \dots 40$

- go and return channel separations should be compatible with BS assigned frequency grouping.

With regard to Region 2, it should be noted that a detailed plan for the broadcasting-satellite service in this band will not be available until 1983, following the Regional Administrative Radio Conference scheduled for this purpose. The frequencies and channel separations for the broadcasting-satellite service in Region 2 will not be known before that date and may be different from those given above.

An example for the frequency band 11.7 to 12.2 GHz has been suggested [CCIR, 1974-78].

3.6 Channelling plan with 5 MHz spacing in the bands 10.38 to 10.45 GHz and 10.58 to 10.65 GHz

In Sweden, these frequency bands are used for the transmission by radio channel of 120 telephone channels (FDM) or of 30 digital channels. The channel arrangement is based on a separation of 5 MHz.

Attention is drawn to the fact that in Region 2 the band 10.38 to 10.45 GHz is not available for radio-relay systems.

REFERENCES

CCIR Documents

[1974-78]: 9/286 (Australia).

* The selection of radio-frequency channels from the 19.18 MHz spacing plan should be determined by agreement between administrations concerned.

ANNEX I

DESCRIPTION OF THE RADIO-FREQUENCY CHANNEL ARRANGEMENT IN THE
FREQUENCY BAND 10.5 TO 10.68 GHz REFERRED TO IN § 3.2 OF THIS REPORT

The channel arrangement is as follows:

- lower half of the band: $f_n = (f_r - 1204 + 7 m)$ MHz
- upper half of the band: $f'_n = (f_r - 1113 + 7 m)$ MHz

The 12 values of m from 1 to 12 will provide the twelve channel frequencies of each half-band.

The reference frequency f_r is:

$$f_r = 11\,701 \text{ MHz}$$

This arrangement is illustrated in Fig. 1.

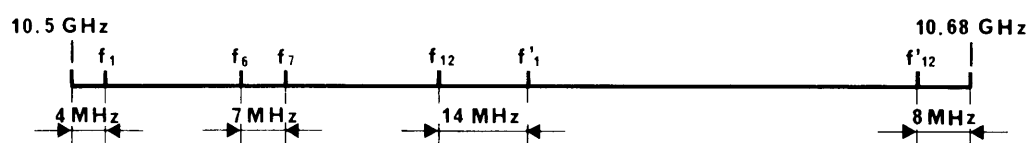


FIGURE 1 — Radio-frequency channel arrangement in the frequency band 10.5 to 10.68 GHz

RECOMMENDATION 497-2

**RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR ANALOGUE RADIO-RELAY SYSTEMS
FOR TELEVISION AND FDM TELEPHONY WITH A CAPACITY
OF 960 TELEPHONE CHANNELS OR THE EQUIVALENT AND FOR MEDIUM
CAPACITY DIGITAL SYSTEMS OPERATING IN THE 13 GHz BAND**

(Question 16/9)

(1974–1978–1982)

The CCIR,

CONSIDERING

- (a) that the 12.75 to 13.25 GHz band is allocated to the fixed and mobile terrestrial services;
- (b) that, at these frequencies, radio-relay systems for digital or analogue transmission are feasible with repeater spacings and other features chosen according to rainfall conditions;
- (c) that it may be desirable to interconnect such systems at radio frequencies on international circuits;
- (d) that a uniform radio-frequency channel arrangement usable for both analogue and digital systems offers considerable advantages;
- (e) that the homogeneous frequency pattern based on an interval of 14 MHz (see Report 607) is adaptable in this frequency band;
- (f) that it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;
- (g) that the radio-frequency channels should be so arranged that an intermediate frequency of 70 MHz be employed for analogue and for digital systems,

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for FDM radio-relay systems with a maximum capacity of 960 telephone channels or the equivalent, and for digital radio-relay systems with a maximum capacity of 480 telephone channels or the equivalent, operating in the 13 GHz band, should be derived as follows:

Let f_0 be a reference frequency (MHz) near the centre of the 12.75 to 13.25 GHz band;

f_n be the centre frequency (MHz) of a radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (MHz) of a radio-frequency channel in the upper half of the band;

then the frequencies of individual channels are expressed by the following relationship:

$$\begin{aligned} \text{lower half of the band: } f_n &= (f_0 - 259 + 28n) && \text{MHz} \\ \text{upper half of the band: } f'_n &= (f_0 + 7 + 28n) && \text{MHz,} \end{aligned}$$

where:

$$n = 1, 2, 3, 4, 5, 6, 7 \text{ or } 8.$$

The frequency arrangement is illustrated in Fig. 1;

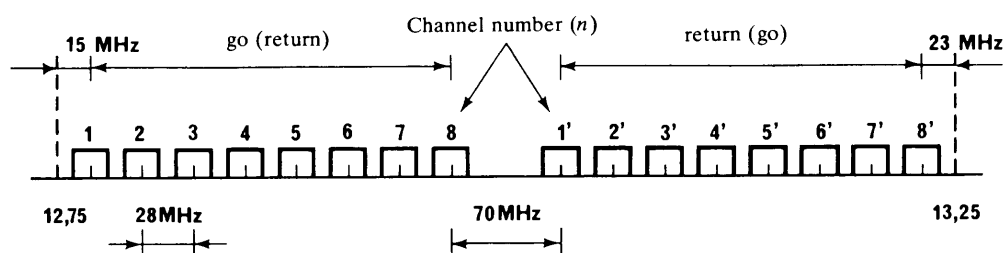


FIGURE 1 – Radio-frequency channel arrangement for radio-relay systems operating in the 13 GHz band (main pattern)

2. that, in the section through which an international connection is arranged to pass, all the go channels should be in one half of the band and all the return channels should be in the other half of the band;

3. that, in FDM systems, horizontal and vertical polarization shall be used alternately for adjacent radio-frequency channels in the same half of the band;

4. that, in digital systems, both horizontal and vertical polarization shall be used, where possible, for each radio-frequency channel;

5. that for digital systems with a capacity of 960 telephone channels the same radio-frequency channel arrangement may be used utilizing the RF channels number $n = 2, 4, 6$ and 8 in the case of a co-channel arrangement or $n = 1, 2, 3, 4, 5, 6, 7$ and 8 in the case of an interleaved arrangement (the possible use of the channel number 1 would depend on the radiated spectrum width);

6. that, when additional radio-frequency channels with a maximum capacity of 300 FDM channels or of 240 digital channels, interleaved between those of the main pattern, are required, the values of the centre frequencies of these radio-frequency channels should be 14 MHz above those of the corresponding main channel frequencies. On the same route, it is advisable to use only systems having capacities no greater than these, when using this spacing;

7. that, when common transmit-receive antennas are used and no more than four channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by making either:

$$n = 1, 3, 5 \text{ and } 7 \text{ or } 2, 4, 6 \text{ and } 8;$$

8. that, for international connections, the reference frequency should preferably be 12 996 MHz. Other values may be used by agreement between the administrations concerned;

9. that, in cases where smaller capacity radio channels having a capacity of 30 digital telephone channels (or the equivalent) are required, the following channel arrangements, (which occupy some of the bi-directional medium-capacity radio channels of the basic channel arrangement), should be used (see Note 2):

– Alternative I:

$$\begin{aligned} \text{lower half of the band: } f_m &= (f_0 - 276.5 + 28n + 7m) && \text{MHz} \\ \text{upper half of the band: } f'_m &= (f_0 - 10.5 + 28n + 7m) && \text{MHz,} \end{aligned}$$

where:

m is equal to 1, 2, 3 or 4, and n refers to the channel number of the basic channel arrangement.

When $n = 1$, the channel arrangement of Fig. 2(a) is obtained.

Additional channels may be obtained by choosing $n = 2$.

By agreement between the administrations concerned, n may be greater than 2.

– Alternative II:

$$\begin{aligned} \text{lower half of the band: } f_m &= (f_0 - 66.5 + 7m) && \text{MHz} \\ \text{upper half of the band: } f'_m &= (f_0 + 3.5 + 7m) && \text{MHz,} \end{aligned}$$

where:

m is preferably 3, 4, 5 or 6.

When additional channels are required, channel values of $m = 1, 2, 7$ or 8 , may be used. This arrangement is illustrated in Fig. 2(b);

– Alternative III:

To achieve double the number of low capacity channels using channels 1 and 1' of the basic plan as compared with Alternative I:

$$\begin{aligned} \text{lower half of the band: } f_m &= (f_0 - 273 + 28n + 3.5m) && \text{MHz} \\ \text{upper half of the band: } f'_m &= (f_0 - 7 + 28n + 3.5m) && \text{MHz,} \end{aligned}$$

where:

m is equal to 1, 2, 3, 4, 5, 6, 7 or 8 and n refers to the number of the basic channel arrangement.

When $n = 1$, the channel arrangement of Fig. 2(c) is obtained.

Additional channels may be obtained by choosing $n = 2$.

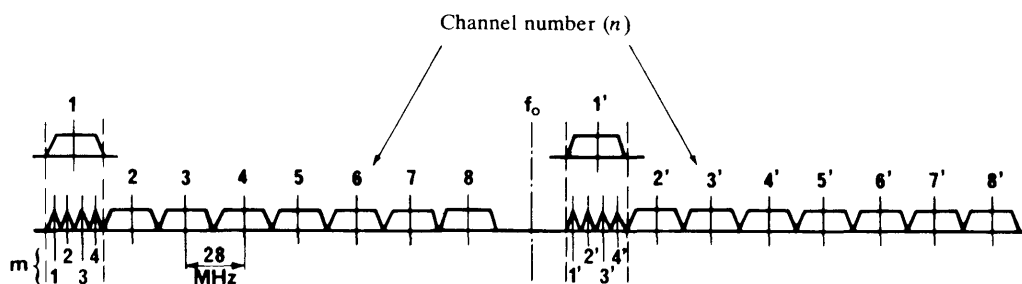
By agreement between the administrations concerned, n may be greater than 2.

10. that due regard should be taken of the fact that a different channel arrangement for up to 960 telephone channel digital systems is also used; this arrangement is described in Annex I;

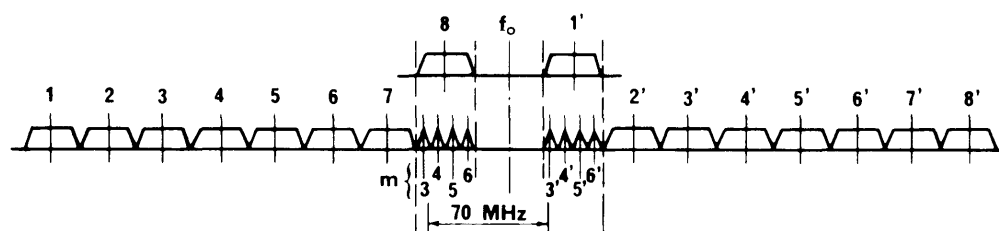
11. that Note 1 should be regarded as part of this Recommendation.

Note 1. – In some countries in Region 1, the basic channel spacing of this frequency pattern may be suitable for extension to adjacent frequency bands in the range 11.7 to 15.35 GHz, taking into account the appropriate Radio Regulations.

Note 2. – In order to reduce the possibility of an unacceptable degradation in performance occurring, care should be exercised in using mixed channel arrangements in a radio-relay network. This would especially apply if the low capacity channel arrangements described in § 9 and medium capacity radio-relay links, operating in accordance with the main channel arrangements are both present in the same network.

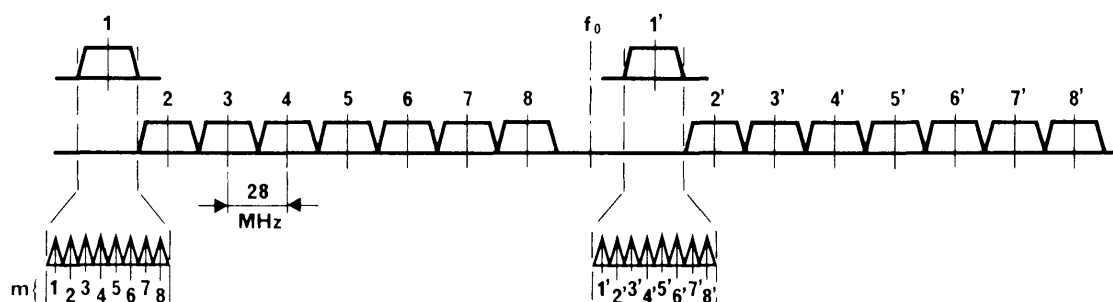


(a) Systems using channels No 1 and 1' of the basic plan



preferred values for m $m = 3, 4, 5, 6$
 additional values $m = 1, 2, 7, 8$

(b) Systems having 70 MHz frequency separation between the send and receive directions



(c) Systems using channels No. 1 and 1' of the basic plan in order to achieve a more efficient use of the spectrum when compared with the arrangement in (a)

FIGURE 2 — Examples of radio-frequency channel arrangements for smaller capacity digital systems
 (as described in § 9)

ANNEX 1

DESCRIPTION OF THE RADIO-FREQUENCY CHANNEL ARRANGEMENT
REFERRED TO IN § 9 OF THIS RECOMMENDATION

For some digital applications with a capacity of up to 960 telephone channels, a radio-frequency arrangement having the following characteristics may be used:

lower part of the band: $f_n = (f_0 - 259 + 35 n)$ MHz

upper part of the band: $f'_n = (f_0 + 21 + 35 n)$ MHz,

where:

$n = 1, 2, 3, 4, 5$ or 6 .

The arrangement is illustrated in Fig. 3.

The preferred reference frequency f_0 is the same as that given in § 8.

All the go channels should be in one half of the band and all the return channels should be in the other half of the band. For the adjacent radio-frequency channels in the same half of the band different polarizations should preferably be used alternately.

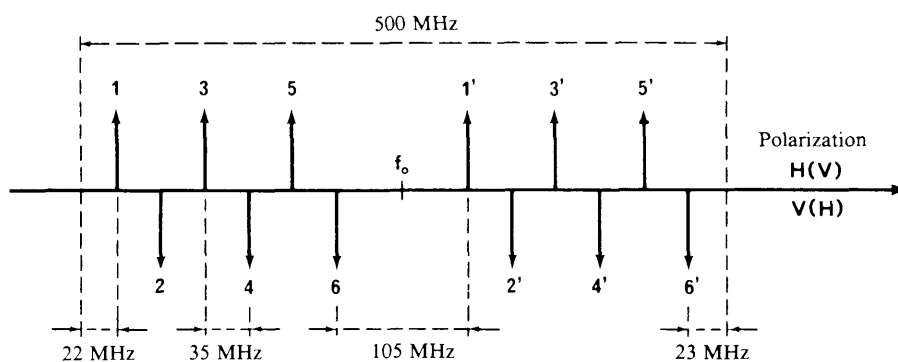


FIGURE 3 — Radio-frequency channel arrangement for high capacity digital systems

RECOMMENDATION 595 *

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR DIGITAL
RADIO-RELAY SYSTEMS IN THE 17.7 TO 19.7 GHz FREQUENCY BAND

(Question 16/9)

(1982)

The CCIR,

CONSIDERING

- (a) that there may be economic and operational advantages in the use of radio-relay systems for the transmission of digital signals in the frequency band 17.7 to 19.7 GHz;
- (b) that it may be desirable to interconnect such systems at radio frequencies on international circuits;
- (c) that a sufficient degree of compatibility between systems of different capacities should be assured,

* This Recommendation cancels Report 609-1.

UNANIMOUSLY RECOMMENDS

1. that the preferred radio frequency channel arrangement for digital radio-relay systems with a capacity of the order of 280 Mbit/s, the order of 140 Mbit/s and 34 Mbit/s operating in the 17.7 to 19.7 GHz band should be derived as follows:

Let f_0 be the frequency (MHz) of the centre of the band of frequencies occupied;
 f_n be the centre frequency (MHz) of a radio-frequency channel in the lower half of the band;
 f'_n be the centre frequency (MHz) of a radio-frequency channel in the upper half of the band;

then the frequencies of individual channels are expressed by the following relationships:

1.1 *Co-channel arrangement*

1.1.1 for systems with a capacity of the order of 280 Mbit/s:

$$\begin{aligned} \text{lower half of the band: } f_n &= (f_0 - 1110 + 220 n) && \text{MHz} \\ \text{upper half of the band: } f'_n &= (f_0 + 10 + 220 n) && \text{MHz,} \end{aligned}$$

where:

$$n = 1, 2, 3 \text{ or } 4.$$

The frequency arrangement is illustrated in Fig. 1(a);

1.1.2 for systems with a capacity of the order of 140 Mbit/s:

$$\begin{aligned} \text{lower half of the band: } f_n &= (f_0 - 1000 + 110 n) && \text{MHz} \\ \text{upper half of the band: } f'_n &= (f_0 + 10 + 110 n) && \text{MHz,} \end{aligned}$$

where:

$$n = 1, 2, 3, 4, 5, 6, 7 \text{ or } 8.$$

The frequency arrangement is illustrated in Fig. 1(b);

1.1.3 for systems with a capacity of 34 Mbit/s:

$$\begin{aligned} \text{lower half of the band: } f_n &= (f_0 - 1000 + 27.5 n) && \text{MHz} \\ \text{upper half of the band: } f'_n &= (f_0 + 10 + 27.5 n) && \text{MHz,} \end{aligned}$$

where:

$$n = 1, 2, 3, \dots 35.$$

The frequency arrangement is illustrated in Fig. 1(c).

1.2 *Interleaved arrangement*

1.2.1 for systems with a capacity of the order of 280 Mbit/s:

$$\begin{aligned} \text{lower half of the band: } f_n &= (f_0 - 1000 + 110 n) && \text{MHz} \\ \text{upper half of the band: } f'_n &= (f_0 + 120 + 110 n) && \text{MHz,} \end{aligned}$$

where:

$$n = 1, 2, 3, 4, 5, 6 \text{ or } 7.$$

The frequency arrangement is illustrated in Fig. 2(a).

1.2.2 for systems with a capacity of the order of 140 Mbit/s:

$$\begin{aligned} \text{lower half of the band: } f_n &= (f_0 - 945 + 55 n) && \text{MHz} \\ \text{upper half of the band: } f'_n &= (f_0 + 65 + 55 n) && \text{MHz,} \end{aligned}$$

where:

$$n = 1, 2, 3, \dots 15.$$

The frequency arrangement is illustrated in Fig. 2(b);

2. that, in the section through which an international connection is arranged to pass, all the go channels should be in one half of the band and all the return channels should be in the other half of the band;

3. that both horizontal and vertical polarizations should be used for each radio-frequency channel in the co-channel arrangement;

4. that the centre frequency f_0 is 18 700 MHz;

5. that for digital systems of low capacity, i.e. below about 10 Mbit/s, individual radio frequency channel allocations may be accommodated within any of the high-capacity channels, without restricting the selection of the go and return channels to the pairs shown in Figs. 1 and 2;

6. that for medium-capacity systems with bit rates different from that given in § 1.1.3 and for low-capacity systems, administrations may adopt other RF channel arrangements in conformity with the recommended pattern for high-capacity systems;

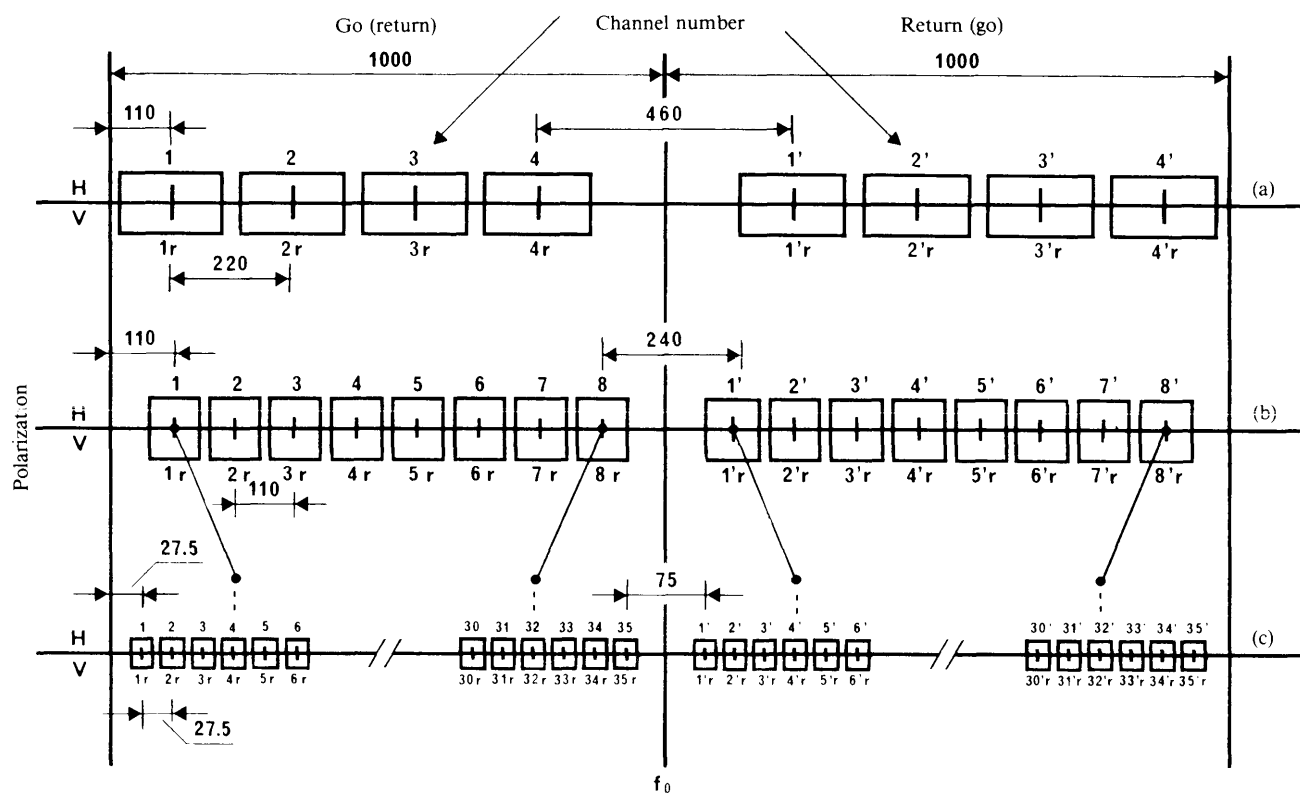


FIGURE 1 — Radio-frequency channel arrangement for radio-relay systems operating in the 17.7 to 19.7 GHz band
(Co-channel arrangement)
(All frequencies are in MHz)

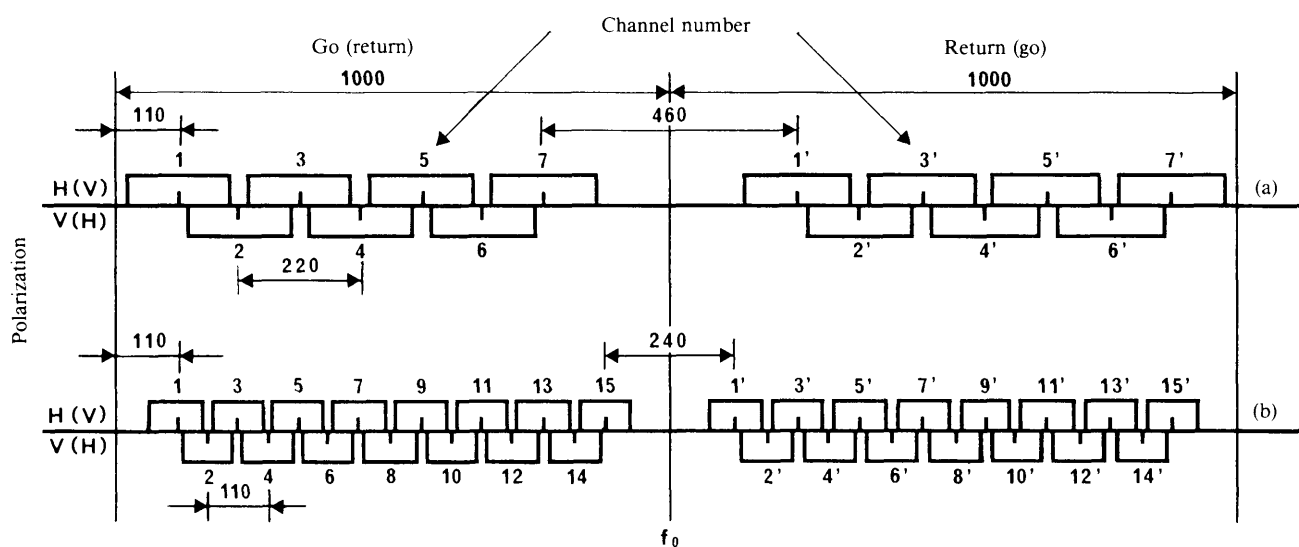


FIGURE 2 — Radio-frequency channel arrangement for radio-relay systems operating in the 17.7 to 19.7 GHz band
(Interleaved arrangement)
(All frequencies are in MHz)

7. that due regard be taken of the fact that in some countries another arrangement of the go and return channels which incorporates a mid-band allocation for low-capacity systems may be used, as shown in Fig. 3;

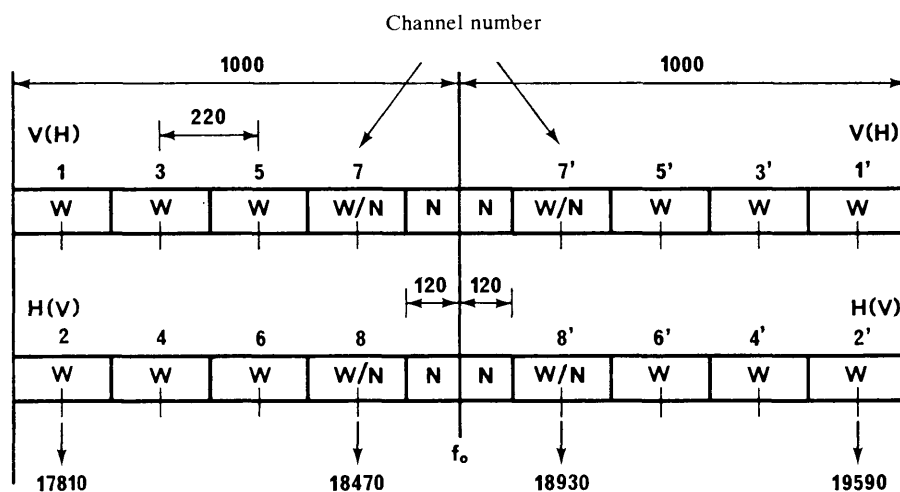


FIGURE 3 — Co-channel radio-frequency arrangement for radio-relay systems operating in the 18 GHz band referred to in RECOMMENDS 7

(All frequencies are in MHz)

W: wide-band channel (high-capacity of the order of 280 Mbit/s)
 N: narrow-band channel (low-capacity, below 10 Mbit/s)
 W/N: wide-band or narrow-band channel

8. that due regard be taken of the fact that in the countries where the band 17.7 to 21.2 GHz is available for the fixed service other channel arrangements may be used.

Note. — In establishing these systems, account should be taken of the need of passive sensors for earth exploration by satellite and space research in the band 18.6 to 18.8 GHz particularly in Region 2 where these services have primary status in conformity with Recommendation No. 706 and other relevant provisions (see No. 871) of the Radio Regulations (see Recommendation 515, Report 694 and Study Programme 17D/9).

REPORT 936

RADIO-RELAY SYSTEMS IN THE BANDS BETWEEN ABOUT 20 GHz AND 40 GHz

(Question 16/9 and Study Programme 16B/9)

(1982)

1. Introduction

In the frequency range between about 20 GHz and 40 GHz some allocations are provided for the fixed service on a world-wide basis according to Article 8 of the Radio Regulations.

Additional use of the frequency band 19.7 GHz to 21.2 GHz is permitted in some countries for fixed and mobile services, with the restriction that such use should not impose any limitation of the power-flux density of space stations in the fixed-satellite service. This frequency band is already in use in Japan for high capacity digital radio-relay systems.

Other administrations are at present contemplating using the frequency range which is the subject of this Report for digital radio-relay systems with low and medium capacities [Pilgrim *et al.*, 1981].

This range of frequencies may also be suitable for point to multi-point services in rural areas or for broadband subscriber connections in urban areas (see Report 940).

Administrations are invited to submit contributions on the use of this frequency range.

2. Specific channel arrangements

In Japan the frequency band between 17.7 GHz and 19.7 GHz is used contiguously with the 19.7 to 21.2 GHz band for radio-relay systems having a transmission capacity of about 400 Mbit/s. An example is given in Annex I.

REFERENCES

PILGRIM, M., SWAIN, R. S., BARNES, B. C. and MOHAMMED, S. A. [17 March, 1981] Local network microwave links at 29 GHz. IEE Conf. Publ. No. 193. IEE Second International Conference on Telecommunication Transmission – Into the Digital Era, London, UK.

ANNEX I

APPLICATION OF THE FREQUENCY BAND 17.7 TO 21.2 GHz FOR A HIGH CAPACITY RADIO-RELAY SYSTEM

1. Radio-frequency channel arrangement

The radio-frequency channel arrangement shown in Fig. 1 occupies a band of 3.5 GHz and provides for 9 go-and-return radio-frequency channels.

Using the definitions of X , Y and Z in Report 378, the values are:

$$X = 1.6 \quad Y = 3.1 \quad Z = 0.8$$

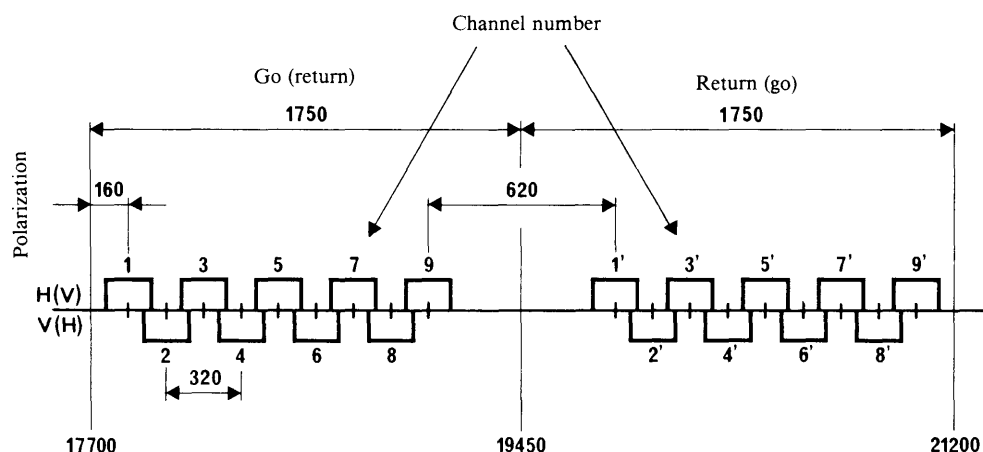


FIGURE 1 — Radio-frequency channel arrangements for digital radio-relay systems operating in the 17.7-21.2 GHz band
(All frequencies are in MHz)

Arrangement type: interleaved arrangement
 Lower half of the band: $f_n = (17\,700 + 160\,n)$ MHz
 Upper half of the band: $f'_n = (19\,600 + 160\,n)$ MHz
 where $n = 1, 2, 3, \dots, 9$

2. System parameters

Transmission capacity of about 400 Mbit/s (5760 telephone channels) per RF-channel is achieved by using 4-PSK modulation. The system operates with a receiver noise figure of 8 dB, a transmitter output power of 22 dBm and an antenna of 1.8 m diameter. The typical repeater spacing is about 3 km, dependant on the precipitation conditions along the route. The system is also used for broadband non-telephone services e.g. picture and data communications in urban areas and also for long-distance circuits.

Further information on design parameters and interference considerations is to be found in the Bibliography.

BIBLIOGRAPHY

- KUWABARA, M., YAMAMOTO, H., YOKOYAMA, S. and TAGASHIRA, Y. [15 June, 1977] Design and performance of 20 GHz radio repeater. IEEE International Conference on Communications (ICC '77), Chicago, Ill., USA, Conf. Rec., Vol. 3, Session 40: High capacity microwave systems, 40.4-93 – 40.4-97.
- NAKAMURA, Y., YOSHIKAWA, T., HOSODA, A. and MUKAI, T. [15 June, 1977] 20 GHz digital radio-relay system. IEEE International Conference on Communications (ICC '77), Chicago, Ill., USA, Conf. Rec., Vol. 3, Session 40: High capacity microwave systems, 40.3-88 – 40.3-92.
- SATO, M., YAMAZAKI, F. and IWAMOTO, M. [July, 1978] Commercial tests on 20 GHz digital radio-relay system. *Japan Telecomm. Rev.*, Vol. 20, 3, 234-242.

REPORT 783-1

RADIO-RELAY SYSTEMS IN FREQUENCY BANDS ABOVE ABOUT 40 GHz

(Study Programme 16A/9)

(1978-1982)

1. Introduction

The World Administrative Radio Conference (Geneva, 1979) has allocated radio frequencies above 40 GHz to fixed services; consequently it is of value to predict the characteristics of radio-relay systems best suited for the exploitation of these frequencies. A parameter of particular importance to the implementation of such systems is the transmitter-to-receiver path length (hop length) that may be achieved when, for example, propagation characteristics, equipment capabilities and system performance are taken into consideration. This parameter is considered in this Report for three systems defined as long, medium and short haul; 2500, 160 and 20 km long respectively. To avoid over-complication, multiple-route systems have not been included, though they may be advantageous in particular instances as the technique provides a means of diversity and may allow fewer repeaters to be used than in the equivalent single-route system.

An investigation of this nature necessarily requires many assumptions to be made concerning propagation characteristics and system parameters. However, in an example relevant to the United Kingdom, an indication has been given of the change in hop length that might result from errors of assumption; also included are the results of a similar study carried out in Japan.

2. System equation

If multipath or similar activity can be neglected (relatively short hop lengths are envisaged) $F(l, p)$, the excess attenuation that is exceeded with probability p for a hop length of l km, is determined by fading due to precipitation. The receiver threshold is reached when $F(l, p)$ becomes equal to the system fade margin as shown in the following equation:

$$F(l, p) = [P + G_t + G_r - L - NF - C - 10 \log B] + R(l) \quad \text{dB} \quad (1)$$

$R(l)$ is a transmission parameter obtained from Fig. 1. It includes the free-space and oxygen absorption losses together with the thermal noise power density:

$$R(l) = -10 \log \left[\left(\frac{4\pi}{3} \right)^2 k \cdot T \cdot f^2 \cdot l^2 \cdot 10^8 \right] - \gamma_o \cdot l$$

With:

- l : hop length
- k : Boltzmann's constant (1.38×10^{-23} J/K)
- T : ambient temperature (290 K)
- f : frequency (GHz)
- γ_o : oxygen absorption coefficient (dB/km).

The other parameters are:

- P : transmitter output power (dBW)
- G_t and G_r : transmitter and receiver antenna gain (dB)
- L : RF losses, including multiplexing (dB)
- NF : receiver noise figure relative to 290 K (dB)
- C : required carrier-to-noise power ratio at threshold (dB)
- B : equivalent receiver noise bandwidth (Hz).

Scintillation can also be neglected, for Report 338 shows it to be of the order of ± 1 dB at 100 GHz (2 km path) and relatively insensitive to frequency. Such fluctuations are small when compared to the likely required rain-fade margins.

For the purposes of equation (1), $F(l, p)$ can be derived by any suitable means, for example, from the results of direct observations or extrapolation from data obtained for other frequencies and/or locations.

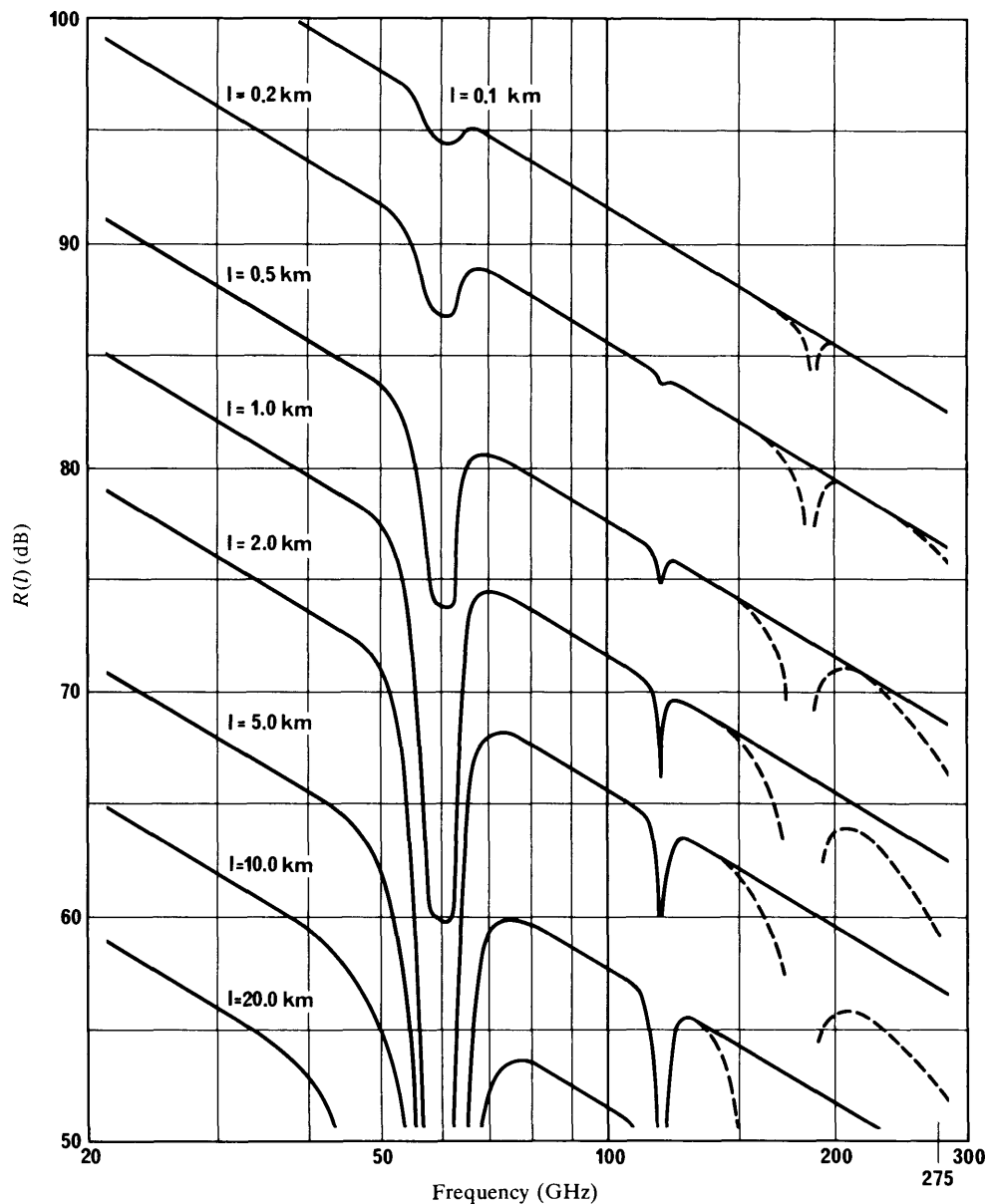


FIGURE 1

The parameter $R(l)$

--- The dashed lines indicate the approximate region of significant absorption by water vapour.

3. Digital radio-relay system hop length

No universal hop-length/frequency characteristic can be constructed but from the following examples, which are relevant to the environments of the United Kingdom and Japan, it is possible to derive some general conclusions.

The examples considered in the United Kingdom study were medium and short haul systems with their higher error-probability threshold being exceeded for 0.01% of the year when considering interruptions due only to the propagation medium. System parameters are given in columns 1 and 3 of Table I. The examples were also considered in Japan on the assumption of system parameters given in Columns 2 and 4 of Table I.

TABLE I — System parameters

	Medium- and long-haul system		Short-haul system	
	(1)	(2)	(3)	(4)
Route length	160 km	2 500 km	20 km	
Unavailability	0.01% (0.0000625%/km)	0.1% (0.00004%/km)	0.01% (0.0005%/km)	0.018% (0.0009%/km)
Error-probability threshold	10^{-4}		10^{-4}	
Modulation	QPSK	QPSK	QPSK	BPSK
P	See Fig. 2, Curve B	See Fig. 2, Curve B'	See Fig. 2, Curve B	See Fig. 2, Curve B'
G_t and G_r — Pole-mounted — Building-mounted	40 dB 48 dB	Theoretical value for 1 m diameter at 50% efficiency	40 dB 48 dB	Theoretical value for 1 m diameter at 50% efficiency
L	8 dB	6 dB	8 dB	6 dB
Noise figure, NF	See Fig. 2, Curve A	See Fig. 2, Curve A'	See Fig. 2, Curve A	See Fig. 2, Curve A'
Transmitted symbol rate, S	154 Mbaud	200 Mbaud	154 Mbaud	32 Mbaud
B	160 MHz	200 MHz	160 MHz	32 MHz
C	16 dB	18 dB	16 dB	15 dB

Columns: (1) and (3): studied in the United Kingdom
(2) and (4): studied in Japan.

In determining $F(l, p)$ attenuation resulting only from rain has been considered. In some cases the effects of snow may also be significant, and water vapour has been considered only at 183 GHz where a strong absorption line exists.

Comprehensive, long-term, rain-fade data for the frequency range of interest do not exist. The approach adopted has therefore been to use data for 20 GHz and convert to higher frequencies by appropriate scaling. For a fixed rain rate it is possible to determine the correct scaling factor from the specific attenuation (dB/km) versus frequency curves given in Report 721. Above about 40 GHz, practical hop lengths will be less than the average rain-cell size, as indicated in Report 563, and the same Report also shows that for 0.001% of the year (the approximate period of interest per hop) the point rainfall rate in the United Kingdom exceeds 50 mm/h. Thus, the specific attenuation curve for 50 mm/h given in Report 721 was used as a reasonable basis for scaling. However, this rainfall rate is subject to year-to-year variations which could be as much as $\pm 30\%$. It has also been assumed that no correlation exists between fading on adjacent hops; this may be reasonable for 20 GHz, but not for frequencies above 40 GHz, and could result in calculated hop lengths being pessimistically short.

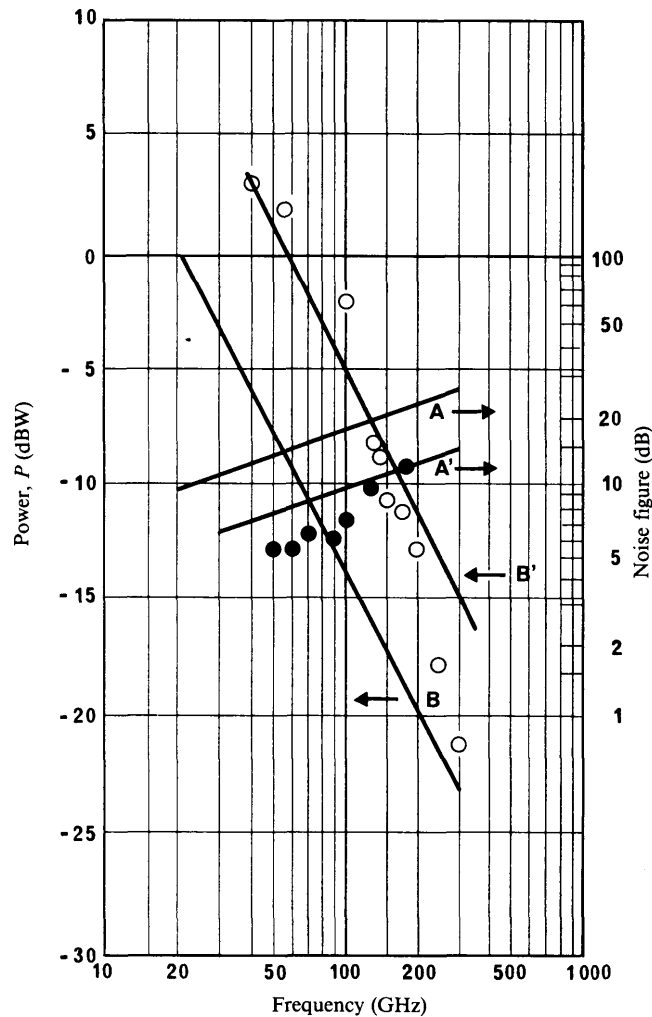


FIGURE 2 — System parameters.

Curves A, A': receiver noise figure
 Curves B, B': transmitter power
 ●: receiver noise figure
 ○: IMPATT oscillator output power

(A and B are feasible values, A' and B' are the values expected with steady progress in millimetre-wave equipment technology.)

In Japan the precise cumulative distribution curve has already been obtained as a result of the development of the radio-relay system using 20 GHz band [Morita and Higuchi, 1976]. Estimated rainfall rate, for example, is about 180 mm/h and 130 mm/h for 0.00004% and 0.0003% of the year, respectively. The rain attenuation is estimated from Fig. 1 of Report 721 and is 60 dB and 45 dB for rainfall rates of 180 mm/h and 130 mm/h, respectively.

The results of solving equation (1) for hop length (l) are given in Fig. 3 (curves A, B and C). Also shown is the clear air, zero humidity, unobstructed range for the same systems, with the received signal level equal to that for threshold performance. These solutions are subject to the validity of the parameters, and to assess their sensitivity to errors the hop lengths were re-calculated at two frequencies with a ± 10 dB addition to equation (1); the results are shown in Fig. 3 as the margin for assumptions. Thus, for example, if the required fade margin was underestimated (or the transmitter power overestimated) by 10 dB then the lower limit of the margin shows the resultant hop length.

The results of a study carried out in Japan of long-haul and short-haul digital systems are also given in Fig. 4 (curves F and G).

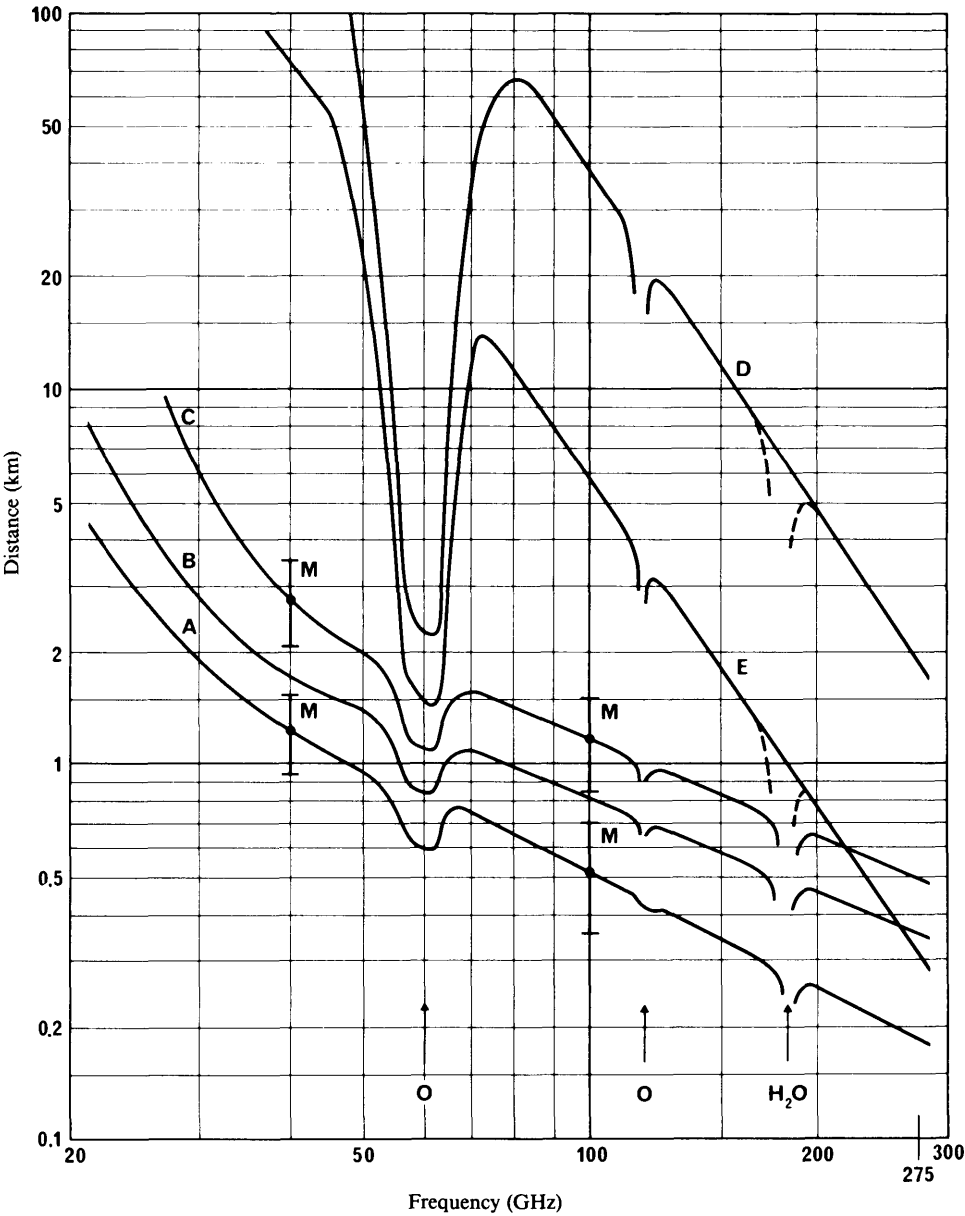


FIGURE 3 — Range for 160 and 20 km radio-relay systems (studied in the United Kingdom)

Hop length	{	Curves A:	route length 160 km, pole-mounted antenna
		B:	route length 160 km, building-mounted antenna
		C:	route length 20 km, building-mounted antenna
Range of interference	{	Curves D:	clear air, zero humidity, unobstructed range using building-mounted antenna
		E:	clear air, zero humidity, unobstructed range using pole-mounted antenna
M : ± 10 dB margin for assumptions			
O : oxygen absorption band			
H ₂ O : water vapour absorption band			
----- The dashed lines indicate the approximate region of significant absorption by water vapour.			

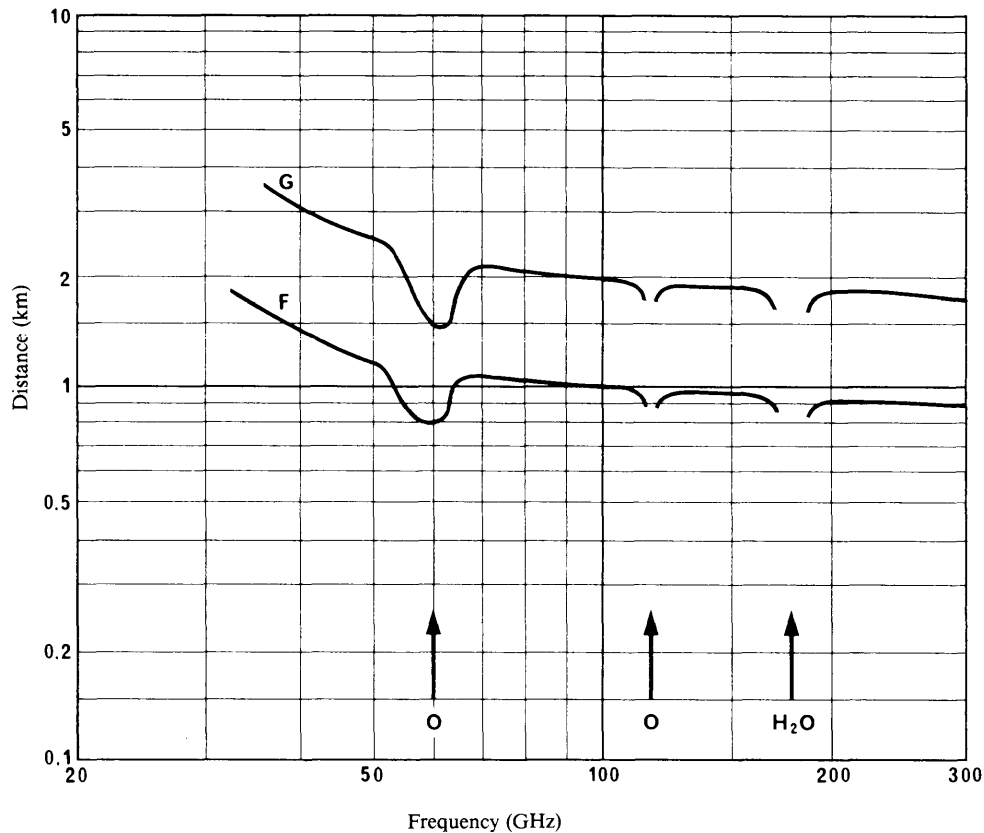


FIGURE 4 — Hop length for 2 500 and 20 km radio-relay systems (studied in Japan)

Hop length { Curves F: route length 2500 km
G: route length 20 km

4. Spectrum use by digital radio-relay systems in the fixed service

Curves A and B of Fig. 3 and F of Fig. 4 show that above 40 GHz at least 90 regenerative repeaters per one-way channel are necessary to equip a high-capacity long-haul or medium-haul radio-relay system. Such numbers of repeaters would, on the basis of currently achieved failure rates, yield availability results well below the presently stated objectives (Recommendation 557); however, it is expected that the full application of integrated-circuit techniques will offset these difficulties.

For the short-haul system, curves C of Fig. 3 and G of Fig. 4, a maximum of 20 repeaters would suffice up to 100 GHz and, except for the 118.7 GHz absorption band, may also be adequate for up to 150 GHz given not unreasonable progress in the achievement of higher equivalent isotropically radiated power and lower receiver noise figures. Though the 60 GHz absorption band is included in the above observation, this band, with its low potential for causing or receiving interference, is clearly potentially useful for the local distribution of signals by radio.

5. Characteristics of digital radio-relay systems above 40 GHz

The suggested use of twenty regenerative repeaters in tandem may seem prohibitively high but their physical characteristics will be very different from current practice in the 4, 6 and 11 GHz bands, for example, much smaller and readily manipulated antenna and equipment assemblies, less antenna height required, etc. It is conceivable that each both-way pair of RF channels may be served by a self-contained unit with antenna and

equipment directly coupled together. Such a configuration would nearly eliminate multiplexing losses as there would be no requirement to multiplex together all the RF channels (approximately 4 dB has been allowed for this loss in Fig. 3). The RF channelling problems would be eased because the necessity to reflect the wanted channel off the adjacent channel filters would be removed. This latter advantage should result in more efficient use of the available RF spectrum.

Though the antenna gains given in columns 1 and 3 of Table I are representative of current practice, being influenced by consideration of wind and thermal stability of the antenna mounting, at higher frequencies it may be economically and practically possible to use more stable structures thereby permitting higher gains.

In the studies carried out in Japan, the antenna gain is assumed to be in proportion to the square of frequency.

6. Interference considerations

The clear air, zero humidity, unobstructed range curves of Fig. 3 (curves D and E) give a measure of the interference potential of high-capacity digital systems above 40 GHz. The interfering systems are assumed to be homogeneous and aligned with each other and will therefore receive interference equal to their threshold signal level. The results suggest that above about 50 GHz inter-system interference problems will be eased, and virtually eliminated in the absorption bands, for they indicate that in the unlikely event of such propagation conditions occurring between two systems, the range of the interfering signal would be less than about 100 km.

Though the short hop lengths indicated in Fig. 3 potentially pose problems of overshoot interference, in rugged terrain they also mitigate the problems of finding suitable line-of-sight routes.

7. An example of a simple radio-relay system in the frequency bands above about 40 GHz

In the 20 GHz band, high-capacity radio-relay systems are already in use [Nishino *et al.*, 1976], and in higher frequency bands around 40 GHz simple radio-relay systems are also in use [Samejima and Kurokawa, 1979].

In the 40 GHz band, compact antennas with sharp directivity are realized. Radio equipment is also designed compactly as compared with that of lower bands. With this antenna and a transmitter and receiver connected directly without feeder, it is possible to realize a simple radio-relay system which may be used as a transportable system if required. An example of the performances of such a system is shown as follows:

TABLE II

Capacity	1.5 Mbit/s (or 6.3 Mbit/s)	Video conference (colour)
Modulation	2 PSK	FM
Frequency	38.6-40.0 GHz	38.6-40.0 GHz
Hop length	To be determined in consideration of rain-rate distribution of the area and on the number of hops and the availability objective where the system is installed.	

8. Conclusions

In this Report three high-capacity digital radio-relay systems have been considered; long- medium- and short-haul systems of 2500, 160 and 20 km length respectively. The Report concludes that transmission over long- and medium-haul systems may be difficult above about 40 GHz in the near future due to the large number of regenerative repeaters likely to be required and the consequent effect on system availability. For short-haul systems the frequency limit seems to be above 100 GHz, and may extend to 150 GHz. Multiple route systems, however, have not been considered but may have advantages in particular circumstances.

Though the problems of over-shoot interference will be increased by the expected short hop lengths, the problem of inter-system interference is likely to be eased above 50 GHz.

Over the frequency range considered, antennas can be sufficiently small to allow consideration of a separate antenna for each both-way RF channel pair. This would permit the near elimination of multiplexing losses and distortions, and thereby enable better utilization of the available RF bandwidth.

The Report also shows that, absorption bands apart, the required hop length changes more slowly above 70 GHz, which suggests that the same radio-relay route may be reused over a range of frequencies if the progress of technology justifies the use of higher frequencies in the future.

REFERENCES

- MORITA, K. and HIGUCHI, I. [July-August, 1976] Prediction methods for rain attenuation distribution of micro- and millimeter waves. *Rev. Elec. Comm. Labs.*, Vol. 24, 7-8, 651-668.
- NISHINO, K., NAKAMURA, Y., HOSODA, A. and MUKAI, T. [January, 1976] 20 GHz PCM radio-relay system. *Japan Telecomm. Rev.*, Vol. 18, 1, 23-31.
- SAMEJIMA, S. and KUROKAWA, S. [October, 1979] Transportable radio equipment using 40 GHz band for video conference system. *Japan Telecomm. Rev.*, Vol. 21, 4, 364-369.

RECOMMENDATION 388

RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR TRANS-HORIZON RADIO-RELAY SYSTEMS

(Question 7/9)

(1959-1963)

The CCIR,

CONSIDERING

- (a) that trans-horizon radio-relay systems are already in service and that systems of this type will come into more extensive use in the future;
- (b) that the high radiated power of trans-horizon radio-relay systems and the long range of tropospheric-scatter propagation may give rise to serious interference at distances extending beyond international boundaries, for example, 1000 km;
- (c) that interference, both between and within trans-horizon radio-relay systems, could be minimized by the coordination of radio-frequency channel arrangements over a large geographical area;
- (d) that many interfering effects between equipment at the same station could be minimized by a carefully planned arrangement of radio frequencies;
- (e) that some technical information for the planning of such systems exists, but that the design of trans-horizon radio-relay systems is subject to change;
- (f) that different methods of modulation are at present being used or proposed, among them, frequency modulation and single-sideband amplitude modulation;
- (g) that, at the present time, standardization of preferred radio-frequency channel arrangements might therefore unduly restrict the future development of trans-horizon radio-relay systems;
- (h) that, nevertheless, a common basis for planning such systems is desirable,

UNANIMOUSLY RECOMMENDS

1. that the radio-frequency channel arrangements for the international connection of trans-horizon radio-relay systems should be agreed between the administrations concerned;
2. that the basis of planning of the radio-frequency channel arrangements for radio-relay systems using frequency modulation given in Report 286 may be used, where appropriate, as a guide.

REPORT 286

**RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR TRANS-HORIZON
RADIO-RELAY SYSTEMS USING FREQUENCY MODULATION**

(Question 7/9)

(1963)

1. Introduction

Study Programme 7A/9 asked for a study of radio-frequency channel arrangements for trans-horizon radio-relay systems. The studies carried out so far give valuable information on the problems to be taken into account for establishing such a radio-frequency channel arrangement usable over a wide geographical area. The results obtained have made it evident that it is neither possible nor even desirable to fix preferred radio-frequency arrangements for such systems. On the contrary, the maximum amount of flexibility should be maintained in the design of such systems, so that their characteristics can best be adapted to current needs (see Report 285).

To simplify the design of equipment and to facilitate its operation, it is, however, desirable that studies of the necessary frequency arrangements in each case should be guided by certain basic rules.

2. Considerations on which a radio-frequency channel arrangement might be based

2.1 The high radiated power of trans-horizon systems and the long range of this propagation method may give rise to serious interference at distances extending beyond national frontiers, for example 1000 km.

2.2 Interference both between and within trans-horizon systems can be minimized by the coordination of radio-frequency channel arrangements over a large geographical area.

2.3 The presence of high-power transmitters and very sensitive receivers in the same station makes protection against local interference very difficult, and as a result it is necessary to minimize such effects by a carefully planned arrangement of radio frequencies.

2.4 Radio-frequency channel arrangements should provide for various capacities of FDM telephony (e.g. from 12 to 120 telephone channels) and perhaps also for television as appropriate.

2.5 With the frequency deviations likely to be employed, the bandwidth of emission may range from a fraction of 1 MHz to several MHz (perhaps up to 8 MHz for television).

2.6 To avoid undue interference between stations, the minimum distance separating a receiving station from an interfering transmitting station operating on the same frequency, may have to be large, for example 1000 km or more, depending on the power used, the characteristics, orientations and polarizations of the antennas.

2.7 If it is desired to make interconnections, it is recommended that use be made of the intermediate frequencies 35 and 70 MHz, in conformity with Recommendation 403 see also Report 285.

2.8 It is important that the arrangement used be responsive to all operational requirements.

2.9 The arrangement used should be amenable to the use of diversity reception. When the system operates in dual-diversity, the avoidance of frequency diversity is recommended.

Where frequency diversity must nevertheless be used in each direction of transmission, the diversity frequencies can either be very close together (for example those in adjacent channels), or separated by several tens of MHz. The radio-frequency channel arrangement must be compatible with such requirements.

2.10 The frequency bands usable by tropospheric-scatter multi-channel radio-relay systems between 100 MHz and 10 GHz have bandwidths ranging from a few MHz to more than 1 GHz. These bands are often taken from those allocated to the fixed and mobile services, according to regional and national regulations. The frequency plan must reflect this situation.

3. General indications to be followed

3.1 An appreciable reduction of the distance envisaged between stations likely to cause mutual interference can generally be realized, on condition that they can be operated on slightly different frequencies, the minimum useful frequency separation being about 0.5 to 1 MHz for narrow-band frequency-modulation systems * as well as for amplitude-modulation single-sideband systems.

3.2 Interference resulting from frequencies produced at a single station (frequencies of transmitters, local oscillators, frequency-changers) is chiefly linked to the choice of intermediate frequency. It is, therefore, not wise to set up a channel arrangement without prior consideration of the value of the intermediate frequencies used.

The most troublesome interference can usually be avoided by choosing a separation between channels, such that the intermediate frequency can never be a multiple of this separation. This rule must be respected, particularly when the effective separations between channels are chosen as appropriate multiples of the unit step between 0.5 and 1 MHz, as proposed in § 3.1.

3.3 To apply a single-channel arrangement to several channels of various telephone capacities, a separation between channels in a station can be used which is a multiple of a frequency module. Typically, the radio-frequency channel separation required for 60 and 120 channel systems could be respectively 3 to 5 times that required for 12 to 24 channel systems, the r.m.s. deviations used being chosen in conformity with Recommendation 404.

3.4 The first channel should be at a minimum distance from the end of the frequency band considered equal to approximately half the channel width.

3.5 At each station, all transmitting frequencies should be in the same half of the band, and all receiving frequencies in the other half. The role of the two half-bands will be reversed in adjacent stations.

3.6 To minimize the problem of duplexing, the minimum frequency separation between transmitted and received signals on the same antenna should be of the order of:

- 40 MHz for systems operating at frequencies below 1000 MHz;
- 80 MHz for systems operating at frequencies above 1000 MHz.

The minimum frequency separation between transmitted and received signals at the same station, but not on the same antenna, should be of the order of:

- 25 MHz for systems operating at frequencies below 1000 MHz;
- 35 MHz for systems operating at frequencies above 1000 MHz.

Finally, the minimum separation between two transmitting frequencies, or two receiving frequencies at the same station, could be seven times the basic unit referred to in § 3.3.

3.7 Taking account of the great number of usable channels, the variety of situations encountered in actual practice, and to keep the maximum flexibility in the use of frequencies, precise assignment of frequencies for interconnection should be the subject of an agreement between the administrations concerned.

RECOMMENDATION 302-1

LIMITATION OF INTERFERENCE FROM TRANS-HORIZON RADIO-RELAY SYSTEMS

(Question 7/9)

(1959–1982)

The CCIR,

CONSIDERING

- (a) that trans-horizon radio-relay systems can cause interference over long distances which in many cases may extend across national boundaries;
- (b) that trans-horizon systems need some form of diversity to circumvent fading;

* Special reference should be made to: MEDHURST, HICKS and GROSSET [May, 1958] Distortion in frequency-division multiplex FM systems due to an interfering carrier. *Proc. IEE*, Vol. 105B, 282-292.

HAMER, R. and ACTON, R. A. [July, 1957] Power spectrum of a carrier modulated in phase or frequency by white noise. *Elec. and Radio Eng.*, Vol. 34, 246-253.

(c) that multiple-diversity can be provided without using additional frequencies, e.g. by employing spaced antennas, with or without cross-polarization,

UNANIMOUSLY RECOMMENDS

in planning trans-horizon radio-relay systems:

1. that account be taken of the high degree of international coordination and planning which will be involved if trans-horizon radio-relay systems of this type are to occupy the same frequency bands in nearby countries without mutual interference, and that the problem would become much more complex if, in addition, they were to occupy the same frequency bands as conventional line-of-sight systems or other services;
2. that the utmost economy in frequency should be observed;
3. that frequency-diversity should be avoided as far as possible, particularly in those parts of the world where the frequency spectrum is likely to become congested;
4. that special efforts should be made to operate such radio-relay systems at the lowest practicable level of radiated power;
5. that special efforts should be made to reduce radiation in, and reception from, undesired directions;
6. that special efforts should be made to reduce spurious emissions to the lowest practicable level.

ANNEX I

Trans-horizon radio-relay systems have interference-producing capabilities and susceptibilities not unlike those encountered in line-of-sight radio-relay systems. Differences are primarily due to the usually higher transmitting powers, narrower antenna beamwidths and more sensitive receivers encountered in trans-horizon systems. This means that siting considerations are very important with trans-horizon systems.

To minimize interference from a trans-horizon radio-relay system line-of-sight situations are usually avoided, as are areas where the diffracted signal will be strong. Under some circumstances, it may be impossible to avoid occasional interference from signals due to diffraction, strong layer reflection, and especially ducting.

To estimate expected co-channel interference, it is necessary to calculate transmission loss by subtracting the path antenna gain G_p given in Fig. 1 of Report 285 from the estimated basic transmission loss. The interfering field depends on the mean long-term loss and any additional fluctuations. At UHF and higher frequencies, the lowest observed values of extra-diffraction transmission loss are the result of atmospheric focusing and ducting, either over sea or over land.

Field strength may be combined with antenna gain to yield azimuthal distance-interference patterns for various systems and combinations. In considering non-co-channel interference, account must also be taken of transmitter spectrum distribution and receiver passband characteristics. For antenna pattern considerations see Report 614.

Although it is not possible to recommend final channel arrangements, there is a need to select frequencies in an orderly manner on a regional basis. In arriving at such agreements between administrations, the guide-lines in Report 286 should be observed.

Polarization discrimination is also suggested to aid the use of space-diversity and the rejection of interference.

It has been general practice to engineer tropospheric-scatter systems on the high propagation attenuations exceeded only during small percentages of the time. It should be realized that under more favourable conditions, prevailing for the rest of the time, transmitter powers and antenna gains so justified can cause increased interference fields. It may be advisable under such conditions to reduce the transmitter power temporarily.

REPORT 378-4

CHARACTERISTICS OF DIGITAL RADIO-RELAY SYSTEMS

(Question 12/9)

(1966–1970–1974–1978–1982)

1. Introduction

In this Report, some consideration is given to certain aspects of the characteristics of digital radio-relay systems. Different coding and modulation techniques are compared. Certain concepts useful for the description of systems are also introduced: carrier-to-noise ratio, net margin, signature, overall capacity of a radio-relay network, and regulation of transmitting power. Other concepts might also be taken into consideration.

On the basis of the digital hierarchies already defined by the CCITT and in view of the proposals advanced by various administrations it seems advisable at this time to sub-divide digital radio-relay systems into the following categories:

- 1.1 Small capacity radio-relay systems for the transmission of digital signals with gross bit rates up to and including 10 Mbit/s.
- 1.2 Medium capacity radio-relay systems with gross bit rates ranging from above 10 Mbit/s up to about 100 Mbit/s.
- 1.3 High-capacity radio-relay systems with gross bit rates greater than about 100 Mbit/s.

2. Coding and modulation techniques

The coding technique used is of particular concern to the radio-relay system. Coding consists of a transformation of the format of the signals in the alphabet to take account of the methods of synchronization, introduction of redundancy in accordance with the error-control and/or correction system, spectrum shaping and to meet the requirements of interfacing the transmission medium or channel.

2.1 Comparison of some methods of modulation

Different modulation techniques may be compared on the basis of their Nyquist bandwidth and power requirements, the latter being indicated by W the normalized carrier-to-noise power ratio, and is given by:

$$W = 10 \log (W_{in} / W_n f_n) \quad (1)$$

where:

W_{in} : received maximum steady-state signal power (the highest value of the mean power during any one radio-frequency cycle);

W_n : noise power-density at the receiver input;

f_n : a bandwidth numerically equal to the bit rate of a binary signal before the modulation process (B).

The bit rate B is the gross bit rate transmitted along the radio system, it takes into account the redundancy possibly introduced for transmission of service or supervisory channels, error control, etc.

By taking values of W corresponding to an error probability of 10^{-6} the following Table I was constructed.

As far as the three types of digital radio-relay system defined in § 1 are concerned, the modulation methods have the following characteristics:

- amplitude modulation, full carrier, double-sideband with envelope detection. This modulation method is simple but wasteful of bandwidth and power and is therefore not considered suitable for other than very small capacity requirements;
- frequency modulation, two-level with discriminator detection. This modulation method is simple but wasteful of bandwidth and is also not considered suitable for other than very small capacity requirements;
- phase modulation, two-level, with coherent or differentially coherent detection. These methods of modulation are fairly simple but wasteful of bandwidth; they are considered the most suitable for the type cited in § 1.1, and possibly § 1.2;
- phase modulation, four-level, with coherent or differentially coherent detection. These methods are considered to be among the most suitable for the types cited in § 1.2 and 1.3. They are also acceptable for the type cited in § 1.1;

TABLE I

System	Variant		W (dB) ⁽²⁾	Nyquist bandwidth
Amplitude modulation	Full-carrier binary double-sideband with envelope detection		17	B
	Double-sideband, suppressed-carrier, two binary channels in quadrature with coherent detection		10.5	$B/2$
	Double-sideband, suppressed-carrier, two binary channels in quadrature with differentially coherent detection		12.8	$B/2$
	Single-sideband binary, suppressed-carrier ⁽¹⁾		10.5	⁽⁵⁾
	Vestigial-sideband binary, suppressed-carrier, with coherent detection ⁽¹⁾		11.3	⁽⁵⁾
	Vestigial-sideband binary, reduced-carrier, with coherent detection ⁽¹⁾		11.8	⁽⁵⁾
	Vestigial-sideband binary, suppressed-carrier, 50% amplitude modulation with envelope detection ⁽¹⁾		17.8	⁽⁵⁾
Phase modulation with coherent detection ⁽³⁾	2-level	Binary phase-shift keying	10.5	B
		Reduced bandwidth binary phase-shift keying	15.5 ⁽⁴⁾	B
	4-level	Quaternary phase-shift keying	10.5	$B/2$
		Reduced bandwidth quaternary phase-shift keying	15.5 ⁽⁴⁾	$B/2$
	8-level		13.8	$B/3$
Phase modulation, with differentially coherent detection ⁽³⁾	2-level		11.2	B
	4-level		12.8	$B/2$
	8-level		16.8	$B/3$
Frequency modulation, with discriminator detection	2-level		13.4	B
	3-level (duo-binary)		15.9	B
	4-level		20.1	$B/2$
	8-level		25.5	$B/3$
Other modulation methods with coherent detection	Two 3-level class 1 partial response channels in quadrature		13.5	$B/2$
	16-level quadrature amplitude modulation		17	$B/4$

⁽¹⁾ The maximum steady-state signal power depends on the shape of the modulating pulses. These figures are therefore based on average power.

⁽²⁾ $P_e = 10^{-6}$.

⁽³⁾ All digital phase modulation may be obtained directly by phase modulation or indirectly by methods of amplitude or frequency modulation.

⁽⁴⁾ The modulation method introduces controlled amounts of inter-symbol interference thus the figure is a quasi- W value, not related to peak value.

⁽⁵⁾ The Nyquist bandwidth for single- and vestigial-sideband systems is difficult to clearly define.

- frequency modulation, three-level (duo-binary), four-level or eight-level discriminator detection, is preferred for the simple adaptation to digital transmission of frequency-modulation radio-relay systems using frequency-division multiplex. A large carrier-to-noise ratio will be available and the method of modulation need not be changed;
- phase modulation, eight level, with coherent detection. This method is particularly suitable for the type cited in § 1.2 which operates below 12 GHz. This method is attractive when systems are to be mixed within existing analogue channel arrangements because it offers good spectrum efficiency even when using a single polarization (see also Report 610). Although theoretically more sensitive to distortion than four-level CPSK, comparable performance can be achieved with this method by optimal equipment filtering and equalization;
- the use of partial response coding techniques [Kretzmer, 1966] may be very attractive to reduce bandwidth occupancy with only a small increase in equipment complexity. This reduction in bandwidth is achieved at the expense of a greater number of transmitted levels for a given number of input levels, or equivalent, at a greater value of W for a given error rate;
- a 16-level QAM modulation technique is attractive for high capacity digital radio-relay systems because it increases spectrum efficiency with only a small increase in equipment complexity [Miyauchi *et al.*, 1976];
- reduced bandwidth quadrature phase-shift keying (RBQPSK). This technique [Chamberlain *et al.*, 1980] permits the bandwidth of an ordinary PSK transmission to be drastically reduced, to the point where inter-symbol interference is of such magnitude as to prevent normal operation of the channel, unless special detection processes are then employed in the receiver to allow energy distributed over several symbol intervals by the inter-symbol interference to be recovered and used in decision making.

The W parameters listed in Table I are, in practical terms, idealistic because the only source of errors is taken to be thermal noise in the receiver. It is recognized that some important factors are not considered, in particular:

- signal distortion introduced by non-ideal transmission characteristics;
- the effects of inter-channel interference (these are discussed in Reports 779 and 610).

The Nyquist bandwidth (b_n) is a concept that unfortunately does not truly indicate the radio-frequency channel bandwidth that in practice must be allotted to a digitally-modulated signal. This bandwidth is influenced by many factors; in particular, the choice of modulation, the chosen trade-off between inter-channel and inter-symbol interference and network constraints, and is expected to vary over a wide range of values. Reference to Report 934 shows that the allotted channel bandwidth may be as low as $0.85 \cdot b_n$ for medium and high-capacity systems which accept increased, but controlled, inter-symbol interference, for example reduced-bandwidth modulation schemes. On the other hand the bandwidth can readily exceed $2 \cdot b_n$ for other systems. The practicability of frequency re-use and the problems of channelization are considered in § 4.

3. Definition of carrier-to-noise ratio

Whilst the ratio W defined in § 2.1 is useful for the comparison of different modulation methods, the real carrier-to-noise ratio (allowing for all imperfections) needs to be considered in order to define real systems. Two such carrier-to-noise ratios (assuming errors are due to thermal noise) may be defined as:

- CNR_a , corresponding to the short-term objective (BER_a) of Recommendation 594;
- CNR_b , corresponding to the long-term objective of Recommendation 594.

4. Channel arrangements

It is recognized that the four main parameters affecting the choice of channel arrangements are:

- adjacent channel spacing, XS (defined as the separation between the centre frequencies of adjacent radio-frequency channels on the same plane of polarization in the same direction of transmission);
- spacing between adjacent transmitter and receiver, YS (defined as the separation between the centre frequencies of the go and return channels which are nearest to each other);
- guard spacing at the edges of the band, ZS (defined as the frequency separation between the centre frequencies of the outermost radio-frequency channels and the edge of the frequency band); – cross-polarization discrimination (XPD) defined as

$$XPD_{H(V)} = \frac{\text{Power received in polarization H(V), transmitted in polarization H(V)}}{\text{Power received in polarization H(V), transmitted in polarization V(H)}}$$

The XPD parameter contributes to the value of the carrier-to-interference ratio which is of interest to the system designer, and possible ways of exploiting XPD , that is, co-channel and interleaved channel plans are also shown in Fig. 1.

The values of X , Y , Z are normalized with respect to the digital symbol rate (S) and are illustrated in Figs. 1(a) and 1(b).

The choice of frequency plan depends on the values of XPD which has a statistical distribution during fading periods (see Report 784).

If XPD_{min} is the minimum value reached for the time percentage required, this value must be compared with the minimum carrier-to-interference $(C/I)_{min}$ acceptable to the modulation method adopted.

Co-channel frequency plans can be used if:

$$XPD_{min} \geq (C/I)_{min}$$

For interleaved frequency plans an additional decoupling between adjacent channels NFD (net filter discrimination), depending on the $X/2$ value, can be obtained by using filter selectivity.

The condition then to be verified is:

$$XPD_{min} + NFD \geq (C/I)_{min} \quad \text{dB}$$

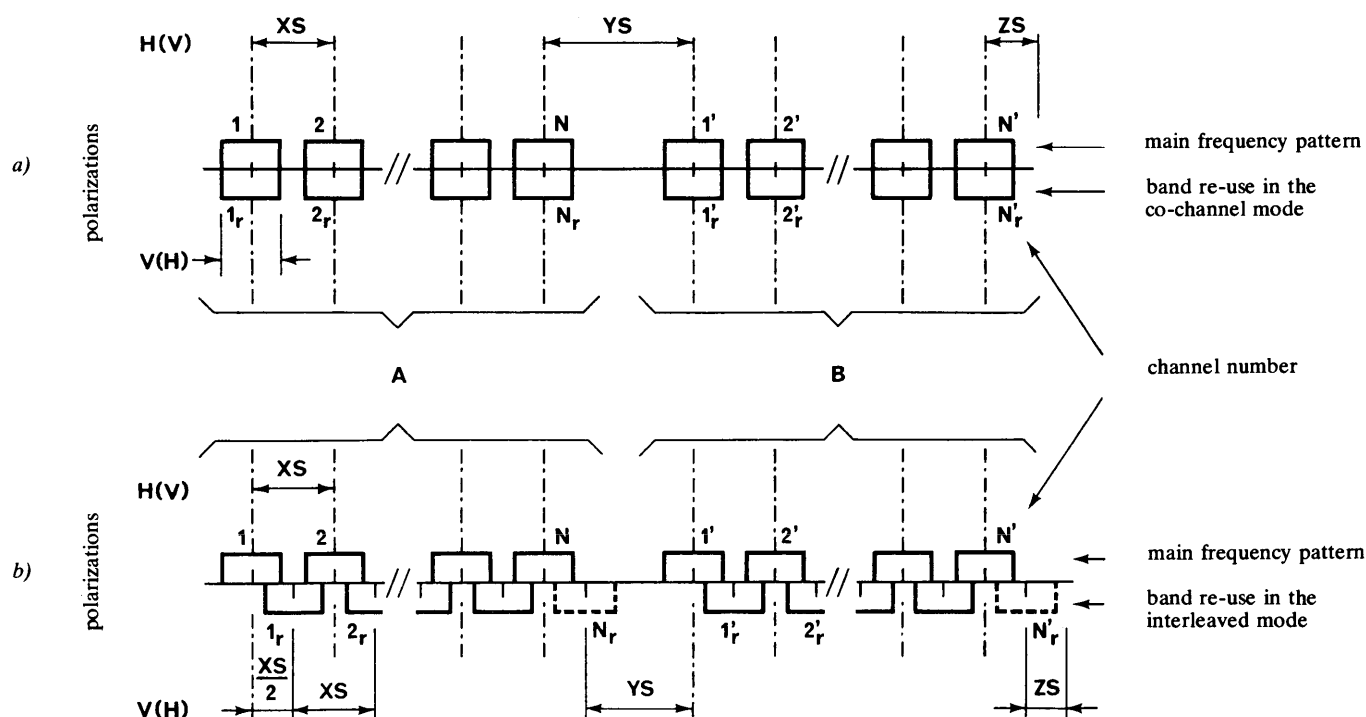


FIGURE 1 – Channel arrangements for the two possible schemes of frequency re-use considered in the text

A: "go" channels

B: "return" channels

5. Net performance and availability margins

Report 784 discusses the concept of flat fade margin and net fade margin, in order to take account for selective fading.

In practice the net fade margin takes into account all imperfections of a system. It is for an unprotected system and relates to the unavailability and performance clauses as defined in Recommendations 557 and 594. Thus two net fading margins may be defined:

- net performance margin (NPM) which corresponds with performance objectives (Recommendation 594),
- net availability margin (NAM), which corresponds with the availability objective (Recommendation 557).

They may be defined as the attenuation (fade depth) (A) which corresponds, on average, with the appropriate criteria. More formally:

$$\text{Prob}(A > NPM) = \text{Prob}(BER > BER_a \mid \text{outage} < 10 \text{ s})$$

$$\text{Prob}(A > NAM) = \text{Prob}(BER > BER_a \mid \text{outage} > 10 \text{ s})$$

As a general rule, short outages can be regarded as being due to multipath propagation, whereas long outages are due to rain, and consequently the application of antenna diversity improves the net performance margin, see Report 784.

6. Signature of an equipment

A convenient means of describing the sensitivity of digital radio-relay equipment to the distortion caused by selective fading consists in the measurement of their signature (see Report 784).

7. Overall capacity of a radio-relay network

Report 662 provides the basic concepts and definitions of spectrum use and efficiency. That Report shows that spectrum efficiency is characterized not only by the number of bits per second per hertz in a given frequency band but also by the necessary spatial (linear, area, angular separation etc.) decoupling between radio transmissions. These concepts may therefore be applied to system nodes and routes.

With regard to nodal capacity, one convenient means of taking these ideas into account is to introduce the concept of system nodal capacity. This nodal capacity may be characterized by the total number of Mbit/s that can be transmitted from a nodal point. It is thus equal to the product of the bit rate transmitted on an RF channel multiplied by the number of possible channels on a link and by the maximum number of routes which are possible from a nodal point which is a function of the angular decoupling.

Another measure of spectrum use is defined as the product of the frequency bandwidth, spatial decoupling and the time denied to other potential users. These ideas and their application to system nodes and routes are considered in [Berry, 1977; CCIR 1978-82].

It should be noted that the maximum nodal capacity does not necessarily correspond to the maximum number of channels on a route and therefore to the same modulation method. The relative importance of nodal capacity and capacity on a route depends upon the network configuration.

8. Automatic regulation of transmitter power

Automatic regulation of the transmitted power of digital radio-relay systems can be used, in particular, to reduce interference between channels on the same route and between channels radiating from the same system node. This reduction of interference is of value in helping to achieve optimum use of digital radio-relay systems in a telecommunications network, particularly by:

- increasing the capacity of a system node; a reduced interference power permits a reduction in angular separation between adjacent radial routes utilizing this regulation method;
- reducing interference from a digital channel into an adjacent analogue channel thus easing compatibility problems in shared bands.

One administration investigated the performance of a power-regulation system having a dynamic control range of 15 dB, able to follow fading rates of the order of 100 dB/s. The calculations showed that such a system can be used:

- to reduce by a ratio of the order of three the angular separation between adjacent routes radiating from the same nodal point (11 GHz, 140 Mbit/s radio-relay system, 8-PSK modulation). This value depends on antenna characteristics;
- to reduce the noise introduced by adjacent digital channels into the upper channel of a 2700-channel analogue system from 5 pW/km to less than 0.5 pW/km, for a 280 km link, (2700-channel analogue radio-relay system and 140 Mbit/s digital radio-relay system, 16-QAM modulation, in the 6.4 to 7.1 GHz band).

However, the full advantages of radiated-power control are only realized if the power-control signal can closely follow the fading characteristic. Attention must also be paid to the partial correlation between AGC signal level, digital-signal distortion and interference power-density distribution (particularly in adjacent channels) during multipath fading events.

9. Stability

It is important to consider the effect of equipment performance stability on the system. Some experimental results have been reported [Iwasaki *et al.*, 1969; Yamamoto *et al.*, 1972].

- In a DCPSK system, deterioration of performance is principally due to phase variation in the delay line of the demodulator and to variation in the intermediate frequency. Intermediate frequency (IF) variation depends on local oscillator (LO) stability. A variation of up to 2×10^{-5} in the frequency of the local oscillator of a 2 GHz system with an IF of 70 MHz has been shown to result in a noise penalty of less than 1 dB.
- In a CPSK system, using a phase-locked loop in the demodulator with a pull-in range of ± 10 MHz at the IF of 1.7 GHz, phase lock can be achieved with an LO stability of 10^{-4} at 20 GHz. A noise penalty of less than 1 dB is incurred when the steady-state phase error in the phase-locked loop is 26° for two-level, 6° for four-level and 1.2° for eight-level CPSK.

REFERENCES

- BERRY, L. A. [August, 1977] Spectrum metrics and spectrum efficiency: proposed definitions. *IEEE Trans. Electromag. Compt.*, Vol EMC-19, 3, 254-260.
- CHAMBERLAIN, J. K., CLAYTON, F. M. and COLLINS, R. V. [4 March, 1980] Reduced bandwidth quaternary phase-shift-keying (RBQPSK) – an evolutionary approach to bandwidth efficient digital microwave transmission. Proc. IEEE International Zurich Seminar on Digital Communications, Switzerland, A3.1-A3.6.
- IWASAKI, S., TACHIKAWA, K., TANAKA, R. and YANO, T. [June, 1969] 2 GHz microwave PCM system. IEEE International Conference on Communications (ICC '69), Boulder, Colo., USA.
- KRETZMER, E. R. [February, 1966] Generalization of a technique for binary data transmission. *IEEE Trans. Comm. Tech.*, Vol. COM-14, 1, 67-68.
- MIYAUCHI, K., SEKI, S. and ISHIO, H. [February, 1976] New techniques for generating and detecting multilevel signal formats. *IEEE Trans. Comm.* Vol. COM-24, 2, 263-267.
- YAMAMOTO, H., HIRADE, K. and WATANABE, Y. [August, 1972] Carrier synchronizer for coherent detection of high-speed 4-level PSK signals. *IEEE Trans. Comm. Tech.*, Vol. COM-20, 4, 803-808.

CCIR Documents

[1978-82]: 9/293 (Italy).

REPORT 610-1

COMPATIBILITY BETWEEN DIGITAL AND FDM-FM RADIO-RELAY SYSTEMS

(Question 23/9 and Study Programmes 12F/9 and 23A/9)

(1974-1978)

1. Introduction

In principle, digital radio-relay systems may be established in frequency bands for which channelling plans have been recommended for frequency-modulation systems using frequency-division multiplex. The special problems of interference between digital and FDM-FM radio systems need to be considered.

These problems will be of particular concern for medium capacity radio systems; however, this Report also considers the problem of compatibility between high-capacity digital systems and FDM-FM systems.

For the medium and small capacity range both the adaptation of existing analogue FM systems and the use of multi-level PSK modulation seems to be feasible.

For the high capacity range it seems that different modulation methods, especially those with a high number of levels, should allow an acceptable degree of compatibility with FDM-FM systems.

The problems of compatibility between digital and FDM-FM radio-relay systems are mainly those arising:

- on the same route;
- on routes in close geographical proximity or converging on a station.

The main means of reducing interference and achieving compatibility are:

- the choice of the modulation method and of the baseband format of the digital signal, permitting an optimum use of the frequency spectrum (§ 2);
- the restriction of the transmitted spectrum (§ 5);
- the choice of criteria for channel arrangement (§ 3);
- use of devices to reduce the interference from digital to analogue systems (§ 5).

System designers will need to consider especially the following problems:

- evaluation of the interference noise power falling into the analogue baseband due to an adjacent or co-channel digital signal (§ 4);
- evaluation of the performance degradation in the digital channel due to limitation of the transmitted spectrum and/or reduction of the transmitted RF power with respect to the analogue RF power.

2. Digital modulation methods for compatible operation

The different digital modulation methods are described in Report 378. They all allow a certain degree of compatibility with FDM-FM radio-relay systems. However in order to make efficient use of the frequency spectrum, digital modulation arrangements achieving a transmission efficiency of about 2 bit/Hz are desirable *. Some remarks relevant to the compatibility problems are mentioned in the following text.

2.1 FM-DPSK modulation

Its attractiveness lies principally in that it permits the use of digital terminals on existing analogue FM radio systems, as the signal is completely compatible with the properties of the analogue FM channel and could operate through a number of FM repeaters before regeneration.

In addition, the FM approach has an advantage, from the standpoint of signal bandwidth at RF, since it is possible to restrict (within limits) the transmitted spectrum by shaping the baseband pulses applied to the FM modulator.

2.2 CPSK modulation

Coherent detection of this signal at the receiver yields the well-known 2.3 dB C/N advantage over the FM-DPSK arrangement in a noise-limited environment.

The 4Φ-CPSK system using path-length rectangular-pulse switching requires all the band shaping to be done by RF filters.

2.3 Quadrature partial-response system (QPRS)

The PSK systems described above require the use of both polarizations to achieve the required transmission efficiency. Satisfactory digital transmission performance will probably require, however, that cross-polarization discrimination (*XPD*) between the two PSK channels be maintained above about 15 dB during multipath fading. Even better *XPD* performance will be required for the FM-DPSK arrangement because its co-channel interference immunity is significantly poorer. The QPRS plan avoids the necessity for co-channel plans since, by using partial-response encoding, the second order side lobes of the combined AM-PM signal at the transmitter can be attenuated to achieve about 2 bit/Hz on a single polarization without excessive inter-symbol interference or interference into adjacent RF channels. This is achieved at the expense of introducing envelope fluctuations in the carrier signal and some 3 to 6 dB threshold degradation over 4Φ-CPSK. It is clear that such a plan would require signal regeneration at every repeater point since maintaining amplitude linearity would be a difficult task.

* The efficiency of 2 bit/Hz may not be achievable in some cases. However in other cases an efficiency of greater than 2 bit/Hz may be possible.

2.4 FSK multi-level modulation

This method has advantages over PSK under some circumstances. It is possible to restrict the transmitted spectrum by shaping the baseband signal and/or reducing the deviation of the carrier. Also, like FM-DPSK it has the advantage of being able, where required, to use existing equipment. However, FSK is particularly sensitive to interference as the number of levels is increased.

2.5 8-level phase modulation with coherent detection

This method is attractive from a compatibility point of view as it is possible to achieve a good spectrum efficiency while operating on a single polarization [CCIR, 1974-78a].

2.6 16-level QAM modulation

This modulation is attractive for high capacity radio-relay systems, from a compatibility point of view, because it permits increased spectrum efficiency and should allow the analogue channel arrangements to be used for digital systems of similar capacity [CCIR, 1974-78b and c].

3. Channel arrangements suitable for the compatible transmission of digital and FDM-FM signals.

The following arrangements may be envisaged to enable digital transmission in frequency bands where channel arrangements have been already recommended for analogue (FDM-FM) transmissions [CCIR, 1974-78d]:

- (a) use of the entire frequency band;
- (b) use of dedicated channels;
- (c) use of dedicated sub-bands.

In case (a), (shown in Fig. 1(a)), the frequency plan adopted for digital transmission could be completely different from that used for analogue transmission.

In fact, because of the dispersal of the digital signal spectra, the analogue and digital channel arrangements may be independent, without significantly affecting the level of mutual interference. This would allow, particularly in the case of high capacity digital channels, the band to be optimized for maximum digital traffic.

In case (b) (see Fig. 1(b)) some RF channels belonging to the CCIR pattern are permanently dedicated to digital transmission.

In the third alternative, (shown in Fig. 1(c)), the overall RF bandwidth is divided into two analogue sub-bands and two digital sub-bands (one for each direction of transmission). A suitable guard band may be required between the adjacent analogue and digital channels, but this protection could be provided partly by means of additional filters. The analogue sub-band could then be exploited according to the CCIR plans while the digital sub-band may have a different channel arrangement.

The three different schemes, indicated as c_1 , c_2 , c_3 in Fig. 1, present some possible variations depending on the values of the 3 main parameters which are:

- the frequency spacing between analogue channels Δf_{AA} ,
- the guard band between analogue and digital channels Δf_{AD} ,
- the frequency spacing between digital channels Δf_{DD} .

4. Interference between FDM-FM and digital systems

4.1 Interference between FDM-FM and digital systems on the same route

The problems of interference are exclusively those between adjacent digital and analogue channels. In this respect channel arrangement “ c_1 ” appears to be preferable, particularly for high capacity digital systems, as it reduces the number of digital/analogue interfaces (channel arrangement a_1 is not appropriate for FDM-FM and digital use on the same route).

For medium and low capacity digital channels it would probably be possible to meet the adjacent channel interference requirements needed for the use of channel arrangements b and c_1 whilst still employing the existing CCIR analogue channel arrangements. However in the case of high capacity, digital systems to utilize the existing analogue channel arrangements would be much more difficult and special arrangements would need to be made in respect to the digital channel, such as:

- use of high performance filters and additional filters, e.g. band-edge filters;
- use of high efficiency digital modulation methods, etc.

Theoretical calculations and practical measurements [Dodo and Kurematsu, 1973; Crippa *et al.*, 1974] have been carried out on adjacent channel interference between FDM-FM systems and digital systems, and some results are shown in Annex I.

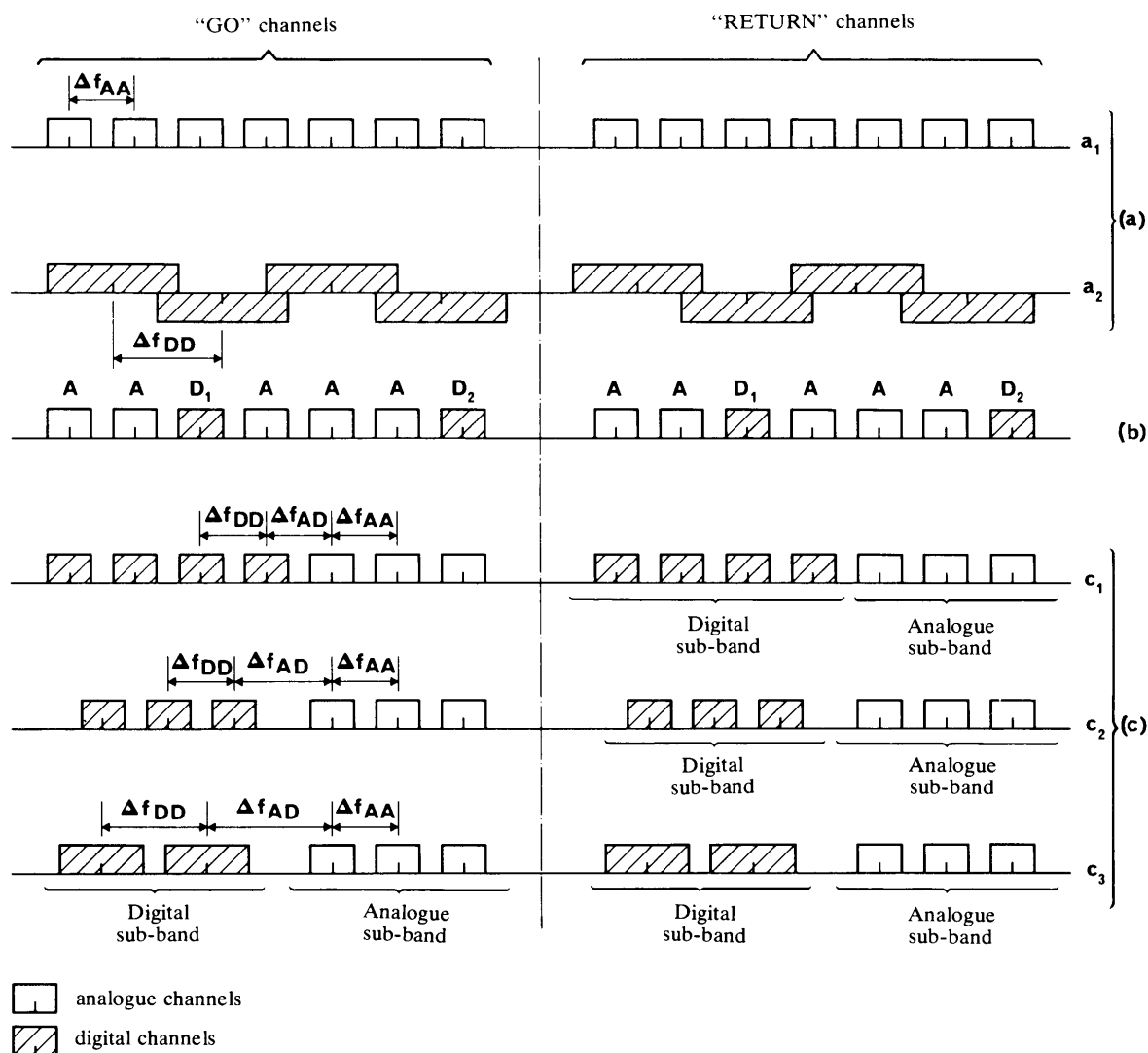


FIGURE 1 – Schemes of possible coexistence of digital and analogue transmissions in the same frequency band (dashed channels are digital and use of alternate polarizations in adjacent RF channels is assumed in all cases)

- (a) use of both analogue and digital frequency plans by exploiting a suitable site decoupling; a_1 = analogue plan, a_2 = digital plan;
 (b) use of dedicated digital channels, having the same frequencies as in the basic analogue plan;
 (c) use of dedicated digital sub-bands, with possible variations of the digital channel spacing Δf_{DD} and of the analogue-to-digital guard band Δf_{AD} with respect to the basic CCIR spacing Δf_{AA} :

$$c_1) \quad \Delta f_{DD} = \Delta f_{AD} = \Delta f_{AA}$$

$$c_2) \quad \Delta f_{DD} = \Delta f_{AA}, \Delta f_{AD} > \Delta f_{AA}$$

$$c_3) \quad \Delta f_{AD} \neq \Delta f_{DD} \neq \Delta f_{AA}$$

4.2 *Interference between digital systems and FDM-FM systems on routes in close geographical proximity or converging on a station*

It is possible that FDM-FM systems occupying a whole frequency band may be geographically adjacent to, or converge to, a station which is also used for a digital system occupying the same frequency band. In this case the digital system may or may not use the same channel arrangements as the FDM-FM system. In both cases there will be co-channel and adjacent channel interference.

For geographically adjacent routes the angular discrimination of the antennas will sometimes be sufficient to ensure that the interference from digital to FDM-FM systems is tolerable. However, the interference from digital systems to FDM-FM systems converging at a station could be intolerable, again depending upon the angular separation of the routes and on the directional characteristics of the antennas, among other things.

Annex II gives values for co-channel interference from various types of digital channels to both 960 and 1800 FDM-FM channels.

5. **Reduction of interference from digital to analogue systems**

In addition to the angular discrimination of the antennas and the restriction of the transmitted digital channel spectrum, interference to analogue systems would be reduced by automatically controlling the digital system output RF power. Whilst this technique and its feasibility require further study it may be possible under normal propagation conditions to reduce the output power to a value just sufficient to ensure acceptable digital performance and thereby for most of the time, reducing the level of interference to the analogue system.

6. **Conclusion**

Analogue/digital coexistence is possible for small and medium capacity systems using CCIR frequency channel arrangements, without a large penalty in frequency spectrum utilization and with an acceptable performance of both the analogue and digital systems.

High capacity digital/analogue coexistence, although more difficult, is possible by utilizing high efficiency digital modulation methods and techniques to reduce digital to analogue interference.

With these methods it may also be possible to employ the existing CCIR analogue channel arrangements.

Administrations are requested to submit further information on this subject.

ANNEX I

ADJACENT CHANNEL INTERFERENCE

With the hypothesis that a noise power contribution of about 1 to 2 pW0p is acceptable in each hop for each adjacent channel interference exposure, the following conclusions can be drawn from theoretical and experimental results:

- 300 FM channels and 17.152 Mbit/s 4-phase signals can be made to coexist in the same hop, with 14 MHz spacing, by using cross-polarization decoupling ($XPD \geq 20$ dB) between analogue and digital RF channels. Suitable RF filters are feasible only at lower frequencies (e.g. 2 GHz).
- 960 FM-FDM channels and 34.304 Mbit/s 4-phase signals can coexist, with 28 MHz spacing. Coexistence is obtained without use of XPD at the lower RF frequencies (i.e. 2 GHz) where sharp cut-off RF filters are feasible.
- In the case of 1800 FDM-FM channels and 34.304 Mbit/s signals with a 29 MHz spacing, it is difficult to achieve sufficient suppression of interference from the digital to the analogue system.

Furthermore, the Italian Administration has presented the following results:

For medium capacity digital systems with a bit rate equal to about 70 Mbit/s, assuming a 35 MHz and a 24.5 MHz transmit filter bandwidth for 8-level PSK and QPR systems (70 Mbit/s) respectively, typical compatibility conditions could be the following [Colavito and Sant'Agostino, 1977]:

- 960 FDM-FM systems and 70 Mbit/s 8-level PSK or QPR can coexist with 28 MHz spacing and cross-polarization decoupling (about 5 pW0p interference noise power for $XPD = 20$ dB);

- 1800 FDM-FM systems and 70 Mbit/s with the same modulation methods and 40 MHz spacing can coexist with cross-polarization decoupling (about 1 pW0p interference noise power for $XPD = 20$ dB).

As far as multilevel FM is concerned there is one more degree of freedom, that is the frequency deviation index, usually defined as the ratio between interlevel deviation and symbol rate. To avoid excessive distortion from band-limiting at RF or IF, the above defined index must be maintained lower than about 0.2 to 0.3. With 8-level FM modulation the following coexistence situations have been found to be possible:

- 300 FDM-FM channels and 17.152 Mbit/s (peak-to-peak deviation $\Delta_{pp} = 7$ to 10 MHz) with 14 MHz spacing and cross-polarization decoupling;
- 960 FDM-FM channels and 17.152 Mbit/s ($\Delta_{pp} = 7$ to 10 MHz) with 20 MHz spacing and cross-polarization decoupling;
- 960 FDM-FM channels and 34.368 Mbit/s ($\Delta_{pp} = 13$ to 16 MHz) with 28 MHz spacing;
- 1800 FDM-FM channels and 34.368 Mbit/s ($\Delta_{pp} = 13$ to 16 MHz) with 29.65 spacing and cross-polarization decoupling. Such a case has also been analyzed with 4-level modulation.

ANNEX II

CO-CHANNEL INTERFERENCE

The co-channel interference noise into 960 and 1800 channel telephone FDM-FM signals, resulting from various digital signals, is reported in the following table, where a carrier-to-interference ratio equal to 60 dB has been assumed.

These values are derived from theoretical calculation.

TABLE I – Co-channel interference noise
(Worst baseband channel noise assuming a 60 dB carrier-to-interference ratio)

Interfering signal		Distributed signal capacity	
		960 channels	1800 channels
Modulation	Capacity	Noise (dBm0p)	Noise (dBm0p)
FDM/FM	Same as disturbed	–80.3	–79.4
8-level FM	17 Mbit/s	–76.7	–68.2
8-level FM	34 Mbit/s	–76.4	–68.6
QPSK	34 Mbit/s	–78.9	–70.3
QPSK	70 Mbit/s	–81.7	–72.3
8 PSK	70 Mbit/s	–80.3	–71.3
QPSK	140 Mbit/s	–84.5	–75.1

REFERENCES

- CRIPPA, G., MAGNONI, A., and CAGLIARI, F. [1974] Compatibility of digital and analogue transmission in microwave radio-relay systems. *Alta Frequenza*, Vol. 43, 1, 16-28.
- COLAVITO, C. and SANT'AGOSTINO, M. [May, 1977] Problems of high capacity digital transmission in analogue frequency bands. European Conference on Electrotechnics (EUROCON '77), Venice, Italy, 587-594 and *CSELT Rapporti Tecnici*, June, 1977, Vol. 5, 3, 149-153.
- DODO, J. and KUREMATSU, H. [March, 1973] Interference problems of digital (PSK) and FM radio-relay system. *Fujitsu Sci. and Tech. J.*, Vol. 9, 1, 43-65.

CCIR Documents

[1974-78]: a. 9/224 (USA); b. 9/253 (France); c. 9/207 (Japan); d. 9/282 (Italy).

REPORT 376-4

DIVERSITY TECHNIQUES FOR RADIO-RELAY SYSTEMS

(Question 13/9)

(1966-1970-1974-1978-1982)

1. Introduction

Most radio-relay systems are affected at times by short-term rapid multipath fading characterized by amplitude/frequency, amplitude/time variations, as well as by associated phase/frequency and phase/time fluctuations. It is also well known from theory as well as experiment that such fluctuations depend on the geometric properties of the path including the location of the antenna and the angle of arrival. Such fluctuations have effects on the transmitted passband, limiting both information bandwidth and quality. Most trans-horizon and some line-of-sight systems have therefore been designed to minimize the deleterious effects of such fluctuations by making use of the partially correlated properties of the transmitted signal through diversity reception and/or transmission. Diversity techniques are also very useful for digital radio-relay systems because they can lead to a reduction of short-term outages which are caused by multipath fading.

2. Methods of obtaining diversity signals**2.1 General**

The most commonly used methods have been frequency and space diversity, i.e., simultaneous transmission of the same signal over two or more channels (frequency diversity) and utilizing two (or more) antennas for reception and/or transmission (space diversity). Some operational systems have used a combination of frequency and space diversity.

Diversity reception, making use of relatively uncorrelative properties of the direction of arrival, has been demonstrated to be beneficial in minimizing not only the rapid-fading problem, but also in lessening antenna-to-medium coupling loss [Vogelman *et al.*, 1959].

Since diversity reception hinges on the reception of partially correlated signals, the necessary displacement in space (including angle of arrival) frequency and/or time to achieve such benefits, is obviously of great importance.

In examining the literature, one finds that the majority of theoretical papers (particularly early ones) calculate diversity benefits predicted on completely uncorrelated (zero correlation coefficient) amplitude distributions. In practice, however, one often cannot achieve correlations of a very low order. Fortunately, to realize substantial operational benefits from diversity reception [Brennan, 1959; Turin, 1961 and 1962], low orders of correlation coefficient are not required.

2.2 Space diversity in tropospheric-scatter systems

For space diversity, the theoretical diversity distances have been examined [Gordon, 1955; Hirai, 1961], in terms of the horizontal correlation distance D_h normal to the path, the horizontal correlation distance D_a parallel to (along) the path and the vertical correlation distance D_v . D_h is the parameter most often utilized, expressed as:

$$D_h = 3 \lambda a / (4 d) \quad (1)$$

where

d : path distance,

a : equivalent radius of the Earth,

λ : wavelength.

Many tropospheric-scatter systems have been installed utilizing $D_h = 100 \lambda$.

2.3 Frequency diversity in tropospheric-scatter systems

The frequency correlation coefficient between the envelopes of two signals has been found theoretically [Rice, 1953] to be:

$$\rho(f_2 - f_1) = \exp [-(2 \pi \sigma)^2 (f_2 - f_1)^2] \quad (2)$$

where σ is $2l(\sin(\theta/2)/c)$, where

c : velocity of light,

θ : angle of scatter,

l : standard deviation of each dimension of the scatter volume (assuming three dimensional rectangular co-ordinates);

l is a function of geometric and radiometeorological parameters.

The subject of frequency correlation has received more experimental attention than space correlation. Frequency correlation is important both in assessing bandwidth capability and as a design parameter for frequency-diversity systems. The minimum necessary frequency separation depends on beamwidth of the antennas and the length of the path. According to [Hirai *et al.*, 1960], a frequency separation of 3 MHz was adequate to produce a correlation coefficient of 0.6 or less on 226 km and 345 km paths at either 600 or 2120 MHz, using a 10 m antenna for transmitting and a 3 m antenna for reception. This seems to be in agreement with Chisholm *et al.* [1954], although Patrick [1963] indicates considerable variance.

2.4 Angle diversity in tropospheric-scatter systems

Angle diversity is a useful method which enables maximum use of a limited frequency band. Some United Kingdom test results [Gough and Rider, 1975] and [Rider and Gough, 1973] between 1.7 and 2.7 GHz over paths of 250 to 350 km show that with antennas in the range 18 to 25 m in diameter, correlation coefficients of 0.2 and 0.4 are obtained with two radio beams separated by approximately one beamwidth, with the lower figure resulting from vertical angle diversity. These results agree closely with theory derived from [Gough, 1970] and [Koono *et al.*, 1962]. Additional information on the statistics of the angle of arrival of signals on the above paths is considered in [Hall, 1973]. A significant medium term decorrelation was apparent from the trials, as was a marked propensity for the short term cross-correlation coefficient between beams to fall with decreasing signal levels. The former effect is unique to angle diversity. The overall performance of a correctly engineered angle diversity link can be expected to approach that of frequency diversity despite the small increase in transmission loss attributable to necessary engineering compromises.

Theoretical considerations outlined in Gough [1970] predict that angle diversity achieves most effective results at large scatter angles.

Further confirmation of the efficiency of angle diversity was obtained in trials in Japan [Iwasa and Kurobe, 1974] at 1.8 GHz over a 256 km path with 19 m diameter antennas (gain = 47.5 dB), where correlation coefficients of less than 0.4 were obtained for beam separations more than about 6 milliradians. (See Report 238.)

2.5 Line-of-sight and diffraction paths

Engineering methods for diversity design [Makino and Morita, 1967] have been developed in Japan for line-of-sight and knife-edge diffraction radio-relay systems. For atmospheric fading within the line-of-sight, space and frequency correlation coefficients were studied, the former being given by the semi-empirical formula:

$$\rho_s = \exp[-0.0021 \Delta h \sqrt{0.4d}] \quad (3)$$

where

Δh : vertical antenna spacing in metres,

f : frequency in GHz,

d : the path length in kilometres.

It is assumed in this equation that the earth-reflected wave is negligible.

The diversity effect varies considerably over the range for which the value of the space correlation coefficient lies between 0.6 and 1 but remains almost constant when it lies between 0 and 0.6. It would therefore seem reasonable to choose the spacing between the antennas so that the value of the space correlation coefficient does not exceed 0.6.

For knife-edged diffraction paths, systems parameters are given which should enable an effective reduction of intermodulation noise due to multipath propagation, and also due to deep fading, to be achieved. These methods of design have been verified experimentally and are now in use.

On line-of-sight systems during periods of multipath fading, the signals received by two vertically separated receiving antennas rarely fade simultaneously when the fades are deep. The available improvement from such a pair of antennas can be defined as a ratio I_0 , in which the numerator is the time for which the signal from the main receiving antenna is below the fade margin and the denominator is the time during which the signals

from the two receiving antennas are below the fade margin simultaneously. The fraction of a month of high fading activity during which the signal in a radio channel on a space-diversity protected link has a value less than the fade margin is, therefore, P divided by I_0 , when a perfect switch is used that will always select the stronger of the two received signals.

In terms of variables shown below, the expression for the available improvement on an overland link which has been engineered to have negligible ground reflections, is given in [Vigants, 1975] as:

$$I_0 = 100 \frac{(S/9)^2 (f/4)}{D/40} v^2 (10^{-4}/L^2) \quad (4)$$

where:

D : path length, kilometres

f : frequency, GHz

L : fade margin expressed as a fraction of normal signal voltage

S : vertical separation of receiving antennas, in metres centre-to-centre

v : relative voltage (the gain of a secondary antenna relative to the main antenna, in dB, is $20 \log v$)

P : fraction of the month during which the received signal in an unprotected radio channel has a value of less than a particular fade margin L .

Numerical values of I_0 can be obtained from the nomogram in Fig. 1, which is the solution to the above equation in which lines have been drawn to illustrate the use on the nomogram. The equation for I_0 applies only for the ranges of parameters on the nomogram. Extrapolation of the scales on the nomogram will lead to errors. Similarly, antenna separations for which the available improvement is less than ten should not be used.

The results are based on experience in the United States of America [Vigants, 1968, 1970 and 1971; White, 1968; Barnett, 1970], where they are associated with a certain set of conditions as regards to climate, terrain and microwave route engineering practices.

Theoretical work on a statistical basis on specular reflection reduction by the use of space diversity has been reported.

Note. — For diversity techniques on line-of-sight and diffraction paths, reference should also be made to Report 338 (Volume V).

2.6 Further remarks

The employment of time diversity hinges on the acceptability of non-real time (such as store and forward) transmission, as well as on the fact that trans-horizon signals do indeed fade relatively rapidly. In variable information-rate systems, information to be transmitted is withheld (or rejected) during weak-signal and released (or accepted) during strong-signal conditions. The average rate then depends on the relative times of transmission and pause.

Variable information rate systems depend on having a return signalling path, hence the rapidity of switching (and thus of unmutated data) is limited by the round-trip transmission time (plus equipment factors). Interruption time is limited by the minimum rate of fading. This type of arrangement is potentially beneficial if space and spectrum considerations limit the practicability of frequency or space diversity.

3. Methods of combining [Brennan, 1959; Baghdady, 1961]

3.1 Arrangements

Several different arrangements have been used. The most straightforward is common with trans-horizon paths, usually involving two or four similar signals combined to form one as in Fig. 2(a). For line-of-sight links, use is often made of combiner operation or 1 + 1 protection switching; but it is more common to use one or two protection channels with several normal channels, as in Fig. 2(b). A method [Makino and Morita, 1967] has been reported upon for a line-of-sight combination of four radio-frequency channels by the use of one pilot and one combiner as in Fig. 2(c).

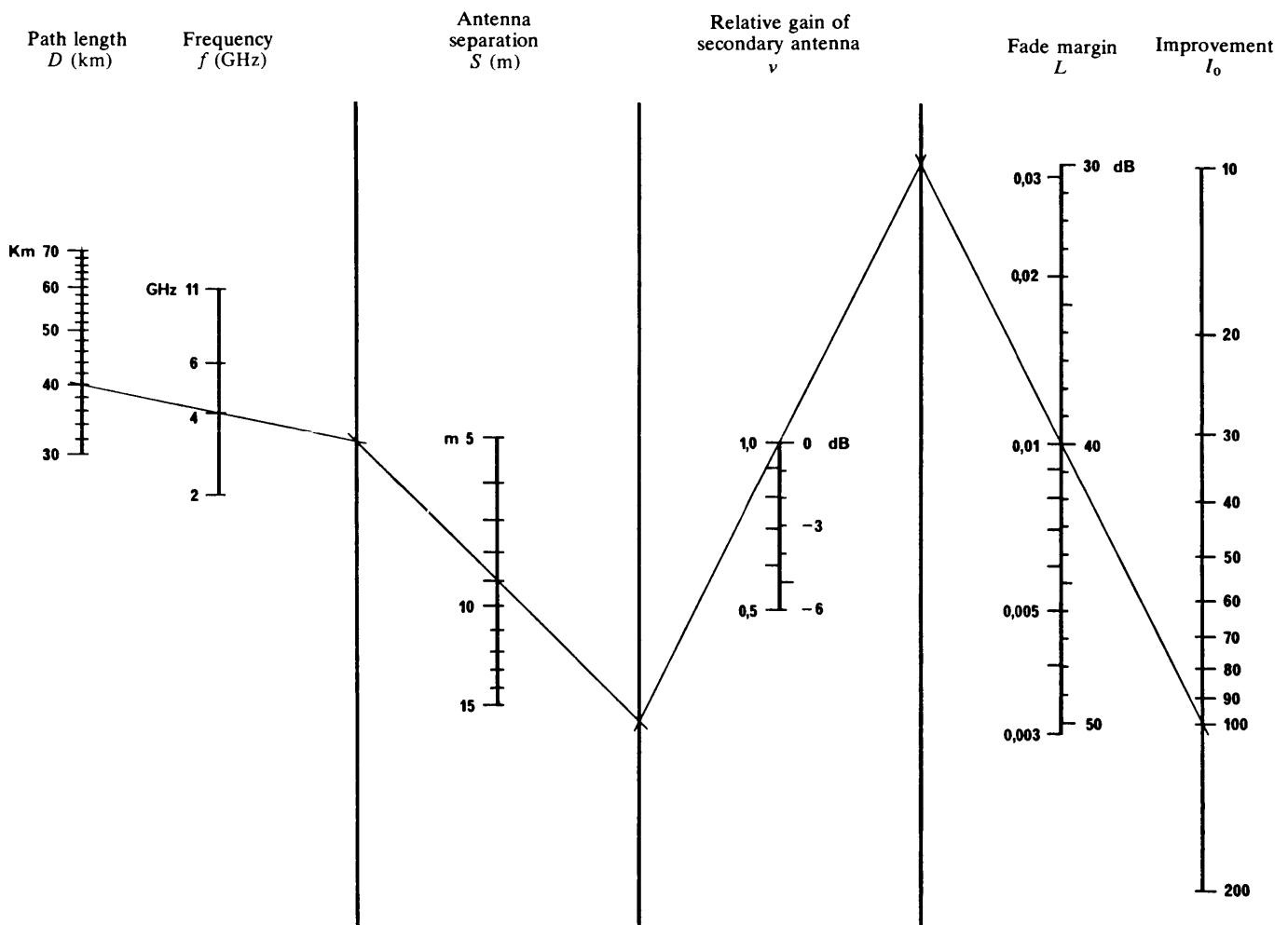


FIGURE 1 – Improvement provided by space diversity (reduction in outage time due to multipath fading when perfect comparative switching is used)

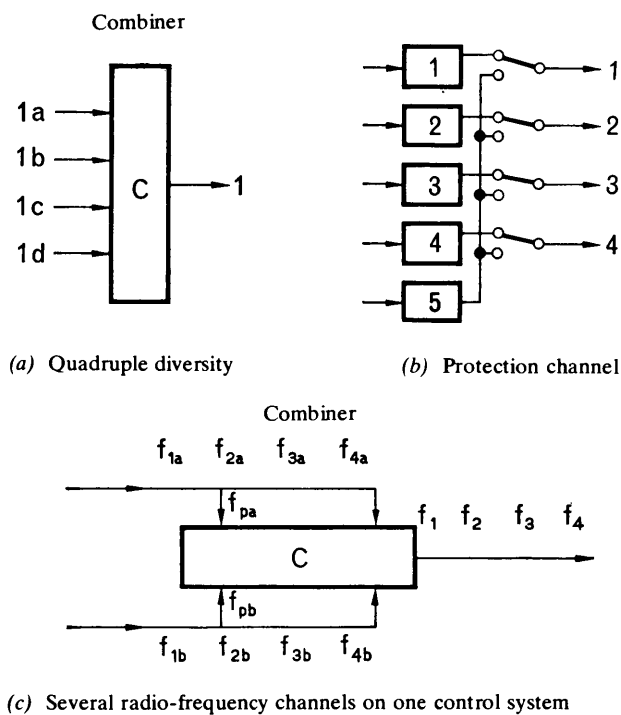


FIGURE 2 – Arrangements for diversity combining

3.2 Operating frequency of the combiners

Combiners are in use at radio, intermediate and baseband frequencies. The radio-frequency combiner [Makino and Morita, 1967, Lewin, 1962] is usually mechanical and well suited to the slow changes which occur over a line-of-sight sea path. Predetection combining [Adams and Mindes, 1958; Altman and Sichak, 1956] has also been reported at intermediate frequency for tropospheric scatter, with enhanced carrier-to-noise ratio prior to detection, and accompanying enhanced system availability. This is the only sort of combining that can be used at a heterodyne repeater if the through signal is to benefit. In frequency-modulation systems, combining after detection is also used.

3.3 Types of combiner

The types of combiner operating after demodulation are, in order of decreasing efficiency, maximal-ratio, equal-gain and selector.

For maximal-ratio combining, it has been shown that, for frequency-modulation systems with dual diversity, the mean thermal-noise power is 1.6 dB below the median without diversity, provided that the signal level for each receiver does not go below threshold more than approximately 5% of the time. With quadruple diversity, the corresponding values were 6.4 dB and 35% of the time [Boithias and Battesti, 1963].

Equal-gain combining can result in equipment and maintenance simplification over maximal-ratio combining [Brennan, 1959], at only a modest sacrifice (approximately 1 dB for quadruple diversity) in performance. A further narrowing of this gap can be achieved by combining equal-gain with selector diversity-combiners (see Fig. 3). With equal-gain combining, if the signal levels differ greatly, a receiver in a weak signal leg can actually degrade overall performance so that normal equal-gain combining may not be preferred for television transmission. Switched off, however, an overall performance, closely approximating the ideal maximal ratio, can be demonstrated under relatively easy conditions of design tolerance.

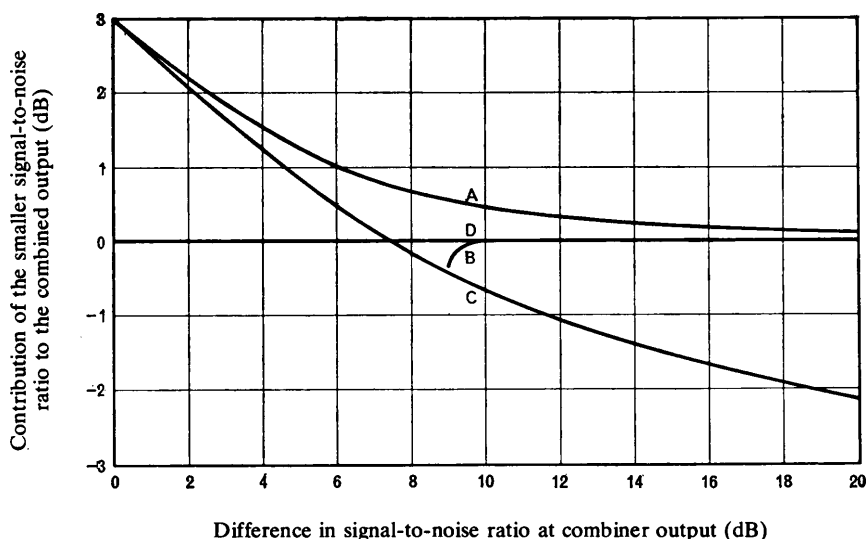


FIGURE 3 – Instantaneous addition of signal and noise in dual-diversity combiner

- Curve A: maximal ratio
- B: equal gain/switch
- C: equal gain
- D: switch

4. Considerations of transmission bandwidth

In estimating the effects of diversity on transmission bandwidth and quality, it is convenient to characterize the transmission system by a network having amplitude/frequency and phase/frequency characteristics which vary in a random manner with time.

A theoretical evaluation of passband amplitude can be made by assuming a Rayleigh distribution of the signal amplitude, z , at the edge of the passband relative to a constant value Z . For non-diversity reception (from [Gusyatinsky, 1959] and [Nemirovsky, 1951]), the probability that $z < Z$ is:

$$P(z < Z) = 1 - \frac{1 - Z^2}{\sqrt{(1 + Z^2)^2 - 4rZ^2}} \quad (5)$$

where:

$$r = \exp \left[- \left(\frac{\Delta f}{\Delta f_0} \right)^2 \right] \text{ and is the bandwidth correlation factor,}$$

Δf : the bandwidth,

$$\Delta f_0 = \frac{ac}{d^2 \alpha} : \text{the correlation passband,}$$

c : the velocity of light,

a : the effective radius of the Earth,

d : the path length,

α : the beamwidth of the antenna at the half-power points.

For diversity reception of order N , the probability of P_N for $z < Z$:

$$P_N(z < Z) = \Phi \left(\sqrt{\frac{\pi N}{4 - \pi}} \right) - \Phi \left(\sqrt{\frac{\pi N}{4 - \pi}} \times \frac{1 - Z}{\sqrt{Z^2 - 2rZ + 1}} \right) \quad (6)$$

where:

$$\Phi(y) = \frac{2}{\sqrt{2\pi}} \int_0^y \exp \left(-\frac{t^2}{2} \right) dt \text{ (the error function).}$$

Measurements to verify the theoretical work have been reported in [Gusyatinsky and Nemirovsky, 1964]. In the experiment, for $\Delta f = 0.5$ MHz, $z < 0.7$ for 30% of the time without, and 3% of the time with, (dual) diversity. Higher orders of diversity are expected to demonstrate additional improvements.

For systems using frequency-division multiplex, the behaviour in the passband of the transmission path can result in the production of intermodulation noise in the transmitted telephone channels [Gusyatinsky and Ryskin, 1962; Ballo and Nelin, 1962; Clutts and Kennedy, 1961]. This noise varies with time and often results in noise spikes. It has been shown that the use of diversity can reduce the probability of occurrence of such intermodulation noise spikes.

A comparison of calculated and measured intermodulation noise caused by multipath propagation [Gusyatinsky and Ryskin, 1962] showed a satisfactory agreement. The measurements were made on the tropospheric-scatter path, the length of which was 303 km with an antenna beam-angle of 1° .

The r.m.s. frequency deviation per channel was 100 kHz (for 800 Hz at a point of zero relative level), pre-emphasis in accordance with Recommendation 275. The system was loaded with 12 to 252 kHz white noise in accordance with Recommendation 399. Dual-diversity reception with predetection combining was used, as well as non-diversity reception.

The intermodulation noise power, due to multipath propagation measured in the telephone channel at 275 kHz at a point of zero relative level, exceeded the following values:

for 20% of measurement time:

3500 to 5500 pW (non-diversity reception),
1000 to 2500 pW (dual diversity);

for 2% of measurement time:

20 000 to 50 000 pW (non-diversity),
10 000 pW (dual diversity).

Measurement in Japan [Tsuzuki *et al.*, 1979] using 1.8 GHz for the 256 km tropospheric-scatter path over the sea shows that the intermodulation noise due to multipath propagation can be improved by diversity reception. For the 1 dB increase in path loss due to short-term fading, intermodulation noise increased by 2 dB when diversity was not employed. With dual (frequency) and quadruple (frequency/space) diversity receptions, the increase of intermodulation noise was reduced to 1 dB and 0.7 dB respectively. Frequency separation and antenna spacing of diversity were 28 MHz and 40 m, respectively.

5. Performance calculations

A large number of papers have included methods and results of various types of performance calculation. In addition to those already cited, the following may be found useful:

- for partially-correlated signals [Staras, 1956; Pierce and Stain, 1960],
- for unequal signals [Barrow, 1963; Granlund and Sichak, 1961],
- for outages and telegraph errors [Grosskopf and Fehlhaber, 1962; Barrow, 1960],
- for tandem link calculation for line-of-sight systems [Pearson, 1965],
- for tandem link calculations for tropospheric-scatter systems [Boithias and Battesti, 1965; Dutka, 1961; Sheffield, 1963].

6. Diversity techniques for digital radio-relay systems

Diversity techniques are well known as a means to improve performance and availability of digital radio-relay systems under multipath propagation conditions.

Frequency diversity, space diversity and cross-band diversity can be used. (Cross-band diversity – a form of frequency diversity where the RF bearers are situated in different frequency bands as against normal frequency diversity where the bearers are in the same frequency band.) In the following sections, consideration is given to applying space-diversity techniques to digital radio-relay systems.

6.1 Space diversity techniques

Space diversity techniques for digital systems can be classified into the following three categories:

- maximum power combiner, which combines the received signals to maximize the combined signal level;
- minimum dispersion combiner, which combines the received signals to flatten the amplitude and/or group delay frequency response of the combined signal;
- baseband switch, which selects the signal with the lower bit error ratio.

6.1.1 Possible benefits using space diversity

Space diversity is able to reduce waveform distortion caused by amplitude and group delay distortion during multipath fading. For digital radio-relay systems with high spectrum utilization, waveform distortion is one of the main causes of outage.

It is reported that outages caused by waveform can be estimated by inband amplitude dispersion, because the inband amplitude dispersion shows a high correlation between waveform distortion and inband [Yamamoto, 1981] delay dispersion.

For digital radio-relay systems it is generally desirable to utilize antennas with a good *XPD*. Space diversity techniques can improve the effective *XPD* of a system. This improvement can be used to increase spectrum efficiency of digital radio-relay systems.

By using space diversity, digital system output power can be reduced, and the necessary antenna discrimination may be reduced in comparison with non-diversity reception; as a result, space diversity can improve the nodal capacity.

Finally, a synergistic effect may appear when space diversity is used with an adaptive equalizer, such as an adaptive spectrum-shape equalizer or an adaptive baseband equalizer; the outage probability improvement factor may be larger than the product of the individual improvement factors.

6.1.2 Minimum dispersion combiner

An experimental high-capacity digital link is under investigation in one country, with a minimum dispersion combiner, which combines the received signals in such a manner as to minimize the inband amplitude dispersion.

This combiner is effective in reducing waveform distortion, but must be used in conjunction with a frequency-response detector. The frequency response is detected by in-service monitoring of the spectrum shape, thus eliminating the need for pilot tone. For effective monitoring of the spectrum shape, the digital signal must be sufficiently scrambled. However, when the combined signal is below a predetermined level, the minimum dispersion combiner is operated as a maximum power combiner.

Figure 4 reports calculated and experimental results, with a 16-QAM system, showing the improvement in amplitude dispersion probability with different space diversity techniques. Other results are reported in [CCIR, 1978-82; Murase *et al.*, 1981].

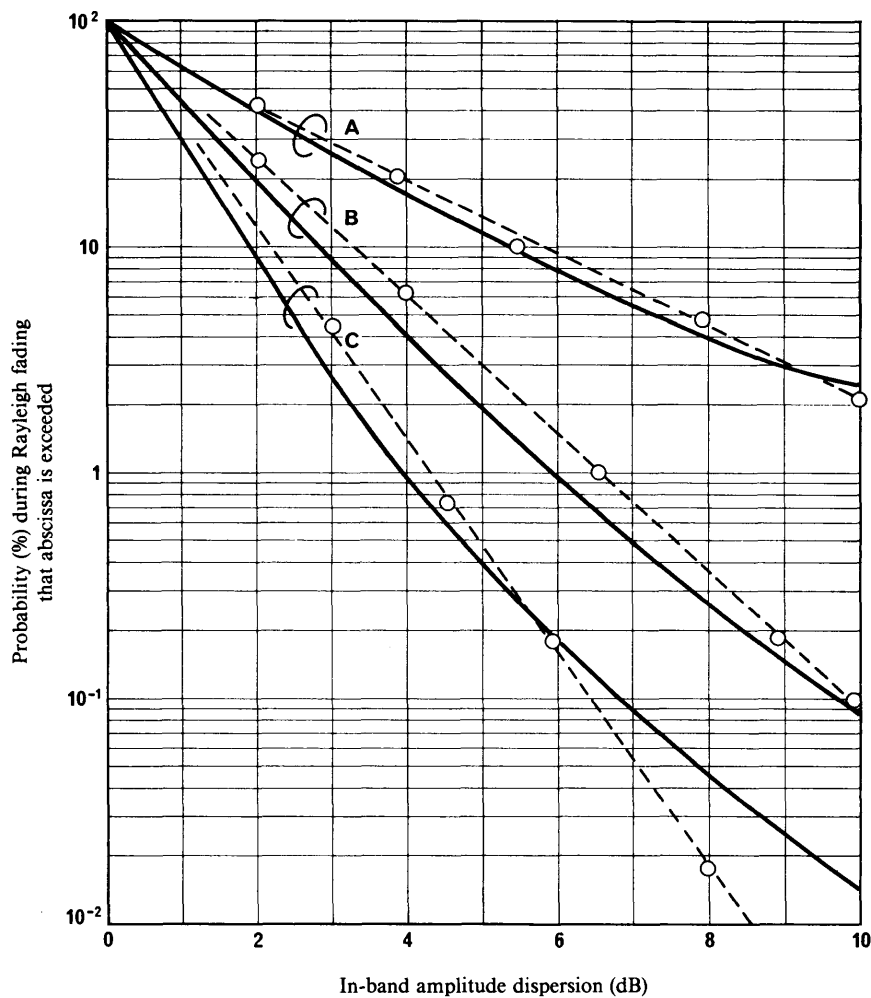


FIGURE 4 — Diagram showing the effect of space diversity on the in-band amplitude dispersion probability on a single-hop 16-QAM system (53 km over-sea hop, in Japan, 5 GHz, 200 Mbit/s, 50% roll-off factor)

- A : non-diversity
- B : maximum power combiner
- C : minimum dispersion combiner
- — — ○ measured
- calculated

7. Conclusions

Generally, for real-time transmission, space diversity or angle diversity, aided if necessary by polarization discrimination, require the least spectrum space (for tropospheric-scatter radio-relay systems see Recommendation 302, § 2 and 3). A combination of angle and space diversity is also beneficial from the viewpoint of spectrum conservation. Frequency diversity may show advantages in economy and space but will be less economic in spectrum usage.

Time diversity may be of interest when real-time transmission is not a requirement and if space and spectrum considerations are important.

Variable information rate systems (a form of time diversity) are of interest where the inquiry and return time delay (approximately 0.66 μ s per km of path length for propagation only) is acceptable.

The last two methods may be applied in addition to space or frequency diversity on specific information channels.

Not only can diversity produce improvements in the reliability of trans-horizon systems, but it can also improve the passband amplitude characteristics and, in systems using frequency-division multiplex, intermodulation noise.

REFERENCES

- ADAMS, R. T. and MINDES, B. M. [June, 1958] Evaluation of IF and baseband diversity combining receivers. *IRE Trans. Comm. Systems*, Vol. CS-6, 1, 8-13.
- ALTMAN, F. J. and SICHAKE, W. [March, 1956] A simplified diversity communication system for beyond-the-horizon links. *IRE Trans. Comm. Systems*, Vol. CS-4, 50-55.
- BAGHDADY, E. J. [1961] *Lectures on Communication System Theory*. Chapter 7, 125-127, McGraw-Hill, New York, NY, USA.
- BALLO, P. and NELIN, B. D. [March, 1962] Predetection diversity combining with selectively fading channels. PGCS, *IRE Trans. Comm. Systems*, Vol. CS-10, 1, 32-42.
- BARNETT, W. T. [October, 1970] Microwave line-of-sight propagation with and without frequency diversity. *BSTJ*, Vol. 49-II, 8, 1827-1871.
- BARROW, B. B. [September, 1960] Error probabilities for telegraph signals transmitted on a fading FM carrier. *Proc. IRE*, Vol. 48, 9, 1613-1629.
- BARROW, B. B. [March, 1963] Diversity combination of fading signals with unequal mean strengths. *IRE Trans. Comm. Systems*, Vol. CS-11, 1, 73-78.
- BOITHIAS, L. and BATTESTI, J. [May-June, 1963] Puissance moyenne de bruit dans les faisceaux hertziens transhorizon à modulation de fréquence. *Ann. des Télécomm.*, Vol. 18, 5-6, 89-93.
- BOITHIAS, L. and BATTESTI, J. [1965] Les faisceaux hertziens transhorizon de haute qualité. *Ann. des Télécomm.*, Vol. 20, 11-12, 237-253.
- BRENNAN, D. G. [June, 1959] Linear diversity combining techniques. *Proc. IRE*, Vol. 47, 6, 1075-1102.
- CHISHOLM, J. H., RAINVILLE, L. P., ROCHE, J. R. and ROOT, H. G. [September, 1954] Angular diversity reception at 2290 Mc/s over a 188-mile path. *IRE Trans. Comm. Systems*, Vol. CS-7, 3, 195-201.
- CLUTTS, C. E. and KENNEDY, R. N. [December, 1961] Results of bandwidth tests on the 185-mile Florida-Cuba tropospheric scatter system. *IRE Trans. Comm. Systems*, Vol. CS-9, 434-439.
- DUTKA, J. [September, 1961] The noise power probability distribution in a multi-hop FM radio-relay system. *RCA Rev.*, Vol. 22, 3, 508-514.
- GORDON, W. E. [January, 1955] Radio scattering in the troposphere. *Proc. IRE*, Vol. 43, 1, 23-28.
- GOUGH, M. W. [September, 1970] Angle diversity applied to tropospheric scatter systems. AGARD Conf. Proc. 70.
- GOUGH, M. W. and RIDER, G. C. [July, 1975] Angle diversity in troposcatter communications; some confirmatory trials. *Proc. IEE*, Vol. 122, 7, 713-719.
- GRANLUND, J. and SICHAKE, W. [June, 1961] Diversity combining for signals of different medians. *IRE Trans. Comm. Systems*, Vol. CS-9, 2, 138-145.
- GROSSKOPF, J. and FEHLHABER, L. [February, 1962] Häufigkeit und Dauer einzelner Schwundeinbrüche bei troposphärischen Scatterstrecken (The probability and duration of individual fading interruptions on tropospheric-scatter links). *NTZ*, 71-78.
- GUSYATINSKY, I. A. [April, 1959] Bandwidth and intermodulation noise power in tropospheric-scatter radiocommunications (in Russian). *Elektrosviaz*, 4, 3-12.
- GUSYATINSKY, I. A. and NEMIROVSKY, A. S. [July, 1964] Experimental study of the passband with single and diversity reception of signals on a tropospheric-scatter path (in Russian). *Elektrosviaz*, 7, 13-16.

- GUSYATINSKY, I. A. and RYSKIN, E. Y. [December, 1962] The theoretical experimental study of intermodulation noise power in multipath reception (in Russian). *Elektrosviaz*, **12**, 3-13.
- HALL, M. P. M. [1973] Statistics of high-level beyond-horizon signals at 2.2 GHz and 2.6 GHz and measurements of the valuation of the arrival angle-structure. AGARD Conf. Proc., 127, Doc. 17.
- HIRAI, M. [September, 1961] Diversity effects in spaced-antenna reception of tropospheric-scatter waves. *J. Radio Res. Labs.* (Japan), Vol. 8, **38-39**, 301-329.
- HIRAI, M., FUKUSHIMA, M. and KURIHARA, Y. [September, 1960] Correlation between amplitudes of radio waves of different frequencies in VHF beyond-the-horizon propagation. *J. Radio Res. Labs.* (Japan), Vol. 7, **33**, 509-529.
- IWASA, H. and KUROBE, A. [September, 1974] Experimental results of angle of diversity effect in transhorizon radio-relay systems. *Trans. Inst. Electron. Comm. Engrs. Japan*, Vol. 57, **9**, 52.
- KOONO, T., HIRAI, M., INOUE, R. and ISHIZAWA, Y. [January, 1962] Antenna-beam deflection loss and signal amplitude correlation in angle-diversity reception in UHF beyond-horizon communications. *J. Radio Res. Labs.* (Japan), Vol. 9, **41**, 21-49.
- LEWIN, L. [1962] Diversity reception and automatic phase correction. *Proc. IEE*, Vol. 109B, 295-304.
- MAKINO, H. and MORITA, K. [August, 1967] Design of space-diversity receiving and transmitting systems for line-of-sight microwave links. *IEEE Trans. Comm. Tech.*, Vol. COM-15, **4**, 603-614.
- MURASE, T., MORITA, K. and KOMAKI, S. [17 June, 1981] 200 Mbit/s 16-QAM digital radio system with new countermeasure techniques for multipath fading. IEEE International Conference on Communications (ICC '81), Denver, Colo., USA, Conf. Rec., Vol. 2, Session 46: Advanced technology for digital radio on multipath fading, 46.1.1-46.1.5.
- NEMIROVSKY, A. S. [1951] Bandwidth with single and dual diversity reception of signals on a tropospheric-scatter path (in Russian). *Elektrosviaz*, **5**.
- PATRICK, W. S. [October, 1963] Experiments in frequency diversity for tropospheric systems. IEEE PGCS 9th National Communications Symposium.
- PEARSON, K. W. [1965] Method for the prediction of the fading performance of a multisection microwave link. *Proc. IEE*, Vol. 112, 1291-1300.
- PIERCE, J. N. and STAIN, S. [January, 1960] Multiple diversity with non-independent fading. *Proc. IRE*, Vol. 48, **1**, 84-104.
- RICE, S. O. [February, 1953] Statistical fluctuations of radio field-strength far beyond the horizon. *Proc. IRE*, Vol. 41, **2**, 274-281.
- RIDER, G. C. and GOUGH, M. W. [September, 1973] The case for angle diversity in troposcatter systems. *Point-to-point Comm.*, Vol. 17, **3**, 108-118.
- SHEFFIELD, B. [September, 1963] Nomograms for the statistical summation of noise in multi-hop communication systems. *IEEE Trans. Comm. Systems*, Vol. CS-11, **3**, 285-288.
- STARAS, H. [January, 1956] Diversity reception with correlated signals. *J. Appl. Phys.*, Vol. 27, 93-94.
- TSUZUKI, T., KAJIHARA, H., SANO, Y. and KUROBE, A. [August, 1979] Characteristics of intermodulation noise due to multipath propagation on a tropo-scatter link. *Trans. Inst. Electron. Comm. Engrs. Japan*, Vol. 62-B, **8**.
- TURIN, G. L. [1961-1962] On optimal diversity reception. Part I, PGIT, *IRE Trans. Inf. Theory*, Vol. IT-7, **3**, 154-166 (July, 1961) and Part II, PGCS, *IRE Trans. Comm. Systems*, Vol. CS-10, **1**, 22-31 (March, 1962).
- VIGANTS, A. [December, 1968] Space-diversity performance as a function of antenna separation. *IEEE Trans. Comm. Tech.*, Vol. COM-16, **6**, 831-836.
- VIGANTS, A. [September, 1970] The number of fades in space-diversity reception. *BSTJ*, Vol. 49, **7**, 1513-1530.
- VIGANTS, A. [March, 1971] Number and duration of fades at 6 and 4 GHz. *BSTJ*, Vol. 50, **3**, 815-841.
- VIGANTS, A. [January, 1975] Space diversity engineering. *BSTJ*, Vol. 54, **1**, 103-142.
- VOGELMAN, J. H., RYERSON, J. L. and BECKELHAUPT, M. H. [May, 1959] Tropospheric-scatter system using angle diversity. *Proc. IRE*, Vol. 47, **5**, 688-696.
- WHITE, R. F. [February, 1968] Space diversity on line-of-sight microwave systems. *IEEE Trans. Comm. Tech.*, Vol. COM-16, **1**, 119-133.
- YAMAMOTO, H. [May, 1981] Advanced 16-QAM techniques for digital microwave radio under research in Japan. *IEEE Comm. Mag.*, Vol. 19, **3**, 36-45.
- CCIR Documents*
[1978-82]: Doc. 9/234 (Japan).

BIBLIOGRAPHY

- BAILEY, C. C. [1971] Multipath characteristics of angle diversity troposcatter channels. IEEE International Conference on Communications (ICC '71) Montreal, Canada. Session 26, 7-12.
- FRIIS, H. T., CRAWFORD, A. B. and HOGG, D. C. [May, 1957] A reflection theory for propagation beyond the horizon. *BSTJ*, Vol. 36, **3**, 627-644.
- HARTMANN, W. J. and DECKER, M. T. Mutual interference between surface and satellite communication systems. NBS Tech. Note. No. 126. Superintendent of Documents, Washington, DC, USA.
- KOMAKI, S., OKAMOTO, Y. and TAJIMA, K. [11 June, 1980] Performance of 16-QAM digital radio system using new space diversity. IEEE International Conference on Communications (ICC '80), Seattle, Wa., USA, Conf. Rec., Vol. 3, Session 52: Digital radio buffet, 52.2.1-52.2.6.

- MONSEN, P. [April, 1972] Performance of an experimental angle-diversity troposcatter system. *IEEE Trans. Comm.*, Vol. COM-20, 2.
- STARAS, H. [August, 1956] The statistics of combined diversity. *Proc. IRE*, Vol. 44, 8, 1057-1058.
- STARAS, H. and VOGELMAN, J. H. [June, 1960] Observations on angle diversity. *Proc. IRE*, Vol. 48, 6, 1173-1174.
- TRAVIS, G. W. [1968] Angle diversity tests. *Proc. National Electronics Conference*, Vol. XXIV.
- WANG, Y. Y. [December, 1979] Simulation and measured performance of a space diversity combiner for 6 GHz digital radio. *IEEE Trans. Comm.*, Vol. COM-27, 12, 1896-1908.
- WATERMAN, A. T. Jr. [October, 1958] A rapid beam-swinging equipment in trans-horizon propagation. *IRE Trans. Ant. Prop.*, Vol. AP-6, 4, 338-340.
- WATT, A. D., FLORMAN, E. F. and PLUSH, R. W. [February, 1960] A note regarding the mechanism of UHF propagation beyond the horizon. *Proc. IRE*, Vol. 48, 2, 252.
- WILLIS, F. H. [March, 1957] Some results with frequency diversity in a microwave radio system. *Comm. and Electron.*, Vol. 3-4, 29, 63-66.

REPORT 614-2

REFERENCE RADIATION PATTERNS FOR RADIO-RELAY SYSTEM ANTENNAS *

(Study Programme 17A/9)

(1974-1978-1982)

1. Introduction

For the study of frequency sharing between radio-relay systems and the fixed-satellite service or of the possibility of frequency re-use in a radio-relay network, it is often necessary to use a reference diagram, because the actual radiation pattern of the antennas is not always accurately known or gives too many details. The reference pattern should therefore represent the side-lobe envelope in a simplified fashion.

The reference radiation pattern to be selected may, however, vary according to the use for which it is intended.

2. Uses of reference radiation patterns

The two main uses of reference radiation patterns are as follows:

2.1 Preliminary elimination studies within the coordination area

In the determination of the coordination area around an earth station, radio-relay station antennas are assumed to point directly at the earth station. However, in most cases there will be some angular discrimination. The use of a simple reference radiation diagram makes it possible to eliminate from further consideration radio-relay stations situated in the coordination area but not likely to produce interference.

This diagram must, of necessity, be conservative to prevent the elimination of critical contributing sources of interference. The precise calculation of the interference level of course, requires more accurate information on the antenna diagram.

2.2 Frequency re-use in a radio-relay network

In a radio-relay network, the same frequency may be used many times, either on sections sufficiently distant from each other or on sections starting from the same station and lying in different directions, or on the same section using cross-polarization.

In the last two cases, the performance of the antenna is of great importance and a fairly precise reference radiation pattern must be used for the network project; this pattern may be less simple than that considered in § 2.1.

* The reference radiation diagrams for earth-station antennas are given in Recommendation 465 and Report 391.

3. Computation of a reference antenna diagram for a circular antenna

The side-lobe patterns of antennas of different sizes are strongly influenced by the ratio of the antenna diameter to the operating wavelength.

The envelope side-lobe diagram may be represented by (see Annex I):

$$G = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{dB} \quad (1)$$

where D and λ are the antenna diameter and the wavelength respectively, expressed in the same units and φ is the angle in degrees measured from the direction of the axis of the main lobe.

This equation is valid for values of the angle φ between φ_1 and φ_2 .

The angle φ_1 corresponds to the position of the first side lobe and is given approximately by the equation:

$$\varphi_1 = \frac{100}{D/\lambda} \quad (2)$$

The angle φ_2 is the angle beyond which it may be assumed that the levels of the side lobes no longer diminish, at least over a certain angular sector. The corresponding gain (residual gain) in the directions of the remote side lobes may be taken as 0 dB for current radio-relay system antennas. Beyond 90° approximately, the levels of the side lobes generally diminish again.

Table I gives the values of φ_1 and φ_2 for various values of D/λ and approximate values for the gain along the axis G_0 and the 3 dB beamwidth, φ_0 .

TABLE I

D/λ	G_0 (dB)	φ_0	φ_1	φ_2
15	31	4.7	6.7	40
20	34	3.5	5	36.5
25	36	2.8	4	33
30	37	2.3	3.3	30
40	40	1.7	2.5	27.5
50	42	1.4	2	25
60	43	1.2	1.7	23
80	46	0.9	1.25	21
100	48	0.7	1	19

4. Results of measurements on the antennas of radio-relay links

Measurements with numerous antennas provide adequate confirmation of the results of the above computation. However, the following points must be borne in mind:

4.1 Some antennas of relatively old designs have less satisfactory performance characteristics than more recent models. The existence of such medium performance antennas should be taken into account for frequency sharing.

4.2 The above computation is based on the assumption that the antennas operate in free-space conditions. The performance characteristics of antennas installed in the field may, however, be slightly less satisfactory owing to reflection from neighbouring obstacles or from other antennas installed on the same mast [Colavito and Masone, 1973].

4.3 For the horn-reflector antennas, which were developed to comply with the requirements of terrestrial radio-relay systems in dense networks, the reference diagram above may be regarded as valid only in the horizontal plane. For planes away from the horizontal significant sensitivity variations are displayed.

Figure 1 gives an example for the radiation diagram of a specific but widely-used pyramidal horn reflector antenna [Butzien, 1981]. Radiation envelope contours are plotted (in dB below the main beam) in a coordinate system using angles φ and θ (the centre of the spherical coordinate system being the centre of the antenna aperture). The strong departure from the rotational symmetry assumed in equation (1) is due to:

- the “spill-over lobe” around $\varphi = +90^\circ$ and θ between 60° and 80° and
- the “weather cover lobe” around $\varphi = -90^\circ$ and θ between 50° and 90° .

The spill-over lobe is a consequence of wave diffraction at the upper lip of the aperture caused by direct rays emanating from the pyramidal horn section. This effect is pronounced only for vertical polarization. The weather cover lobe is due to reflection of energy by the tilted plastic weather cover back onto the parabolic surface which then re-directs most of the energy downward over the lower lip of the aperture. This phenomenon is polarization and frequency insensitive.

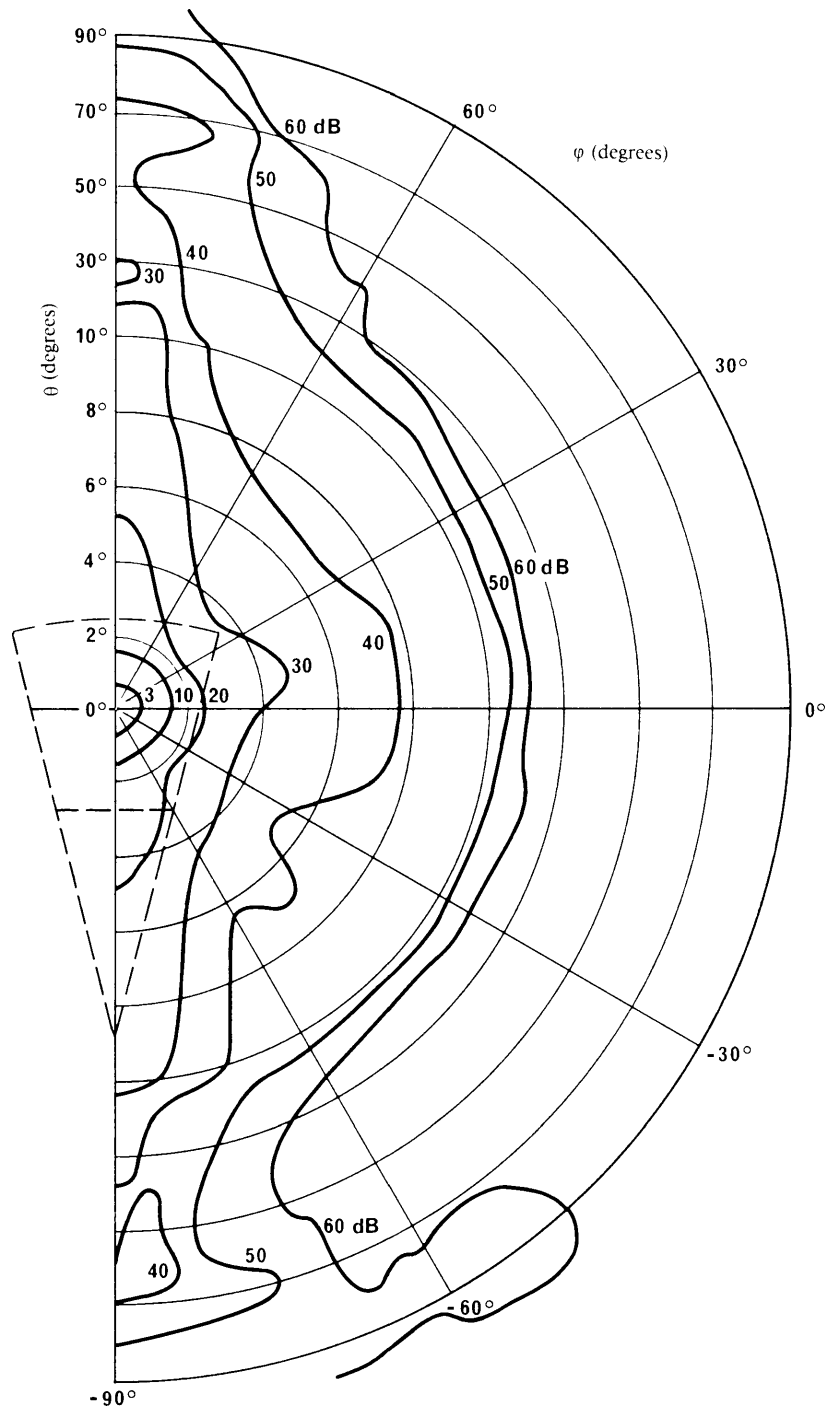


FIGURE 1 — Three-dimensional radiation pattern for a pyramidal horn-reflector antenna at 3.9 GHz and vertical polarization
(Note scale change at $\theta = 10^\circ$)

5. Reference patterns for frequency-sharing problems

If the diameter of a radio-relay antenna is known, equation (1) may be used. It may also be assumed that the residual gain is 0 dB up to the backward direction ($\varphi = 180^\circ$).

If the diameter of the radio-relay antenna is not known, the formula:

$$G = 38 - 25 \log \varphi \quad (\text{for } 1^\circ < \varphi < 33^\circ) \quad (3)$$

may be used and it may again be assumed that the residual gain is 0 dB up to the backward direction.

Note. — This value is different from the value of -5 dB which was provisionally adopted by the CCIR Special Joint Meeting, 1971. It should be noted that a value lower than 0 dB, for example -5 dB, seems appropriate when a large number of multiple entries are involved because generally only a fraction of these will coincide with the peaks of the antenna side lobes. Further study by the administrations is invited.

6. Reference patterns for frequency re-use problems in radio-relay systems

For frequency re-use account has to be taken of the parallel polarization pattern and the cross polarization pattern. It may, however, be assumed that only high-performance antennas are used.

With parallel polarization, use may be made, as in the above case, of equation (1), but with a residual gain of 0 dB only up to 90° . Between 90 and 180° , a lower residual gain may be chosen. A typical value is -15 dB.

With cross polarization, polarization decoupling depends both on the antenna and on propagation. The influence of propagation was investigated by Study Group 5 Report 338. It may be assumed that 25 dB represents a typical decoupling value of an antenna near the axis of the main beam.

When an appropriate envelope of the radiation pattern is known, the use of this pattern would be preferable.

REFERENCES

- BUTZIEN, P. E. [July-August, 1981] Three dimensional radiation characteristics of a pyramidal horn-reflector antenna. *BSTJ*, Vol. 60, 6, Part 1, 913-921.
- COLAVITO, C. and MASONE, G. [May, 1973] The radiation diagrams of antennas used in terrestrial microwave line-of-sight systems. AGARD Conference Propagation Effects on Frequency Sharing, Rome, Italy.

ANNEX I

REFERENCE DIAGRAM FOR A CIRCULAR APERTURE

It can be shown [Boithias and Behé, 1971] that the upper limit of the isotropic gain outside the main lobe of a circular beam has the form:

$$G = M - 10 \log \frac{D}{\lambda} - 30 \log \varphi \quad \text{dB} \quad (4)$$

where

D is the diameter of the antenna operating at wavelength λ ,

φ is the angle between the axis of the main beam and the direction considered,

M is a parameter which depends on the illumination function of the beam and the relative size of the central obstruction caused by the primary source or the sub-reflector. For normal illumination functions, M is approximately 52 dB when φ is expressed in degrees.

This equation is valid when φ is greater than a value φ_1 which corresponds to the position of the first side-lobe and which is approximately given by the equation:

$$\varphi_1 = \frac{100}{D/\lambda} \quad \text{degrees} \quad (5)$$

In this equation, however, the spill-over of the radiation about the main reflector or sub-reflector is not considered. This spill-over creates side-lobes in particular directions. Similarly, no account is taken of surface irregularities or of the effect of the supports of the primary source or the sub-reflector.

Allowance can be made for these factors as follows:

- the coefficient of the last term of equation (4) can be slightly reduced. It has been found experimentally that if 30 is replaced by 25, acceptable results are generally obtained;
- the range of validity of equation (4) is limited to an angle φ_2 beyond which it is assumed that the gain remains constant. This gain will be designated by the term "residual gain". The value of the residual gain is to a large extent characteristic of the quality of the antenna from the point of view of the distant side-lobes. In the case of radio-relay antennas, the residual gain may be taken as ranging from 0 dB for antennas with average performance down to –20 dB for antennas with very high performance.

Making the above-mentioned substitutions in equation (4) above, gives equation (1) in the text.

Alternative form for equation (4)

Equation (4) may be rearranged by the introduction of G_0 , the gain along the axis, and φ_0 , the 3 dB beamwidth of the main lobe. Thus, using:

$$G_0 = 10 \log \left[0.6 \left(\frac{\pi D}{\lambda} \right)^2 \right] \text{ and} \quad (6)$$

$$\varphi_0 = \frac{70}{D/\lambda} \quad (7)$$

If M is again taken to be 52, equation (4) may be written:

$$G_0 - G = 11 + 30 \log \frac{\varphi}{\varphi_0} \quad (8)$$

To make allowance for spill-over, the coefficient 30 may be replaced by 25 in equation (8).

This is the form of the equation used by other services (e.g. the broadcasting service).

REFERENCE

BOITHIAS, L. and BEHÉ, R. [September-October, 1971] Directivité maximale en dehors de l'axe des ouvertures rayonnantes équiphasées. *Ann. des Télécomm.*, Vol. 26, 9-10, 325-340.

REPORT 785-1 *

FREQUENCY TOLERANCES FOR RADIO-RELAY SYSTEMS

(Study Programme 19A/9)

(1978-1982)

1. Introduction

In many areas of the world increasingly intensive use is being made of radio-relay systems for the transmission of telephony, television and digital signals. New equipment capable of transmitting more information in a given radio frequency bandwidth has been developed, thereby providing more efficient use of the spectrum. However, such equipment is often more subject to interference, which may result in a situation where existing radio-relay routes cannot be expanded to their full potential due to the congested radio frequency environment.

Frequency tolerance limits are generally a compromise between the desirability of keeping these values to a realistic minimum, the ability to produce equipment that will meet a tight specification, and the cost in terms of economic and system performance of achieving such results. This Report provides a brief summary of the current techniques of carrier generation; discusses the frequency tolerance behaviour for various radio-relay repeater schemes and some interference conditions; identifies the increasing difficulties of achieving efficient spectrum utilization at higher frequencies and finally, offers insights to techniques for establishing reasonable frequency tolerance requirements for a class of heterodyne repeater systems. This Report gives preliminary answers to DECIDES 7 of Study Programme 19A/9.

* This Report should be brought to the attention of Study Group 1.

2. Definitions

The Radio Regulations give as a definition of frequency tolerance: "The maximum permissible departure by the centre frequency of the frequency band occupied by an emission from the assigned frequency or, by the characteristic frequency of an emission from the reference frequency. The frequency tolerance is expressed in parts in 10^6 or in hertz".

This definition clearly restricts the use of the word "tolerance" to the specified limit of excursion of the carrier frequency in the case of most radio-relay systems and it should be noted that a tolerance of x parts per million (ppm) implies limits of $\pm x$ ppm. In a chain of radio-relay repeaters the definition is usually most relevant to the last transmitter. In this document frequency error is taken to mean any unwanted departure of the characteristic frequency.

The difference between any instantaneous value of the carrier frequency and the assigned frequency may be due to two components, the constant inaccuracy of setting the frequency and a time-varying instability which may have distinct long and short-term characteristics. Both the instability and inaccuracy are measurable quantities.

3. Frequency stability of the carrier source

Excessive variations of the carrier source frequency due to variations of the ambient temperature can be prevented either by temperature control of the carrier source, or through the use of a frequency controlling device with low temperature sensitivity, or by a combination of both. Temperature control alone is rarely used in radio-relay systems. The prevailing carrier source designs can be categorized by the type of frequency controlling device and by the type of its frequency control function.

Two types of frequency controlling device are currently in use: the quartz crystal and the temperature-compensated, high- Q cavity. Their frequency control function can be described as being either direct or indirect. In the direct case the stabilizing device is incorporated in the oscillator, whereas in the indirect case it provides a stabilized reference frequency for an AFC (automatic-frequency-control) or an APC (automatic-phase-control) circuit which tunes the carrier oscillator to the reference frequency. Variety in the design of carrier sources is further enhanced by the choice between direct, fundamental-frequency generation and indirect generation at a subharmonic, followed by frequency multiplication. However, considerations of frequency stability can be limited to the properties of the frequency controlling device used.

While technological and economic factors in practice limit the maximum usable quartz crystal resonance frequencies to the lower VHF range, frequency control with this device is applicable over the entire microwave spectrum exploited for radio-relay links. This is accomplished through the use of frequency multiplication or frequency division, depending on the carrier source design. Frequency control with a stabilizing cavity, on the other hand, is practically excluded from the lower end of the microwave spectrum, where the cavity size would become excessive and therefore incompatible with compact equipment design.

A frequency stability with standard quartz crystals of 50 ppm over the -30°C to $+60^{\circ}\text{C}$ ambient temperature range, is, for example, readily achievable. Selected crystals can assure better stability, typically 20 ppm. The addition of an oven for temperature stabilization can bring about improvements of orders of magnitude dependent upon the characteristics of the crystal used and the temperature control of the oven. Such techniques can achieve stabilities of better than 5 ppm. The frequency stabilization figures obtainable with cavities differ for direct and indirect stabilization: 100 ppm for oscillators incorporating the stabilizing cavity, and 50 ppm for reference cavities, with 30 ppm obtainable over the normal ambient temperature range (e.g. $+10^{\circ}\text{C}$ to $+40^{\circ}\text{C}$). These figures are for temperature compensated environmentally sealed cavities. The practicality of additional frequency stabilization through temperature stabilization depends on the size and mass of the cavity. Where applicable, a frequency stability of 5 ppm can be obtained.

4. Factors affecting the frequency tolerance requirements of the emitted signal *

4.1 General

In radio-relay links using remodulating repeaters the emitted frequency error equals the error of the carrier source, but in radio-relay links using heterodyne repeaters this is generally not the case.

* Further study of this subject is required.

The conventional heterodyne system design for analogue transmission, for example, which uses independent carrier sources in a chain of up-conversions and down-conversions of the frequency-modulated intermediate frequency, leads to a buildup of the frequency tolerance along each homogeneous section terminated with a modulator and demodulator. Such heterodyne systems therefore require carrier sources with substantially narrower frequency tolerance limits than remodulating systems. There are other heterodyne system schemes, however, which aim at reducing the frequency stability requirements on the carrier sources without extending the tolerance limits of the emitted frequency.

In the repeaters one of these schemes uses a fixed frequency separation between the received and emitted carriers, which requires only a single microwave carrier source of moderate frequency stability and a high-stability VHF shift oscillator. These two are used in such a way that frequency variations of the microwave carrier source do not affect the emitted signal frequency. The frequency error of the transmitted signal is determined only by that of the VHF shift oscillator. Another heterodyne system scheme aimed at easing the frequency tolerance requirements of the carrier sources uses automatic control of each transmitter frequency. Frequency errors are therefore non-cumulative, and each carrier source is permitted to drift over the whole tolerance range of the emitted signal, as in a remodulating system.

4.2 Cumulative frequency errors in some heterodyne systems

The instantaneous frequency error F at the end of a multi-hop heterodyne repeater system with cumulative frequency errors depends on:

$$F = M + T + \sum_{1}^{n-1} R \quad (1)$$

where

M : frequency error of the modulator,

T : frequency error of the terminal transmitter,

R : frequency error of the repeater which varies with the type of repeater in use and which depends on the circuit configuration.

In a repeater system having two independent local oscillators, one for a receiver and the other for a transmitter, R is equal to the sum of the frequency error of the two oscillators (i.e., $R = r_1 + r_2$ where r_1 and r_2 are the frequency errors of the oscillators).

In the case of, for instance, 9 hops, the maximum frequency error of the emitted signal becomes equal to 17 times the maximum of one carrier source plus the modulator frequency error.

In a repeater system with a local oscillator in either the receiver or transmitter and with the other local signal obtained by shift converting the local oscillator output, R is equal to the frequency error S of the shift oscillator. Since the shift frequency is generally about 150 MHz to 600 MHz, S is below about 15 kHz when the shift oscillator error is 20 ppm.

A linear addition of the appropriate frequency errors is necessary to determine total frequency error for estimating bandwidth occupancy. The use of the above formula may result in unduly pessimistic conclusions, whereas a statistical determination of the total frequency error may offer a more realistic result.

4.3 Statistical considerations

If a baseband section with N heterodyne repeaters is assumed, the contributors to the final frequency error are two local oscillators in each repeater, one local oscillator and the modulator at the transmit terminal.

The frequency error of a local oscillator depends upon the frequency setting error, the temperature characteristics, variations with time, etc. Probability distribution models of the frequency error may be hypothesized into three types:

- normal distribution;
- rectangular distribution, and
- trapezoidal distribution.

In the case of normal distribution of local oscillator frequency error, the instantaneous frequency error at the end of the link can be assumed to follow a normal distribution with a mean value μ and a standard deviation s . Once μ and s are known, it is possible to calculate the probability that the frequency error is higher than a set reference value. The problem is to determine the relationship between s and N and the given frequency error of the local oscillators and the modulators.

Assuming that the mean value of the frequency error of each local oscillator and modulator is zero, it can be assumed that the normalized mean value of the frequency error of the last transmitter in a radio link will present a mean value μ equal to zero, then the standard deviation s of the normal distribution of the frequency error of the last transmitter in a radio link will be given by:

$$s = \sqrt{\sigma_m^2 + (2N + 1) \sigma_{oe}^2} \quad (2)$$

where

- σ_m : standard deviation of the frequency error of the modulator,
- σ_{oe} : standard deviation of the frequency error of a local oscillator,
- N : number of repeaters in a baseband section.

Assuming that the frequency error of modulators is negligible (e.g. when the modulators are automatically frequency controlled by a phase-lock-loop), Fig. 1 shows the results of these calculations under three hypotheses: the first hypothesis (continuous lines) is based on the experimental results of one administration* and assumes a standard deviation of the local oscillator frequency error equal to 1/3 the local oscillator tolerance. The second hypothesis (dashed lines) is more conservative and assumes a probability density function of the local oscillators frequency error flat within a range of plus and minus the frequency tolerance and zero outside the range. The third hypothesis, intermediate between the preceding two, adopts a trapezoidal distribution of the local oscillator frequencies with the following characteristics:

- zero probability outside the frequency tolerance,
- a flat distribution between $\pm 1/3$ of the frequency tolerance centred on the nominal frequency,
- a linear distribution between $\pm 1/3$ of the frequency tolerance and the frequency tolerance.

The results of frequency error at the end of the link are shown in Fig. 1.

4.4 Additional considerations

Other factors which make only a small contribution towards the difference between the carrier source stability and the tolerance of the emitted signal, include the initial frequency-setting accuracy of the source and the effects of frequency-locking networks.

It is thus evident that the specified frequency tolerance of the emitted carrier often has to be considerably less stringent than the available source stabilities and has to cover the possibility of using different types of equipment design and interference considerations in a particular band.

Interference arising from frequency error of the emitted signal causes effects which depend on the carrier modulation as well as on the type of baseband signal. For example, FDM-FM radio-relay systems with co-channel interference from other FDM-FM transmissions may experience a significant beat signal type of interference in the demodulated signal.

5. Problems of frequency tolerance at higher frequencies

Techniques for achieving the required stability may become increasingly difficult at the higher frequencies. However, when frequency tolerance is expressed in terms of parts per million, the total tolerance permitted in terms of hertz increases in direct proportion to the emitted frequency, and could eventually exceed the information bandwidth being conveyed by the system.

* Measurements were carried out in Italy in the period 1971-1972 on more than 200 solid state oscillators and 100 solid state frequency modulators without any automatic frequency control. The components under measurement had been installed from one to three years before the beginning of the measurements and their frequency had not been adjusted after the installation.

In order to investigate how much the frequency errors could be reduced by periodic adjustment of local oscillators and modulators, it was decided to set the frequency of each local oscillator and modulator and repeat the measurements three months later.

The results confirmed the validity of the normal distribution with a normalized mean value practically equal to zero, but with a standard deviation considerably improved for the solid state oscillator, while for the modulator the standard deviation was practically the same as in the previous measurements.

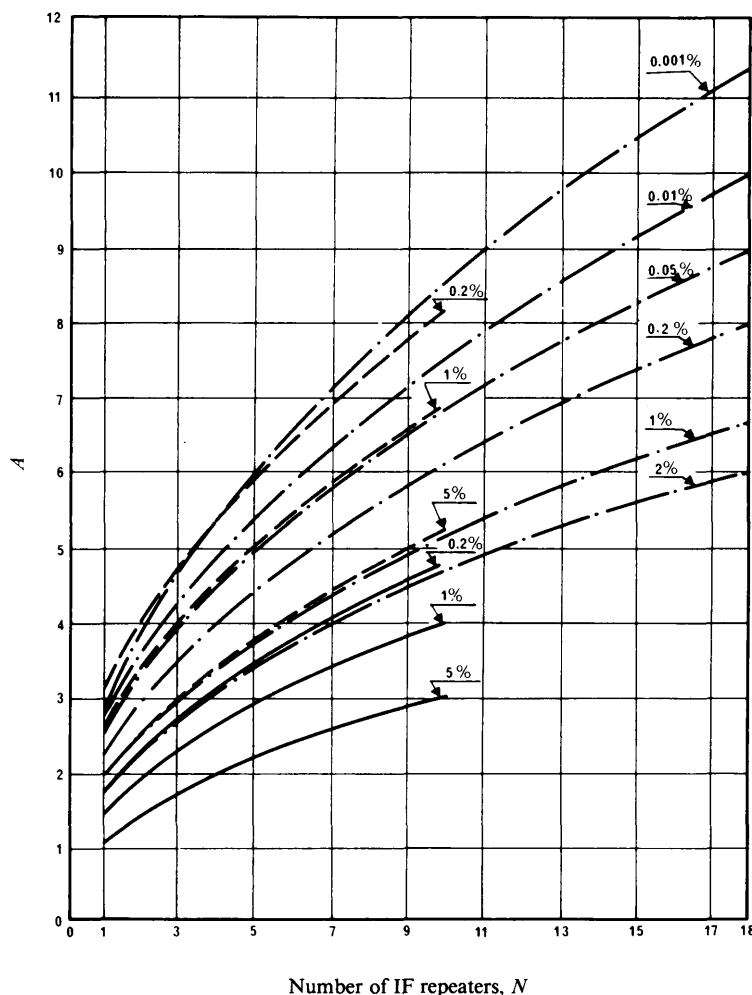


FIGURE 1 — Relationship between A and number of IF repeaters N

A : ratio between the frequency error at the last transmitter output in a baseband section and the frequency tolerance of local oscillators.

Each curve reports the value of the ratio exceeded only for the percentage of cases specified in the graph.

Case of IF repeaters with individual local oscillators for transmitters and receivers.

- Curves calculated on the hypothesis of local oscillator frequency error standard deviation equal to $\frac{1}{3}$ of the local oscillator tolerance (assumption based on experimental results).
- Curves calculated on the conservative hypothesis of a probability density function of local oscillator frequency error flat within a range of plus and minus the frequency tolerance and zero outside this range.
- . - . - Curves calculated on the hypothesis of a probability density function of local oscillator frequency error of trapezoidal distribution.

In the bands now being used (below about 20 GHz) and with the information bandwidths of present CCIR channelling plans, this has not been a problem. However, as the higher bands are put to use, this effect may create a significant problem. This will be especially true if there is a substantial demand for relatively low capacity systems. For example, for equipment operating on a carrier frequency of 39 GHz, a tolerance of 300 ppm (the figure now specified in the Radio Regulations) would correspond to an absolute tolerance of ± 11.7 MHz. This figure would be quite large with respect to the bandwidth of relatively low capacity equipment.

One administration proposed a frequency tolerance of 400 ppm for the frequency band above 40 GHz. The reason taken into account is that in a radio-relay system operating at a high frequency band such as 40 GHz or more, the carrier sources and the local oscillators for the repeaters are required to be as simple as possible, for reasons of reliability and economy, and the number of heterodyne relays in a baseband section will be within one or two in these frequency bands.

6. Conclusions and suggested frequency tolerances

It is important that administrations should consider tighter frequency tolerances for new equipment in the range up to 40 GHz.

Table I gives current frequency tolerance values for fixed stations operating between 100 and 40 000 MHz as adopted by the WARC-79.

TABLE I — *Frequency tolerances (in parts per million) for fixed stations*

Frequency range (MHz)	Frequency tolerances adopted by the WARC-79
100- 470	20 (1)
470- 2 450	100
2 450-10 500	200
10 500-40 000	300

(1) For fixed stations operating at 50 W or less.

Note 1. — Standards are for fixed stations operating at 100 W or less except where indicated.

Note 2. — Further study is necessary for fixed stations operating at more than 100 W.

Note 3. — Further study is required of frequency tolerances for fixed stations operating at frequencies above 40 GHz.

BIBLIOGRAPHY

CCIR Documents

[1978-82]: 9/13 (Japan).

REPORT 937

SPURIOUS EMISSIONS OF RADIO-RELAY SYSTEMS

(Study Programme 19A/9)

(1982)

1. Introduction

Spurious emissions from transmitters should be controlled in an appropriate manner in order to prevent excessive interference between radio-relay systems in an allocated frequency band, or between radio-relay systems and other radio services sharing the same band or in different frequency bands.

Interference due to spurious emissions between similar radio-relay systems sharing the same frequency band can generally be maintained at an acceptable level by means of good system design.

A more significant problem is the generation of interference by spurious emissions from other radio services operating in different frequency bands. It is not practicable to completely estimate and control the extent of these emissions, and therefore the study of spurious emissions should primarily be directed to an evaluation of the interference introduced into different radio services in different frequency bands.

2. Study of spurious emissions

Consideration should be given to the following points in the study of spurious emissions:

- the nature of baseband signals and modulation techniques of radio-relay systems;
- the effect of interference injected into a radio-relay system by spurious emissions from various sources;
- the character of spurious emissions generated by radio-relay systems;
- the nature of the signals transmitted by other radio services and the effect on these signals of interference caused by spurious emissions from other sources;
- the optimum way of expressing spurious emission characteristics in order that the interference created by such emissions can be readily assessed;
- the determination of the maximum level of spurious emissions from other sources which can be tolerated by radio-relay systems without introducing excessive interference.

3. Baseband signals and modulation techniques of radio-relay systems

3.1 Baseband signals

Although radio-relay systems at present generally carry telephony signals, a rapid growth is envisaged in the transmission of other signals such as facsimile, video, computer data and supervisory/control functions. Many of these signals contain elements which are particularly sensitive to interference – for example error correction messages in computer signals. Digital telephony signals also contain elements which are particularly sensitive to interference, such as control signals for switching systems, frame alignment words for digital multiplexes or control signals for digital speech interpolation systems. It is, therefore, necessary to ensure that spurious emissions into radio-relay systems carrying such traffic are maintained at a sufficiently low level to protect the sensitive signal elements from interference.

3.2 Modulation techniques

Modulation techniques for radio-relay systems can be divided into two categories: techniques for analogue systems (such as AM, FM and SSB) and techniques for digital systems (such as AM, FSK, PSK and multi-level modulation such as QAM).

4. Effect of interference by spurious emissions on radio-relay systems

The transmission quality of non-telephony signals tends to be affected by the instantaneous value of noise or bit errors caused by interference rather than by the mean value. Whilst error-correction techniques are effective in minimizing the effect of random errors, it is difficult to correct burst errors by such techniques without excessively lowering transmission efficiency.

As is noted above, instantaneous errors in the control signals of many digital systems can also have an important effect on the reliability or performance of the complete digital signal which is being transmitted.

It is therefore considered that the instantaneous or short-term value of an interfering signal created by a spurious emission may be more important than the value averaged over a long period of time. The short-term period of most significance cannot readily be estimated, however, as it is dependent on the nature of the signal being transmitted by the system suffering the interference.

5. Spurious emissions from radio-relay circuits

SSB transmitters produce signals with a high peak factor, and spurious emissions are estimated to have an even higher peak factor as a result of the non-linear transmitter characteristics. Transmitters for large capacity SSB radio-relay systems have relatively high transmission powers, but are designed to maintain intermodulation noise at a low level in order to meet the required performance objectives.

The mean value of the spurious emission can therefore be maintained at a relatively low level, but the instantaneous value of the power will vary at a rate inversely proportional to the bandwidth of the SSB signal.

Both FSK and PSK transmitters emit RF signals which include an amplitude variation resulting from the limited bandwidth of the transmitted spectrum, but FM transmitters emit signals of virtually constant amplitude. QPRS (quadrature partial response signals), QAM (quadrature amplitude modulation) and similar modulation techniques produce RF signals which are both phase and amplitude modulated. The variation with time of the power level of spurious emissions from such digital modulation techniques generally depends on the symbol rate.

6. Characteristics of spurious emissions from other radio services

6.1 *Satellite systems*

The baseband signals of satellite systems are comparable with those of radio-relay systems.

Certain satellite systems, such as time division multiple access (TDMA) and single channel per carrier (SCPC) system, are particularly susceptible to interference. These systems incorporate dedicated channels or time slots which control the overall system operation. Corruption of such control channels can affect the performance and availability of the complete satellite system, and therefore the instantaneous values of interfering spurious emissions have as significant an effect on the system performance as the mean values.

Satellite transmitters often incorporate amplifiers which are shared by several carriers. Spurious emissions from such transmitters have peak power to mean power ratios of the same order as SSB transmitters. Satellite transmitters tend to be operated further into the saturation region than comparable transmitters for radio-relay systems and therefore the ratio of spurious emissions to the transmitter output level is relatively high.

6.2 *Other radio services*

Certain other radio services need also to be considered in a study of spurious emissions:

- SSB transmitters are used by maritime mobile and aeronautical mobile systems;
- aeronautical radionavigation services in some cases use TDM codes of burst signals. The short-term characteristics of interference are therefore significant;
- radio-determination and meteorological aid services use various different types of emissions in radar equipment, but they all tend to be based on very small duty cycles with large instantaneous peak output powers. With a large peak to mean power ratio of the main transmitted signal, it is difficult to estimate the peak values of spurious emissions from the mean value.

7. Impact of spurious emissions by radio-relay systems on other radio services

As has already been discussed, a number of different modulation methods are used, or are envisaged, for radio-relay systems, for example FM, PSK and SSB. Some of these modulation methods result in a large difference between peak power and mean power and others result in a small difference.

Some radionavigation services carry out navigation control by TDM transmission methods and many satellite systems now employ TDMA techniques. In both of these cases, the peak power of spurious emissions from radio-relay systems may be the limiting factor in determining acceptable levels of interference than the mean power.

8. Control of spurious emissions

In studying the control of spurious emissions, the following points need to be considered:

8.1 Radio-relay systems and systems of other radio services are increasingly carrying digital signals whose reliability or transmission quality is affected by short burst of errors. An important aspect in the study of interference caused by spurious emissions is therefore the effect of such interference on the information signals being transmitted;

8.2 Interference caused by spurious emissions from other radio services in shared or different bands is becoming increasingly significant. The types of emissions from these services are diversifying and the estimation of the relationship between mean and peak power is becoming more and more difficult;

8.3 The use of mean power levels may in some cases be inadequate to properly evaluate the interference resulting from spurious emissions and the use of peak power levels may be more appropriate.

8.4 The spectrum of a spurious emission is closely related to that of the wanted modulation output signal and a strong phase relationship can be seen in the spurious emissions of systems which use modulation methods incorporating amplitude modulation techniques. The evaluation of such spurious emissions must be made by a synthesis of as many spectrum components as possible but an analysis of spurious emissions split into a large number of spectrum components would be impracticable.

8.5 The receiver bandwidth of radio-relay systems depends on the symbol rate but this bandwidth also determines the extent of the interference caused by spurious emissions. It is, therefore, suggested that the receiver bandwidth should be adopted as the bandwidth across which spurious emissions should be defined. This concept could also be applied to other radio services.

8.6 It should be noted that the World Administrative Radio Conference on the Aeronautical Mobile (R) Service, Geneva, 1978 defined the spurious power level for SSB transmitters in the aeronautical mobile service in terms of "peak envelope power".

9. Conclusion

Appendix 8 of the Radio Regulations states that the maximum permitted levels of spurious emissions should be indicated in terms of the mean power level of any spurious component supplied by a transmitter to the antenna transmission line. The control of such spurious emissions is important if interference to different radio services is to be minimized. It may be necessary in some cases to evaluate spurious emissions in terms of peak power levels rather than mean power levels.

SECTION 9C: INTERCONNECTION CHARACTERISTICS
(BASEBAND AND INTERMEDIATE FREQUENCY)

Recommendations and Reports

RECOMMENDATION 306

**PROCEDURE FOR THE INTERNATIONAL CONNECTION OF RADIO-RELAY SYSTEMS
WITH DIFFERENT CHARACTERISTICS**

(Question 1/9)

(1956-1959)

The CCIR,

CONSIDERING

- (a) that, to simplify interconnection across frontiers and to ensure the best transmission quality on international circuits, interconnection between systems with different characteristics should be avoided as far as possible;
- (b) that, however, when such interconnection cannot be avoided, special arrangements will have to be made at the junction;
- (c) that CCITT Recommendation G.352 *, "Interconnection of coaxial carrier systems of different types" (Vol. III, Fascicle III.2) recommends that, where different types of coaxial systems are directly connected across a frontier, each administration concerned should accept, on the receiving side, the transmission conditions normal to the incoming system,

UNANIMOUSLY RECOMMENDS

that, if different types of radio-relay systems are directly connected across a frontier, each administration concerned should accept, on the receiving side, the transmission characteristics normal to the incoming system, unless a better or more practical arrangement can be arrived at between the administrations concerned.

RECOMMENDATION 268-1 **

**INTERCONNECTION AT AUDIO FREQUENCIES
OF RADIO-RELAY SYSTEMS FOR TELEPHONY**

(Question 1/9)

(1970)

The CCIR,

CONSIDERING

- (a) that radio-relay systems for telephony may form part of an international circuit;
- (b) that international connections between such systems, among themselves or with other radio-relay or line systems, may at times have to be made at audio frequencies;
- (c) that the objective should be to comply with the relevant CCITT Recommendations in respect of overall performance measured between audio-frequency terminals;
- (d) that it will be necessary to signal over telephone circuits provided by means of such systems,

* Formerly Recommendation G.336 "Interconnection of coaxial systems using different techniques", renumbered at the IVth CCITT Plenary Assembly, Mar del Plata, 1968.

** This Recommendation cancels Recommendation 297.

UNANIMOUSLY RECOMMENDS

that, as far as is practicable, radio-relay systems for telephony providing circuits which may form part of an international connection should be such that these circuits conform with the relevant CCITT Recommendations for modern types of telephone circuit in the following respects:

1. the transmission characteristics of the circuits between audio-frequency terminals (the relevant Recommendations are contained in CCITT Vol. III, Fascicle III, 1);
2. the characteristics of the multiplex terminal equipment, where applicable (see CCITT Recommendations G.232 and G.412, Vol. III, Fascicle III.2);
3. the method of signalling over international circuits (the relevant Recommendations are contained in CCITT Vol. VI; see also CCITT Recommendation G.422, Vol. III, Fascicle III.2).

RECOMMENDATION 380-3 *

**INTERCONNECTION AT BASEBAND FREQUENCIES OF RADIO-RELAY SYSTEMS
FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX**

(Question 1/9)

(1956-1963-1966-1970-1974)

The CCIR,

CONSIDERING

- (a) that frequency-division multiplex radio-relay systems may form part of an international circuit;
- (b) that international connections between such systems, among themselves and with other radio-relay or line systems, may at times have to be made at baseband frequencies;
- (c) that definitions for the points *R* and *R'* of interconnection at baseband frequencies are given in Annex I to this Recommendation and Fig. 1;
- (d) that the levels of the points *T* and *T'*, which are the responsibility of the CCITT (see Recommendation G.213, Vol. III, Fascicle III.2), should be known to system designers,

UNANIMOUSLY RECOMMENDS

1. that the important baseband characteristics for a frequency-division multiplex radio-relay system forming part of an international circuit are:
 - 1.1 maximum number of telephone channels;
 - 1.2 limits of band occupied by telephone channels;
 - 1.3 frequency limits of the baseband, including pilots or frequencies which might be transmitted to line;
 - 1.4 relative input and output power levels, at the points of interconnection *R* and *R'*;
 - 1.5 nominal impedance of the baseband circuits at the point of interconnection;
2. that, as far as practicable, these characteristics should conform to the preferred values given in Table I **;

* This Recommendation applies to line-of-sight and near line-of-sight radio-relay systems, and also to trans-horizon radio-relay systems of the capacities concerned.

** It is recognized that in certain cases and regions it may be desirable to use baseband characteristics other than those given, by agreement between the administrations concerned.

3. the return loss at the points of interconnection should be ≥ 24 dB.

TABLE I

1	2	3	4	5	6	7	8
Maximum number of telephone traffic channels (Note 5)	Limits of band occupied by telephone channel (kHz)	Frequency limits of baseband (kHz) (Note 4)	Nominal impedance at baseband (Ω)	Relative power level per channel (dBr) (Notes 1, 2)			
				Radio-relay system output R (Note 7)	Main repeater station		Radio-relay system input R' (Note 7)
					T	T'	
24	12-108 (Notes 3, 6)	12-108 (Notes 3, 6)	150 bal.	-15	-23	-36	-45
60	12-252 60-300	12-252 60-300	150 bal. 75 unbal.	-15	-23	-36	-45
120	12-552 60-552	12-552 60-552	150 bal. 75 unbal.	-15	-23	-36	-45
300	60-1300 64-1296	60-1364	75 unbal.	-18	-23	-36	-42
600	60-2540 64-2660	60-2792	75 unbal.	-20 (1)	-23 -33	-36 -33	-45 (1)
960	60-4028 316-4188	60-4287	75 unbal.	-20 (1)	-23 -33	-36 -33	-45 (1)
1260 (2)	60-5636 60-5564 316-5564	60-5680	75 unbal.	-28	-33	-33	-37
1800	312-8204 316-8204 312-8120	300-8248	75 unbal.	-28	-33	-33	-37
2700	312-12 388 316-12 388 312-12 336	300-12 435	75 unbal.	-28	-33	-33	-37

(1) Alternative levels $R = -23$ dBr and $R' = -42$ dBr can be used when the associated line transmission equipment is wholly of a type for which the C.C.I.T.T. recommends baseband interconnection levels $T = -33$ dBr and $T' = -33$ dBr (Main repeater station equipped with transistors).

(2) Other limits of band occupied by telephone channels may be used by agreement between the Administrations concerned.

Note 1. — The particular preferred values of the relative power level given in the Table are agreed with the CCITT. These values apply to future systems.

Note 2. — The level shown is referred to a point of zero relative level in the system, in accordance with the practice of the CCITT.

Note 3. — For 12-channel systems, either of the basic groups A (12 to 60 kHz) or B (60 to 108 kHz) recommended by the CCITT may be accommodated in the band 12 to 108 kHz.

Note 4. — Including pilots or frequencies which might be transmitted to line.

Note 5. — Larger capacity systems are not excluded by the Table.

Note 6. — A permissible alternative arrangement uses the frequency range 6 to 108 kHz. With this first alternative, it is possible to use only the noise measuring channel, situated above the baseband according to Recommendation 398. A further permissible alternative arrangement uses the frequency range 12 to 120 kHz. With this second alternative, it is possible to use only a continuity pilot situated below the baseband, according to Recommendation 381.

Note 7. — The variation with frequency, over the range of baseband frequencies, of the equivalent loss of a homogeneous section of the hypothetical reference circuit from point R' to point R , should not exceed a limit of ± 2 dB relative to the nominal value except under abnormal propagation conditions. This tolerance is similar to that accepted by the CCITT for line links by means of cable (see CCITT Recommendation M.450).

It is desirable to study the variation of loss as a function of time.

ANNEX I

DEFINITION OF THE POINTS OF INTERNATIONAL CONNECTION AT BASEBAND FREQUENCIES

The points of international interconnection at baseband frequencies, called R' and R , form the input and output of a radio-relay system, conforming to CCITT Recommendation G.423 and the present Recommendation.

At the output of the radio-relay system (point R), the following conditions are found in the baseband:

1. All the telephony groups (groups, supergroups, mastergroups, etc.), and the pilots (line regulating, frequency comparison and monitoring pilots) included in the baseband are assembled in the position in which they are transmitted, as defined in the CCITT and CCIR Recommendations mentioned above.
2. All the continuity and switching pilots and other signals transmitted in a radio-relay system outside the telephony band, inherent to the radio equipment, are suppressed in accordance with Recommendation 381.
3. Any radio-relay protection switching shall be performed as part of the radio-relay system. With diversity reception, the combined output of the receivers used corresponds to point R .
4. Any de-emphasis networks are part of the radio equipment, so that the relative levels of the telephone channels are independent of frequency, within the limits of the tolerances stated in Note 7 of this Recommendation.

A similar point R' is defined for the baseband input of a radio-relay system, where similar conditions are to be met.

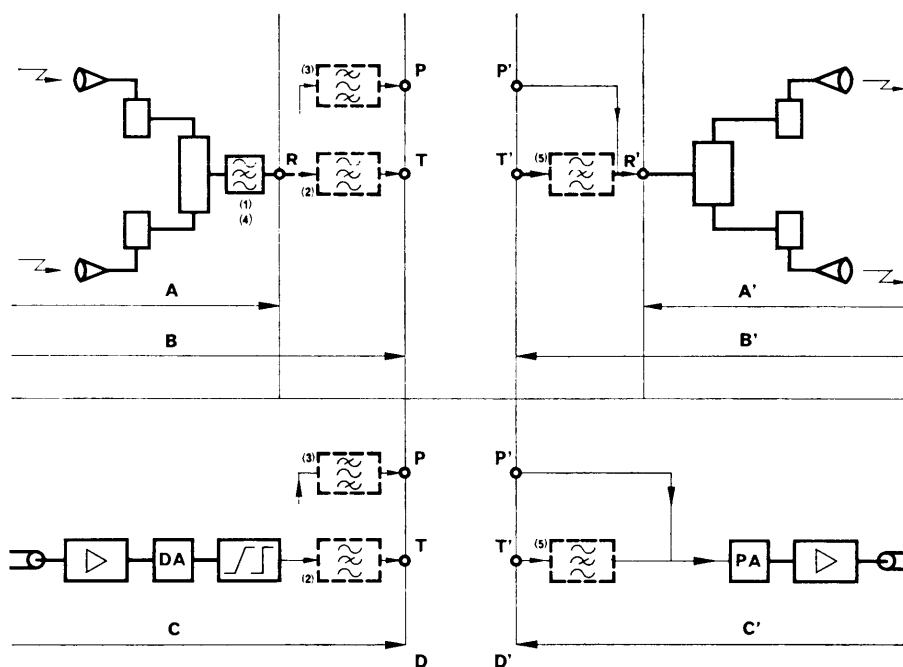


FIGURE 1

- A, A':** Radio-relay system
B, B': Line link by means of radio-relay system
C, C': Line link by means of cable system
D, D': Boundary of the high-frequency line equipment
R: Radio-relay system output
R': Radio-relay system input
Point P': Provided for possible injection of regulating pilots
Between T and T': Telephony translating equipment and/or direct through-connection equipment
DA: De-emphasis network
PA: Pre-emphasis network
(1): Blocking of continuity pilots, and if necessary, of regulating pilots
(2): Blocking, if necessary, of regulating pilots, and pilots that must not go beyond the line link
(3): Through-connection filter for regulating pilots, if necessary
 Through-connection filter for telephone groups can, if necessary, be inserted
(4): Blocking of unspecified pilots or supervisory signals
(5): Filter for blocking any unwanted frequency before injecting a pilot, ensuring with (2) the requisite protection against a pilot (or other) frequency coming from another regulated line section (B or C, as the case may be)

RECOMMENDATION 381-2 *

**CONDITIONS RELATING TO LINE REGULATING AND OTHER PILOTS AND TO LIMITS
FOR THE RESIDUES OF SIGNALS OUTSIDE THE BASEBAND IN THE INTERCONNECTION
OF RADIO-RELAY AND LINE SYSTEMS FOR TELEPHONY ****

(Question 1/9)

(1953-1959-1963-1966-1970)

The CCIR,

CONSIDERING

- (a) that it may be necessary to interconnect radio-relay and line systems when establishing international circuits;
- (b) that a continuity pilot may be required to establish the continuity of the transmission path between the input and output terminals of a radio-relay system, independently of the frequency-division multiplex telephony being transmitted;
- (c) that in addition, a line-regulating pilot may be required to measure the level stability in the baseband of a frequency-division multiplex telephony radio-relay system;
- (d) that the variations of the level of the line-regulating pilot should correspond closely to the variations of the overall gain of the radio-relay system between its input and output terminals at the frequencies of the frequency-division multiplex telephony signals;
- (e) that pilots are also required on line systems for gain-regulating, monitoring and frequency-comparison purposes;
- (f) that the line pilots used for monitoring and frequency comparison may also be required to be transmitted over a radio-relay system;
- (g) that a pilot frequency of 308 kHz is already in use by line systems for gain-regulating and other purposes, and that there is a gap in the frequency-division multiplex signal spectrum within which the pilot is located;
- (h) that, in some radio-relay systems, it is permissible to place the service channels of a radio-relay system below the baseband (in certain cases, a service channel may be very near to a telephone channel in the general network);
- (j) that it is essential to avoid undesirable effects, such as the interaction of the gain-regulating systems and interference or crosstalk from the pilots, when radio-relay and line systems are interconnected;
- (k) that all signals transmitted on a radio-relay system, even if they cannot cause interference to either the telephone channels or the pilots of a cable system interconnected with that radio-relay system, must have a limited power to avoid overloading the cable system;
- (l) that, if such interfering signals have to be eliminated by a filter incorporated in the radio equipment, that filter, the attenuation-versus-frequency characteristic of which has a finite slope, must not cause appreciable attenuation distortion on the telephone channel thus protected,

UNANIMOUSLY RECOMMENDS

1. that the point of interconnection between a radio-relay system and a line system forming part of an international circuit shall be considered as a junction between line-regulating sections, except when the cable system constitutes a short extension of the radio system and is then a part of the same line-regulating section; if the radio-relay link constitutes a regulated line section, the station at one end of the system would be called "the radio-link control station" and the station at the other end would be called "the radio-link sub-control station". The duties of these stations are given in the maintenance instructions in Vol. IV of the CCITT;

* This Recommendation applies to line-of-sight systems and near line-of-sight systems, and also where appropriate, to trans-horizon radio-relay systems.

** Attention is drawn to the fact that, for direct through-connection between two radio-relay systems, frequencies outside the baseband may pass between the points *R* and *R'*, with negligible attenuation relative to the baseband. The precautions called for to protect cable systems may, therefore, also be necessary to protect radio-relay systems. The points *R* and *R'* and the points *T* and *T'* are defined in Fig. 1 of Recommendation 380.

2. that the continuity pilot of a multi-channel telephony radio-relay system should be located outside the band of frequencies occupied by the frequency-division multiplex signal and the preferred frequencies and levels will be as shown in Recommendation 401 *;
3. that the level of the continuity pilot of a radio-relay system for telephony be suppressed below -50 dBm0 at the point of connection with a line system (point R);
4. that, for a line-regulating pilot on a frequency-division multiplex telephony radio-relay system with a capacity of 60 channels or more, $308\text{ kHz} \pm 3\text{ Hz}$ be the preferred frequency and the preferred pilot level be -10 dBm0. A second line-regulating pilot situated in the upper part of the baseband may also be used, the preferred value of frequency and level of which should be those recommended by the CCITT for cable systems **;
5. that the level of the line-regulating pilot of a telephony radio-relay system be suppressed below -50 dBm0 at the point of connection with a line system, in all cases where this point is a junction between line-regulating sections (point T or before this point);
6. that the level of any line-regulating pilot of a line system to which a radio-relay system is connected be suppressed below -50 dBm0, before the input of the radio-relay system (point R'), in all cases where point T' is the junction between line-regulating sections, except by agreement between the administrations concerned;
7. that, when cable systems constitute short extensions of the radio system and are then part of the same line-regulating section, the same line-regulating pilots may be transmitted in the two systems;
8. that in the absence of any special agreement between administrations, the level of any pilot or supervisory signals, transmitted outside the baseband of a radio-relay system at a frequency not specified by the CCIR, should, within the radio equipment, be reduced below -50 dBm0 at point R ;
9. that similarly, in the absence of special agreements between the administrations concerned, the levels of all pilots or supervisory signals, transmitted over the cable system and having frequencies outside the baseband of the radio-relay link, should, within the equipment of the cable system, be reduced below -50 dBm0 at point T (and consequently at point R');
10. that, if a radio-relay system service channel, adjacent to a telephone channel in the baseband, uses the levels, frequency allocation and signalling levels corresponding to those which would be recommended by the CCITT for an ordinary telephone channel in the same position in the frequency spectrum, the channel filters are adequate to avoid the risk of cross-talk interference; if this condition is not met, an additional filter may be necessary and should be provided within the radio equipment;
11. that the frequencies mentioned in § 8 and 10 must be sufficiently distant from the baseband to ensure that the filters (or other appropriate devices) required to eliminate them do not cause attenuation distortion in the passband to exceed the recommended values;
12. that, to avoid overloading the cable system, the level of any other signal outside the baseband range be less than -20 dBm0 at the point R ; similarly, to avoid overloading the radio-relay system, the level of any other signal outside the baseband should be less than -20 dBm0 at the point R' ;
13. that, further, the level of the total power of all the signals outside the baseband range, including thermal and intermodulation noise, be less than -17 dBm0 at the points R and R' ;
14. that all other line pilots *within* the band of frequencies occupied by the frequency-division multiplex telephony signal be freely transmitted by the radio-relay system to which the line system is connected.

* A continuity pilot within the baseband, possibly acting as the line-regulating pilot, may be used in systems of up to 120 channels for reasons of economy, after agreement between the administrations concerned.

** For systems up to 120 channels a line-regulating pilot of 60 kHz with a level of -10 dBm0 may be used; in this case the suppression level should conform with the provisions of CCITT Recommendation G.243, § 3.1 (Vol. III, Fascicle III.2); thus the level of the line-regulating pilot, established by the CCITT for lines, differs according to whether it concerns coaxial cables or symmetrical pairs (-10 dBm0 for coaxial cables and -15 dBm0 for symmetrical pair systems).

RECOMMENDATION 270-2

INTERCONNECTION AT VIDEO SIGNAL FREQUENCIES OF
RADIO-RELAY SYSTEMS FOR TELEVISION

(Question 3/9)

(1959-1970-1978)

The CCIR,

CONSIDERING

- (a) that radio-relay systems for television may form part of an international circuit;
- (b) that interconnections of such systems amongst themselves, or with other radio-relay or line systems, may at times have to be made at video signal frequencies,

UNANIMOUSLY RECOMMENDS

that radio-relay systems for television, forming part of an international circuit, should conform in their baseband characteristics to the requirements for video interconnection points given in Recommendation 567; in particular, the following characteristics are preferred:

1. the nominal impedance Z_0 at the video interconnection point should be 75 Ω unbalanced, and the return loss should not be less than 30 dB;
2. the nominal amplitude of the video signal at the input and output (excluding the chrominance sub-carriers) should be 1 V peak-to-peak (see Notes 1 and 2);
3. the nominal upper limit of the video-frequency band for different television systems should conform to the design objectives and tolerances for the various television standards as given in Report 624 and part D of Recommendation 567.

Note 1. — In the design of equipment, account should be taken of the losses in the interconnecting cables, when the video interconnection point is at some distance from the terminals of the modulating and demodulating equipment.

Note 2. — The nominal relative levels of the chrominance sub-carriers are given in Report 624 for the various television standards.

RECOMMENDATION 463-1 *

LIMITS FOR THE RESIDUES OF SIGNALS OUTSIDE THE BASEBAND
OF RADIO-RELAY SYSTEMS FOR TELEVISION

(Question 3/9)

(1970-1978)

The CCIR,

CONSIDERING

- (a) that the interconnection of radio-relay systems and line systems, as well as the direct through-connection of radio-relay systems, may be necessary when establishing international circuits;
- (b) that a continuity pilot may be required to establish the continuity of the transmission path between the input and output terminals of a radio-relay system independently of the traffic (e.g. television plus sound programme channels);
- (c) that it is essential to avoid undesirable effects, such as interference or cross-talk from the pilots, when systems are interconnected;
- (d) that limits should be placed on the level of any signal transmitted on a system, even if it cannot cause interference to either the traffic or the pilots of a following system, to avoid overloading that system;

* This Recommendation terminates Study Programme 3B/IX.

(e) that if such signals have to be eliminated by a filter incorporated in the output of the equipment, the attenuation and group delay variation caused by that filter should not cause the system performance to differ from that appropriate to the system,

UNANIMOUSLY RECOMMENDS

1. that the point of interconnection between radio-relay systems or between radio-relay systems and line systems, forming part of an international connection, should be considered as a junction between line-regulating sections, except when the cable system constitutes a short extension of the radio system and is then a part of the same line-regulating section; if the radio-relay link constitutes a regulated line section, the station at one end of the link will be called "the radio-link control station" and the station at the other end of the link will be called "the radio-link sub-control station". The duties of these stations are given in the maintenance instructions in CCITT Recommendations, Series N, Vol. IV, Fascicle IV.3;

2. that the continuity pilot should be located outside the band of frequencies occupied by the television signal and any associated sound programme channels. The preferred frequencies and levels are shown in Recommendation 401;

3. that, in the absence of any special agreement between the administrations concerned, the level of any continuity pilot (Recommendation 401), sound programme sub-carrier (Report 289), service channel (Report 444), harmonic of the traffic or other unwanted signal, within prescribed limits above the television frequency band should, within the equipment, be reduced to not more than -50 dB relative to 1 V peak-to-peak (about 1 mV r.m.s.) at a point in the system corresponding to point *T* (Recommendation 380, Fig. 1) for telephony. The limits of the baseband frequency range over which this should apply are as follows: for 525-line systems the limits are 1.25 to 2.5 times the nominal upper limit of the frequency band (Report 624). For 625-line systems the limits are 1.2 times (Note 1) to twice the nominal upper limit of the frequency band (Report 624). Alternatively, the aforementioned reduction of level may be restricted to the continuity pilot and the sound programme sub-carrier;

4. that, to avoid overloading and other deleterious interference effects on the following systems such as radio-relay systems, cable systems or other interconnected systems, the level of the residue signals above 1.2 times (Note 2) the nominal upper limit of the television frequency band should be at least 30 dB (Note 3) below that of the television signal measured as the ratio of the nominal peak-to-peak amplitude of picture luminance signal to the r.m.s. amplitude of the residue signals.

Note 1. — For television systems using an upper limit of the frequency band of 6 MHz and four sound programme sub-carriers in accordance with Plan *A* (Report 289), the limits are 1.13 times to twice the nominal upper limit of the frequency band.

Note 2. — For television systems using an upper limit of the frequency band of 6 MHz and four sound programme sub-carriers, in accordance with Plan *A* (Report 289), the figure is 1.13 times the nominal upper limit of the television frequency band.

Note 3. — This is a provisional level, subject to further study.

RECOMMENDATION 402-2

THE PREFERRED CHARACTERISTICS OF A SINGLE SOUND CHANNEL SIMULTANEOUSLY TRANSMITTED WITH A TELEVISION SIGNAL ON AN ANALOGUE RADIO-RELAY SYSTEM

(Question 3/9)

(1959-1963-1974-1978)

The CCIR,

CONSIDERING

(a) that it may be desirable for economic or operational reasons to transmit the sound signal accompanying a television signal over the same radio-relay system;

(b) that a channel suitable for the transmission of the sound signal may be provided by means of a frequency modulated sub-carrier inserted in the baseband of the radio-relay system above the video-frequency band and below the continuity pilot (see Recommendation 401);

(c) that a sound channel provided by these means may form part of an international connection,

UNANIMOUSLY RECOMMENDS

1. that the transmission performance of the sound channel should conform to the requirements of the CMTT for international sound-programme circuits (Note 1);

2. that the following transmission characteristics are preferred:

		General recommendation	French system	U.S.S.R. 625-line system
2.1	<i>Frequency of sub-carrier (MHz)</i>	7.5	10	8
2.2	<i>Modulation characteristics of sub-carrier</i>			
2.2.1	Nominal input impedance of audio channel (Ω)	600 (bal.)	15 000 (bal.)	600 (bal.)
2.2.2	Maximum audio-frequency signal at a zero relative level point (dB rel. 0.775 V r.m.s.) (Note 2)	+9	+9 (in 600 Ω)	0 (input) + 17 (output)
2.2.3	Audio-frequency bandwidth (Hz)	30-10 000 (Note 3)	40-12 000	50-10 000
2.2.4	Deviation of sub-carrier (for a sinusoidal test tone of maximum level given in § 2.2.2)	140 kHz r.m.s.	70 kHz r.m.s. (at 800 kHz)	150 kHz peak
2.2.5	Pre-emphasis of audio-frequency channel (μ s) (Note 4)		50 (see Rec. 450)	nil
2.3	<i>Deviation of IF and RF carrier</i>			
	The amplitude of the unmodulated sub-carrier should be such as to produce a deviation of the IF and RF carrier of:	300 kHz r.m.s.	600 kHz r.m.s.	750 kHz peak

Note 1. — See Recommendation 504. Maintenance is dealt with in CCITT Recommendations Series N, Vol. IV, Fascicle IV.3. The conditions of measurement should be the subject of further study.

Note 2. — The input and output levels for an international programme line and for an international programme link have been defined in CCITT Recommendation J.14 (Vol. III, Fascicle III.4). It is the responsibility of the administrations concerned to choose the appropriate value for their particular use.

Note 3. — The upper limit may be increased should there be evidence of need.

Note 4. — Pre-emphasis may be used by agreement between the administrations concerned. Attention is drawn to Recommendation 450, § 1.2. The network defined in that Recommendation may also be suitable for the sound channel, but it should be studied to see if the nominal deviation of 800 Hz can remain at the value used for transmission without pre-emphasis, or if it is necessary to fix the nominal deviation at a higher frequency to avoid increase in the peak signal to the sub-carrier modulator.

REPORT 289-4

**THE PREFERRED CHARACTERISTICS FOR THE SIMULTANEOUS TRANSMISSION
OF TELEVISION AND A MAXIMUM OF FOUR SOUND CHANNELS
ON ANALOGUE RADIO-RELAY SYSTEMS**

(Study Programme 3A/9)

(1963-1970-1974-1978-1982)

1. Introduction

This mode of operation is only intended for systems with a capacity of 1800 telephone channels (for systems of smaller capacity, it may not be possible to achieve the simultaneous transmission of four sound channels. In Annex III design considerations are discussed for the simultaneous transmission of an NTSC 525-line colour television signal and two sound channels on a radio-relay system of 960-telephone channel capacity). In conformity with the decisions of the CCIR Meeting of Experts, Cannes, 1961, a bandwidth of up to 6 MHz is envisaged for international television transmission (e.g. Eurovision). As it is desired to make the separation between the highest video frequency and the sound channels sufficiently large, lest the filter necessary between the video and sound signals gives rise to undue transients in the video channel, the space available in the baseband spectrum for accommodating the sound carriers is restricted approximately to the band 7 to 8.8 MHz. Four sound channels of high quality may be accommodated in this band. In studying the choice of frequencies, the performance objectives as indicated by the CMTT should be considered.

2. Baseband frequency arrangement for simultaneous transmission of television and four sound channels

2.1 *Frequency position of intermodulation products*

The sub-carriers of the four intended sound channels lie within a frequency octave, which implies they will be free from any quadratic non-linear distortion products.

The third-order non-linear distortion products of the sub-carrier frequencies may be positioned in such a way so that they fall outside the audio-bands; taking into account the practical frequency tolerances of the sub-carriers. It seems sufficient to offset the nominal frequencies of the third-order intermodulation products some 40 kHz from the sub-carrier frequencies, because systematic frequency changes of all the interacting sub-carriers (caused for example by ambient temperature) will cancel out, so that the offset must be provided for individual frequency changes only.

Some of the third-order non-linear distortion products may fall near the upper fringe of the video channel, but they are expected to be negligible in comparison with those of the second order. Care should be taken that the third-order intermodulation product between the lowest sub-carrier and the continuity pilot is sufficiently spaced from a possible colour carrier at frequencies corresponding to the chrominance sub-carriers of the television system or systems to be transmitted.

It is further desirable that the third-order non-linear products between the sub-carriers should not be permitted to fall too close to the frequency of the continuity pilot so that neither the operation of the pilot nor its sidebands used for a service channel or other facilities might be disturbed. Lastly, to prevent interference in the sound channels, it is desirable to make their sub-carrier frequencies different from those of the second harmonics of the largest components of the chrominance signal.

To meet the above-mentioned requirements, the intervals between the sub-carriers must be unequal. To attain an offset of 40 kHz for example, the various intervals between the sub-carriers and between the upper sub-carrier and the continuity pilot must differ from one another by at least 40 kHz. Care should be taken that the minimum separation between the sub-carriers is sufficiently large, lest the bandpass filters necessary to eliminate non-linear cross-talk between adjacent sub-carriers give rise to undesirable linear distortion within their passbands, causing intolerable non-linear distortion in the sound channels. In choosing the minimum separation, account should be taken of the fact that the nominal maximum voltage level in a sound channel may be exceeded due to level misadjustments and/or non-ideal volume control. Hence, provision should be made for an additional margin of 3 dB.

A lower and an upper limit may be estimated for the smallest interval between two adjacent sub-carriers. The other intervals are greater by multiples of the frequency offset. Starting from a maximum frequency deviation of ± 100 kHz for the nominal maximum voltage level and taking into account 3 dB margin for overload, for the lower limit of the frequency interval a value of $310 \text{ kHz} + \Delta$ seems appropriate, where Δ represents a practicable value for the slope between the passband and the stopband of the bandpass filters (some 50 to 100 kHz). On the other hand, starting from the maximum frequency band available and an offset value of 40 kHz, one obtains for the upper limit of the smallest frequency interval a value of 495 kHz. The smallest interval may have therefore, a value of between 350 and 500 kHz.

Finally, when choosing the frequencies of the four sub-carriers, account must be taken of techniques not directly related to the sound-on-vision transmission, e.g., the frequency position of an eventual noise measuring channel, used for protection systems, which must be kept free from sub-carriers.

2.2 To reduce these problems, two sets of sub-carrier frequencies have been determined. As, up to now, no international agreement has been reached on this subject, it seems advisable for the time being to propose these two sets of frequencies. It was the unanimous wish of the delegates that, if possible, a final set of sub-carrier frequencies be chosen such that they could be used with any colour television system at present in use. There would also be an advantage if the final choice could be made from these two plans:

TABLE I

Plan	Sub-carrier frequencies (kHz)				
A	7020	7500	8065	8590	
B_1 ⁽¹⁾	7000	7360	7765	8215	
B_2 ⁽¹⁾		7360	7765	8215	8710

⁽¹⁾ B_1 and B_2 are two variants of the same plan with B_1 being used for television systems having a maximum video frequency of 5.0 MHz and B_2 being used for those systems having a maximum video frequency of 6.0 MHz.

2.3 Subsequent studies in Canada have concluded that the two frequency plans suggested in § 2.2 above create difficulties for the transmission of the 525-line NTSC colour television system on systems with 20 MHz channel spacing. The major reason for this is that the sound sub-carrier in each plan is close to the band of frequencies occupied by the second harmonic of the colour sub-carrier and its major line frequency harmonics, i.e. at $7.16 \text{ MHz} \pm 0.35 \text{ MHz}$.

An appropriate four channel sound sub-carrier frequency plan has been developed for use with the 525-line NTSC colour television systems. This plan is based on some of the principles outlined in this Report and other significant factors which allow universal use on radio systems with telephone channel capacities of 1200 channels or more operating with 20 MHz channel spacing. It should be noted that 20 MHz channel spacing is a spectrally efficient channelling plan for transmitting 525-line colour television and four sound sub-carriers. The factors considered in the development of a four channel sub-carrier system for the 525-line NTSC television system and the major system characteristics are described in Annex IV.

2.4 The second-order intermodulation products (type $f_e - f_k$), which can be of a periodic character, are to be measured in the absence of loading of the sub-carriers in order to find the worst case values.

3. Choice of the frequency deviation for the sub-carriers, and of the frequency deviation of the radio-frequency carrier produced by the sub-carriers

When choosing the frequency deviation of the main carrier frequency, account should be taken of the three main sources of noise:

- thermal noise,
- non-linear products falling into video channels,
- non-linear products falling into the sound channels.

As regards thermal noise, it will suffice to obtain a performance that is 12 dB better than that for telephone channels provided for long distance operation. The improvement can be obtained by the use of a maximum signal deviation of the sub-carriers of ± 100 kHz. It will then be more than sufficient, if the main carrier frequency deviation due to one sub-carrier is made equal to the nominal frequency deviation of a telephone channel occupying the same position in the baseband, taking into account the use of pre-emphasis.

It seems, however, that this value of deviation would be somewhat low from the point of view of intermodulation noise into the sound channel; this statement is based on experience with a sound channel in accordance with Recommendation 402; this applies still more to the present case, since the above-mentioned frequency deviation is smaller than the corresponding frequency deviation given in Recommendation 402 by a factor of 2.

In consequence, proposals for the frequency deviation of the main-carrier would first require values to be specified for the deviation and pre-emphasis of the video signal. It has been suggested that the same pre-emphasis be used for systems designed for the simultaneous transmission of television and 600 telephone channels, or for television and several sound channels, as is used for systems loaded with 1800 telephone channels. A frequency deviation for television has been proposed which has, at the lower frequencies, the same value as that given in Recommendation 405. This results in a deviation at the highest video frequencies which is somewhat lower than that given in Recommendation 405 with pre-emphasis.

On the basis of the above assumptions, a provisional value for the main carrier-frequency deviation which is 3 dB larger than the nominal deviation for a telephone channel in the same baseband position is proposed. In this proposal, note has been taken of the fact that a system with a capacity of 1800 telephone channels must be more linear than a 960-telephone channel system.

With the four sub-carriers and the television signal, in the most unfavourable condition, which is the addition of the instantaneous peak frequency deviation, one obtains a value of ± 3.8 MHz, while for a 1800-telephone channel system, the corresponding figure is ± 6.2 MHz.

4. Characteristics of the multiplex equipment

The sub-carrier modulators and the network combining the sub-carriers with the video signal should be separate from the 1800-telephone channel radio-relay equipment. The question remains to be studied of how to design the filters necessary for the separation of the video signal and the sound channels, to conform to all pertinent Recommendations for television and sound programme circuits of the CMTT.

5. Conclusions

The following transmission characteristics should be studied as preferred values:

5.1 Frequencies of the sub-carriers

TABLE II

Plan	Frequency (kHz)				
<i>A</i>	7020	7500	8065	8590	
<i>B₁</i>	7000	7360	7765	8215	
<i>B₂</i>		7360	7765	8215	8710

5.2 Maximum audio-frequency signal at a point of zero relative level: + 9 dB relative to 0.775 V r.m.s.

Note. — In CCITT Recommendation J.14 (Vol. III, Fascicle III.4), the figure defines the input and output levels for an international programme line and for an international programme link. It is the responsibility of administrations to choose the appropriate value for their special use.

5.3 Audio-frequency bandwidth: 30 to 15 000 Hz (the upper limit may be decreased, should there be evidence of need).

5.4 Maximum signal deviation of sub-carrier frequency: ± 100 kHz for the level defined in § 5.2.

5.5 Pre-emphasis in the sound channel needs further study.

5.6 Main carrier-frequency deviation due to each of the four sub-carrier frequencies should be that corresponding to a power of $+3$ dBm0 in a telephone channel with the same baseband position, taking into account the use of pre-emphasis.

Note. — Recommended characteristics in OIRT countries are given in OIRT Recommendation No. 77 [CCIR, 1974-78].

REFERENCES

CCIR Documents

[1974-78]: 9/287 (OIRT).

ANNEX I

Table III gives, for those frequency plans under consideration, the calculated values of the absolute and relative frequency separations, within which the filters must reach the attenuation necessary for separating the highest sound channel from the unmodulated continuity pilot (line 3), the lowest sound channel from the video band (line 4) and the adjacent sound channels from one another (line 5).

TABLE III

1	Plan			A	B ₁	B ₂
2	Sub-carrier frequencies (kHz)			7020 7500 8065 8590	7000 7360 7765 8215	7360 7765 8215 8710
3	Frequency gap available for the slope of the separation filter fourth sound channel/continuity pilot (9023 kHz)		Abs. (kHz)	270	645	150
			Rel. (%)	3.05	7.4	1.7
4	Frequency gap available for the slope of the separation filter television Band/first sound channel	5 MHz television band	Abs. (kHz)	1857	1837	
			Rel. (%)	37.0	36.6	
		6 MHz television band	Abs. (kHz)	857		1197
			Rel. (%)	14.3		20.0
5	Smallest frequency gap available for the slope of the separation filter sound channel/sound channel	Between adjacent sub-carriers	Abs. (kHz)	480	360	405
		Between adjacent modulation bands	Abs. (kHz)	154	34	79
			Rel. (%)	2.12	0.475	1.04

The above figures were calculated on the following assumptions:

Peak-deviation 100 kHz
 Overload 3 dB
 Audio-frequency bandwidth 15 kHz
 Frequency error of sub-carrier $1 \times 10^{-3} \approx 7$ kHz
 Total modulation band 163 kHz

The percentages in lines 3 and 5 refer to the centre frequencies of the gaps.
 The percentages in line 4 refer to the upper limit of the video-frequency bands.

ANNEX II

1. The main parameters which determine the choice of the number of sub-carriers and their frequencies for the transmission of sound signals simultaneously with a television signal, are the following:

- thermal noise,
- non-linear products falling into the video-frequency band,
- non-linear products falling into sound channels.

2. In Tables IV to VIII the data are given concerning the choice of frequency plans of the sound channel sub-carriers.

In Table IV the frequency spacing between the third-order non-linear products and the nominal values of the sub-carrier frequencies for plans A , B_1 and B_2 are shown.

TABLE IV

Variant of the frequency allocation plan	Narrowest separation (kHz)
A	40
B_1	45
B_2	45

Table V shows the permissible values of instability of the sub-carrier frequencies which should not be exceeded for the three frequency plans.

TABLE V

Variant of the frequency allocation plan	Permissible of the sub-carrier
A	1×10^{-3}
B_1	1.15×10^{-3}
B_2	1.15×10^{-3}

The intermodulation products in the video signal spectrum of the $(2f_1 - f_2)$ and $(f_1 + f_2 - f_3)$ type are shown in Table VI. The data in this Table refer to 625-line, 5 and 6 MHz television standards.

TABLE VI

Variant of the frequency allocation plan	Intermodulation products in the television spectrum	
	Standard 625-line, 5 MHz	Standard 625-line, 6 MHz
A	4977 kHz not considered	5017, 5450, 5497, 5975, 5977 not considered 5697
B_1		
B_2		

3. Some measurements were carried out on a 1674 km long radio link (18 hops) approximately equivalent to two sections of the hypothetical reference circuit. The results of these measurements are summarized in Table VII and Table VIII and refer to frequency Plan A only.

Table VII contains data concerning third-order intermodulation products falling in the baseband (dB referred to 0.7 V).

TABLE VII

Sub-carriers	$2f_2-f_3$	$2f_3-f_4$	$2f_2-f_1$	$2f_3-f_2$
Plan A	-68	-71	-74	-72

In Table VIII the signal-to-noise ratios in the audio-frequency band are shown.

TABLE VIII

	7020		7500		8065		8590	
	(¹)	(²)	(¹)	(²)	(¹)	(²)	(¹)	(²)
With psophometric filter	60	67	65	73	62	69	61	67
With 40 Hz to 15 kHz filter	55	63	60	67	58	64	59	64
With 20 Hz to 20 kHz filter	55	63	60	67	58	64	59	64

Note. — Column (¹): signal-to-noise ratio with video signal.
Column (²): signal-to-noise ratio without video signal.

4. Some tests were carried out to consider the noise produced in the sound signals by non-linear products due to a colour video-frequency signal in the presence of different types of pre-emphasis, both in baseband and in the audio-frequency band. The measurements were made by changing linearly the group-delay characteristic in the intermediate-frequency band. The data obtained refer to frequency Plan A only.

The following test video-signals were used during measurements:

- a sine-wave signal swept continuously from 0.5 MHz to 6 MHz having an amplitude of 0.5 V peak-to-peak;
- a signal similar to CCIR test signal No. 3b with no superimposed sine-wave.

By means of the first signal, it was possible to determine the interference due to the second harmonics of the video signal falling into sound channels. By means of the second signal, with a fundamental component of 3.9 kHz, it was possible to monitor intermodulation products of the $(f_1 \pm f_2)$ type, due to the beat between sound sub-carriers and video-frequencies below 15 kHz.

The following conclusions can be drawn from the tests carried out:

- as regards pre-emphasis in the audio-frequency band, the one proposed by the CCITT shows better psophometric signal-to-noise ratios under the same conditions; measurements on real links with 50 μ s pre-emphasis, also show better signal-to-noise ratios (the choice of pre-emphasis and de-emphasis, if any, should be the subject of further study);
- the type of baseband pre-emphasis used can have noticeable effects on the magnitude of non-linear distortion falling in the sound channel (see Fig. 1);
- the group delay being the same, the signal-to-noise ratio of the sound channels is much better because the sub-carrier frequencies are lower (see Figs. 2 and 3).

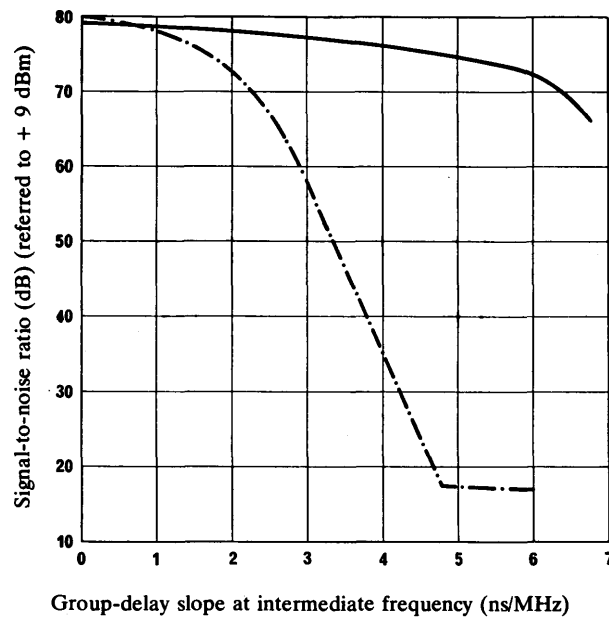


FIGURE 1 – Signal-to-noise ratio as a function of the group delay, measured on channel 3

Audio-frequency pre-emphasis: CCITT

- : baseband frequency pre-emphasis, CCIR, 1800 telephone channels
- · - · - : baseband frequency pre-emphasis, CCIR for 625-lines

(noise due to second harmonic of video signal)

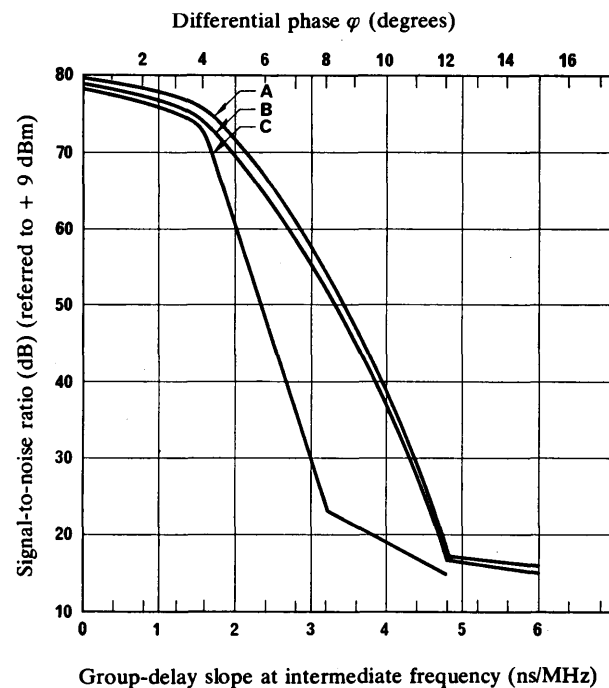


FIGURE 2 – Signal-to-noise ratio as a function of the group delay, measured on channels 1, 2, 3 and 4

Audio-frequency pre-emphasis: CCITT
 baseband frequency pre-emphasis: CCIR for 625-lines
 (noise due to second harmonic of video signal)

Curve A: channel 1
 B: channels 2 and 3
 C: channel 4

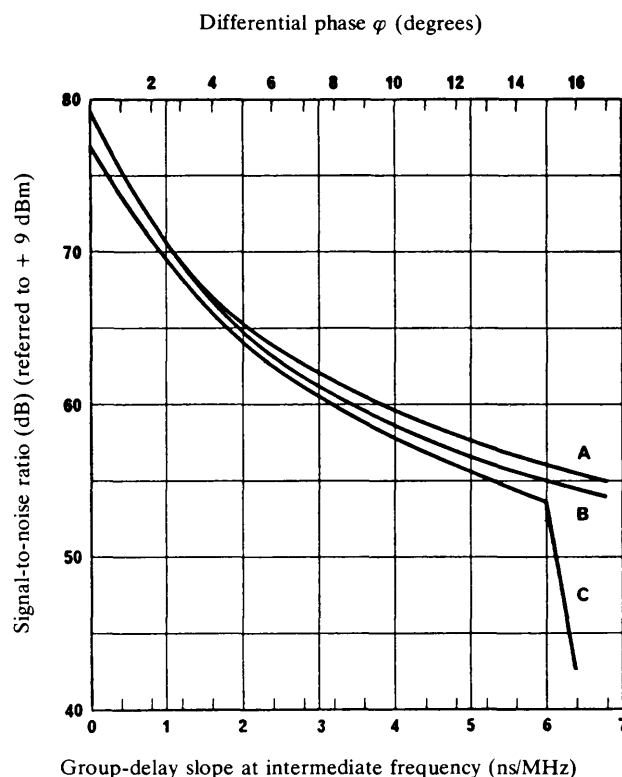


FIGURE 3 – Signal-to-noise ratio as a function of the group delay, measured on channels 1, 2, 3 and 4

Audio-frequency pre-emphasis: CCITT
 baseband frequency pre-emphasis: CCIR for 625-lines
 (noise due to intermodulation products of the type $(f_1 \pm f_2)$)

Curves A: channel 1
 B: channels 2 and 3
 C: channel 4

ANNEX III

1. Simultaneous transmission of an NTSC 525-line colour television signal and two sound channels is possible for a radio-relay system with a capacity of 960 telephone channels in frequency-division multiplex. The baseband signal is the combination of the video-frequency signal and two frequency-modulation sound sub-carriers [Miyoshi *et al.*, 1969].

2. Sound sub-carrier frequencies should be selected considering the following factors:

2.1 They should be located as far away as possible from the second harmonic of the colour sub-carrier (7.16 MHz) and from the continuity pilot (8.5 MHz).

2.2 The second- and the third-order products of the colour sub-carrier (3.58 MHz), its second harmonic, the continuity pilot and the sound sub-carrier frequencies caused by distortion in the transmission line should be as far away as possible from the frequencies of the sound sub-carrier.

2.3 They should be as high as possible compared with the upper video signal frequency to avoid adverse effects on the short-time wave-form characteristics, although sound signal performance becomes worse with increasing sound sub-carrier frequency.

2.4 Further studies are required on the selection of sound sub-carrier frequencies.

3. In Japan, a system with the following characteristics is now in use to transmit stereophonic (bandwidth is about 10 kHz) or bilingual sound programme signals associated with a colour television signal [Matsumoto *et al.*, 1980].

- sound sub-carrier frequency: No. 1 6.50 MHz
No. 2 7.65 MHz
- nominal input impedance of sound channel: 600 ohms;
– maximum sound input level at a point of zero relative level: + 9 dBm0;
- sound channel frequency band: 50 to 10 000 Hz (the upper frequency can be raised to 15 000 Hz if necessary);
- frequency deviation due to sound carrier: 140 kHz r.m.s. (test signal is sinusoidal with a maximum level of + 9 dBm0);
- frequency deviation of main carrier due to each of the sound sub-carriers: 300 kHz r.m.s.

4. Consideration should also be given to the possibility of choosing sound sub-carrier frequencies from either Plan A or Plan B.

REFERENCES

- MATSUMOTO, S., SAMEJIMA, S. and KUROKAWA, S. [January, 1980] Television programme relay system for simultaneous transmission of picture signal and stereophonic or bilingual sound signal. *Japan Telecomm. Rev.*, Vol. 22, 1, 40-46.
- MIYOSHI, T. and MATSUMOTO, K. [1969] Simultaneous transmission of colour television and sound programmes. *Japan Telecomm. Rev.*, Vol. 11, 3, 184-195.

ANNEX IV

Requirements for the transmission of up to four sound sub-carrier channels over radio systems in Canada with telephone channel capacities of 1200 channels or more have resulted in the development of a system which is compatible with transmission of the 525-line NTSC colour television system. Details of the factors considered and major characteristics of the system are provided in the following sections.

1. Interference between sound sub-carriers and the television signal

In the formulation of an acceptable system, interference considerations in three areas are necessary.

1.1 Interference from non-linear products of the television signal

The primary concern is the second and third harmonic products of the colour sub-carrier and its major line sidebands. To provide reasonable protection for the sound channels, sound sub-carrier frequencies should not be assigned to the bands $7.16 \text{ MHz} \pm 0.35 \text{ MHz}$ and $10.74 \text{ MHz} \pm 0.7 \text{ MHz}$.

1.2 Intermodulation products of the sound and colour sub-carriers

Second and third order products of the sound sub-carrier frequencies should be separated from the sound and colour sub-carrier frequencies by at least 40 kHz. Products of the sound and colour sub-carriers should be removed from the sound and colour sub-carrier frequencies by at least 100 kHz.

1.3 Direct intermodulation between the sidebands of the television line components and sound sub-carriers

This source of interference is not affected by the precise location of the sound sub-carrier frequencies. Since the interference mechanism is analogous to differential phase and gain the magnitude can be reduced by the provision of proper sub-carrier limiting in the sub-carrier receiver to reduce differential gain products. Differential phase products, generated primarily within the modulated part of the radio system, can be reduced somewhat by assigning sound sub-carriers to the lowest frequency possible. This consideration is important on radio systems where the carrier separation of 20 MHz limits the RF band to 20 MHz, thus increasing the magnitude of higher order differential phase distortions.

2. Noise bands used for multi-line protection switching

The choice of sub-carrier frequencies should be such that the noise monitoring band used for switch initiation should be protected against intermodulation, especially when the intermodulation product involves the colour sub-carrier frequency.

3. Interference into adjacent radio channels

When radio-relay frequency plans with 20 MHz carrier separation are used, adjacent channel interference resulting from "spill-over" of television signal and sound sub-carrier modulation products must be considered. Adjacent channel interference from sideband spill-over is particularly troublesome when the radio channel affected carries telephony signals.

Interference can be limited by intermediate frequency band restriction at the radio channel modulator output when relatively low intermediate frequencies are used. When modulation is applied directly to the carrier, or to higher intermediate frequencies, this method is not so effective. Alternative considerations are:

- restriction of the frequency assigned to the highest sub-carrier frequency,
- restriction of the frequency deviation on the radio carrier caused by the sub-carrier,
- reduction of the frequency deviation of the radio carrier caused by the television signal.

The first two alternatives have been adopted for the Canadian system.

When multi-line protection switching is employed it is likely that modulation products spilling into adjacent radio-relay channels may fall into the noise slot used to initiate a switch on the adjacent channel. If possible, this noise band should be protected by choice of sub-carrier frequency, considering also the effective shift in relative spacing of the radio-relay carrier frequencies caused by carrier stability and the asymmetry of the television signal. This has been found to be very difficult and in general, protection from interference, which is likely to be transitory, has been built into the switching system logic.

4. Other factors affecting the choice of sound sub-carrier frequencies

The generation of linear group delay in radio-relay systems causes a progressive reduction in the modulation index with modulating frequency when carrier amplitude compression occurs between the location of the distortion source and the corrective equalization. This effect results from sideband phase rotation caused by the group delay and is theoretically periodic with frequency in the baseband, the first null usually falling above the top baseband frequency.

When long-distance transmission is considered, the impact of this phenomena can be reduced by limiting the upper frequency assigned to sound sub-carrier systems. Sound sub-carriers which operate in the upper portion of the radio-relay baseband are placed in a very noisy environment as a result of the triangular noise generated by the radio system. Under fading conditions FM threshold effects are apparent before similar effects are noted on the television signal. Adjacent radio channel interference limitations preclude the use of increased deviation of the radio carrier by the sound sub-carrier as a solution to this problem. The only alternative available is once again to restrict the top frequency assigned for the sound sub-carriers, an approach which provides some delay in the onset of FM threshold effects during fading.

5. An example of the basic characteristics of a four channel sound sub-carrier system compatible with the 525-line NTSC television system developed for use in Canada on systems with 20 MHz channel spacing

- Sound sub-carrier frequencies: Channel No. 1: 5.6 MHz
Channel No. 2: 6.17 MHz
Channel No. 3: 6.8 MHz
Channel No. 4: 7.67 MHz

Other sub-carrier frequencies can also be used with 525-line NTSC television systems where channel spacings greater than 20 MHz are used.

- Frequency deviation of main carrier due to each sub-carrier: 200 kHz r.m.s. (Note 1).
- Maximum deviation of sub-carrier caused by a peak level test signal (1.0 kHz sinusoidal at +18 dBm) equivalent to absolute peak level of sound programme signal: 185 kHz peak.
- Deviation of sub-carrier caused by a reference test tone (1.0 kHz sinusoidal at +8 dBm) (Note 2): 58.5 kHz peak.
- Sound channel pre-emphasis 50 or 75 μ s (Note 3).

- Nominal sound channel input/output impedance: 600 Ω .
- Sound channel bandwidth: 40 to 15 000 Hz.
- Sub-carrier frequency stability: 5.0 kHz maximum.
- Television band filter cut-off: 5.0 MHz minimum (Note 4).

Note 1. — Main carrier deviation of 200 kHz r.m.s. is a preferred maximum when adjacent radio-relay channels impose constraints on spill-over interference.

Note 2. — This test-tone level causes an equivalent level on a VU meter to that used to set programme levels.

Note 3. — A 50 μ s pre-emphasis is preferred to prevent overload and peak distortion.

Note 4. — Rigid specifications are provided to ensure a design which minimizes short time distortions in the television signal.

Note 5. — Rigid chrominance non-linearity specifications are provided to ensure proper active (video) filter design to allow combiners and separators to be located within the pre-emphasized path of the video signal.

REPORT 786-1

ANALOGUE RADIO-RELAY SYSTEMS FOR SIMULTANEOUS TRANSMISSION OF ANALOGUE AND DIGITAL SIGNALS

(Study Programme 26A/9)

(1978-1982)

1. Introduction

Unused frequency bands below and above the occupied basebands of analogue radio-relay links may be used for the transmission of digital signals. The transmission of data under the baseband (data under voice) can be used only on telephony radio links, while data above the baseband (data above voice and data above video) can be used both on telephony and television radio links. In particular, data above video can be conveniently employed for the transmission of several sound programmes.

In these systems, attention should be paid to the interference between analogue baseband signals and digital signals.

2. Data under voice (DUV)

This system utilizes the available sub-baseband of telephony radio-relay links which, for capacities of 1800 or more telephone channels, is limited to 300 kHz (see Recommendation 380). However, it is recognized that in certain cases other limits may be used by agreement between the administrations concerned.

The method consists of combining a multi-level digital signal or a sub-carrier modulated by the digital signal, with the analogue baseband signal. At the terminals the combination and separation of the two signals is performed with a "passive" filter.

In Japan an 8-level amplitude modulated digital signal, corresponding to 1544 kbit/s has been developed for insertion in the 300 kHz sub-baseband of a conventional 1800 channel radio link. Since the available bandwidth is close to the Nyquist bandwidth, an automatic equalizer has been inserted at the receiving side to minimize the bit error ratio system parameters are given in Table I.

In Canada, a seven-level amplitude modulated signal using partial-response coding technique corresponding to 1544 kbit/s, has been developed and is extensively used for insertion in the 564 kHz of sub-baseband bandwidth used in Northern American microwave networks. In order to improve the performance quality and availability, a parallel data under voice system is used with a fast selecting device at the receiving terminal. This technique provides a level of transmission quality inherently superior to that of the single data under voice approach and provides a high level of system availability with what is essentially a "1 for 1" protection system. Table II shows the system parameters.

TABLE I — System parameters

	Items	Contents
Transmission line	Transmission capacity	1544 kbit/s/system
	Bandwidth	0-292 kHz
	Transmission quality (P_e : bit error ratio)	For most of the time $P_e \leq 10^{-8}$ /PCM-FDM link The probability that P_e exceeds 10^{-6} : less than 0.1%/2500 km per year
	Required S/N in lower band	35.6 dB
	Circuit configuration	1 PCM-FDM link consists of 3 radio transmission base-band links ($280 \text{ km} \times 3 = 840 \text{ km}$)
	Transmission waveform	8-level signal
PCM-FDM converter	Modulation system	8-level AM modulation (polarity controlled)
	Repetition of 8-level pulse	530.75 kHz
	Frame structure	One frame consists of 32 information symbols and 1 frame symbol
	Timing phase adjusting method	Automatic phase following control 21 (centre ± 10) taps
	Automatic equalizer algorithm	Zero forcing + maximum level error method

TABLE II — System parameters

	Parameters	Figures/method
Transmission facility	Transmission capacity	1544 kbit/s
	Bandwidth	100 Hz to 500 kHz
	Transmission quality (error free seconds) (BER, approx.)	99.9909% EFS (over 7 day test period) 1 in 10^{10}
	Required S/N ratio in DUV spectrum	24.3 dB (at full fade)
	Circuit configuration	Link consists of 2 PDUV (parallel data under voice) sections connected in tandem, with up to 5 FDM regenerated spans in each section. Total length 2140 km
	Transmission waveform	7-level signal
Coder/decoder	Modulation systems	7-level AM, partial response coding
	Jitter	Phase locked loop control
	Scrambling	Random (to reduce interference)
	Error detection	Running error count of code violations (even and odd numbered symbols must cancel)

All the above mentioned systems utilize the complete sub-baseband, and this requires the removal of all order wire, supervisory channels, noise-measuring slots and synchronizing pilots from this portion of the baseband.

In particular cases, when a capacity lower than 1544 kbit/s is sufficient, a simple method of data transmission may be used with the aid of a 2-PSK modulated sub-carrier which does not utilize the complete sub-baseband. Order wire and supervisory channels could be provided in the sub-baseband.

Up till now a system capable of transmitting the European standard bit rate of 2048 kbit/s in the conventional 300 kHz sub-baseband has not been developed.

3. Data above voice and above video (DAV)

Radio-relay systems at present carrying FDM telephone channels or colour TV programmes using FM modulation can carry an additional signal of up to several Mbit/s (e.g. 1.544 Mbit/s or 2.048 Mbit/s or multiples thereof). In general the method consists of modulating a sub-carrier with the digital signal and combining it with the analogue baseband signal by means of filters. The analogue baseband signal may be a colour TV programme or an FDM signal with up to 1800 telephone channels.

The transmission quality of the combined signal depends on several factors such as:

- thermal noise;
- non-linear products falling into the video channel or FDM baseband;
- non-linear products falling into the band occupied by the modulated sub-carrier.

In this respect the following characteristics of (amongst others) the transmission system have to be taken into account:

- the FM analogue modem non-linearity;
- the group delay distortion of the radio link;
- the type and loading of the analogue baseband signal;
- the sub-carrier frequency and the IF-RF deviation due to the unmodulated sub-carrier.

All these characteristics have an influence on the bit error ratio of the digital signal transmitted by the sub-carrier and on intermodulation in the analogue baseband.

3.1 *Influence of the FM analogue modem non-linearity*

Theory and experience have shown that second order FM analogue modem non-linearity intermodulation noise in the top telephone channel is an important consideration when determining the optimum loading of the digital signal. A high-performance analogue radio-relay system may have several dB of noise performance margin in the absence of the digital signal. The best method of determining what digital signal loading can be used without causing more than the allowable degradation in the noise performance of the top telephone channel is by direct measurement using the digital modem under consideration.

Non-linearities of second and higher orders, particularly in the portion of baseband occupied by the digital signal, may cause tone intermodulation noise at certain frequencies, primarily the following:

- the symbol frequency,
- harmonics and sub-harmonics of the symbol frequency,
- sum and difference products generated by any pilot frequency used for signal processing purposes.

These unwanted effects can be reduced by various means, e.g. the use of QPSK-0 (off-set) digital sub-carrier modulation [CCIR, 1978-82; Minkin, 1980] substantially reduces tone intermodulation noise in the telephone channel at the frequency of symbol transmission. However, it is advisable in all cases under consideration to first test the analogue transmission system with the digital signal in the absence of the analogue signal and search the entire analogue baseband for tones and/or intermodulation noise caused by the digital signal. The most prominent of the tones and noise spectra may be identified in this way and then searched for under simultaneous digital and analogue signal loading conditions.

3.2 *Influence of the group delay distortion and of the analogue signal*

Theory and experience shows that the group delay distortion has an important influence on intermodulation, especially between the analogue signal and the sub-carrier. Not only the absolute value of the distortion has to be taken into account but also its shape.

Experimental results have shown that the worst case happens when the distortion is not symmetrical with reference to the RF carrier. When a significant group delay distortion is present the bit error ratio becomes dependent also upon the presence of the analogue signal, in particular in the case of television. A good correlation between differential phase measured at the colour sub-carrier and the bit error ratio of the digital signal exists when the thermal noise is of secondary influence (non-faded propagation conditions).

A detailed description of this subject can be found in [Tomati, 1980].

3.3 *Choice of the sub-carrier frequency and of the IF-RF deviation due to the unmodulated sub-carrier*

The choice of the frequency of the sub-carrier depends on the consideration of various aspects including the following:

- the RF channel spacing;
- the bandwidth of the analogue baseband signal;
- the type of the analogue baseband signal;
- the use of the continuity pilot;
- the aim to minimize the intermodulation effects between the analogue and digital signal;
- the modulation method used for the sub-carrier(s);
- the amplitude, delay and noise characteristics within the baseband portion considered for digital signal transmission.

The choice of the deviation produced by the sub-carrier is the result of a compromise between the signal-to-noise ratio of the data above voice signal and the level of the intermodulation products produced in the analogue baseband by the sub-carrier. The optimum range of deviations produced by the sub-carrier depends also on the characteristics of the radio link and on the type of the analogue and digital signal. Equalization is an effective method of increasing the baseband portion usable for digital signal transmission. Pilot stop filters may require special attention in this respect.

3.4 *Technical characteristics of existing systems*

In various countries, systems for the simultaneous transmission of an analogue and digital signal with the DAV method have been put into operation. Contributions about those systems have been received from the Federal Republic of Germany, Canada, the United States of America, France, Italy and the U.S.S.R.

The main characteristics of these systems as reported so far are summarized in Table III:

TABLE III

	Colour TV ⁽¹⁾ or up to 960 channels	Colour TV or up to 960 channels	1800 channels	2700 channels
Sub-carrier frequency	4.05 ⁽²⁾ -5.5 MHz	1.65 ⁽²⁾ -7.5 MHz	10-13.13 MHz	15.8-18.13 MHz
Bit rate	1544 kbit/s or 2 × 1544 kbit/s	2048 kbit/s or 2 × 2048 kbit/s or 4 × 2048 kbit/s	2048 kbit/s or 4 × 2048 kbit/s	4 × 2048 kbit/s
Frequency deviation of the RF carrier by the sub-carrier(s) (r.m.s.)	300-500 kHz	360-1500 kHz	700-1300 kHz	700 kHz
Emphasis of the analogue signal	Recs. 275 or 405	Recs. 275 or 405	Recs. 275 or 405	Recs. 275 or 405

⁽¹⁾ System M only.

⁽²⁾ The lower frequencies correspond to telephony transmission only.

4. **Conclusions**

The possibility of using analogue radio-relay systems for simultaneous transmission of analogue and digital signals has been demonstrated with DUV and DAV methods. Digital performance with bit error ratios in the order of 10^{-7} or better, has been achieved with no significant degradation measured in the telephone baseband or TV channel. Taking into account the possible variation of the performance of the system due to the propagation effects, a suitable margin for the bit error ratio should be provided according to the characteristics of the transmission system. Administrations are invited to submit further information on their experiences and particular problems concerning these systems.

REFERENCES

MINKIN, V. M. [1980] Energeticheskii spektr produktov preobrazovaniya fazomanipulirovannykh signalov na amplitudnoi nelineinosti (Power spectrum of conversion products of PSK signals on amplitude non-linearity). *NIIR Proc.*, 1, Moscow, U.S.S.R.

TOMATI, L. [May-June 1980] Trasmissione numerica di segnali musicali in supervideo sui ponti radio televisivi (over-video digital transmission of musical signals on television radio-relay links). *Elettronica e Telecomunicazioni*, 3, 107-115.

CCIR Documents

[1974-82]: 9/259 (USA).

BIBLIOGRAPHY

HAUGHEY, S. and KRIVOHLAVEK, M. [11 June, 1980] Adding digital capacity to analog transmission systems using a QAM baseband digital modem. IEEE International Conference on Communications (ICC '80), Seattle, Wa., USA, Conf. Rec., Vol. 3, Session 52: Digital radio buffet, 52.6.1 - 52.6.5.

CCIR Documents

[1974-78]: 9/29 (Japan); 9/218 (Canada); 9/248 (India); 9/215 (Canada); 9/47 (Italy); 9/280 (Italy).

[1978-82]: 9/55 (Germany (Federal Republic of)); 9/98 (France); 9/48 (U.S.S.R.).

RECOMMENDATION 596

INTERCONNECTION OF DIGITAL RADIO-RELAY SYSTEMS

(Question 12/9 and Study Programmes 12B/9 and 12H/9)

(1982)

The CCIR,

CONSIDERING

- (a) that the capacity of digital radio-relay systems should be that of a CCITT recommended hierarchical level or an integral multiple of it;
- (b) that the signal characteristics at the interface of digital radio sections (points TT' in Fig. 1 of Report 938) are given in CCITT Recommendation G.703;
- (c) that the characteristics of some radio-relay systems (for instance due to code conversion, insertion of justification bits, parity bits and service bits) may cause the bit rate within a digital radio section to be different from the CCITT recommended hierarchical level or an integral multiple of it;
- (d) that interconnection at other points than TT' of Fig. 1 of Report 938, which could be included in the future as part of this Recommendation, will necessitate the standardization of many parameters of system design and service techniques;
- (e) that at this time interconnections between digital radio-relay systems may only be practicable at baseband,

UNANIMOUSLY RECOMMENDS

that interconnection of digital radio-relay systems be made at points TT' of Fig. 1 of Report 938.

REPORT 938

BASEBAND INTERCONNECTION OF DIGITAL RADIO-RELAY SYSTEMS

(Study Programme 12H/9)

(1982)

1. General

With the expected development in the application of pulse-code modulation and other types of digital signals, interconnection of digital radio-relay systems or radio sections with one another and with other component parts of the digital network will become necessary.

The point TT' of interconnection of digital radio sections at baseband frequency should be chosen in conformity with the scheme given in Fig. 1. The baseband characteristic at interconnection points forming part of an international interconnection are being studied by the CCITT, and the main characteristics for hierarchical bit rates up to 140 Mbit/s are given in CCITT Recommendation G.703 (see Note 1).

For the interconnection between digital radio-relay systems interface points TT' should also be used according to Recommendation 596. The possible use of interface points RR' (different from TT'), which is still under study, seems to be difficult at present.

If necessary, interconnection between receivers or transmitters and switching equipment may be made via the functional interface points Z , Y and Y' , Z' (see Fig. 1). These interfaces would allow national and international interconnection between switching and radio equipments. Switching equipment and radio equipment need not be co-located.

It may be desirable in some cases to allow compatibility between switching and radio equipments of different origin and design. In order to allow this compatibility it would be necessary:

(a) to specify the following characteristics for interface points, Y , Y' , Z , Z' :

- bit rate and its tolerance;
- code;
- level and shape of pulses;
- impedance and return loss;
- jitter;
- signal structure.

It is desirable to define the parameters mentioned above in the same manner as those adopted by the CCITT in Recommendation G.703.

(b) to specify the location of quality detectors and the control interfaces between the radio and switching equipments (different locations and different detecting methods may have implications on the operation of the whole system);

(c) to define the interface characteristics of the medium utilized to transfer switching orders and confirmations between switching ends.

Section 2 deals with the possible processing of the baseband digital signal, taking into account its location in the units shown in Fig. 1, while § 3 considers the interconnection points between switching and radio equipments.

Note 1a. — For systems based on the 2048 kbit/s hierarchy, the signals and signal levels are defined at the input and output ports of the corresponding equipments in accordance with Recommendation G.703. The losses in station cables required to connect the input and output ports of two successive equipments, must be taken into account in engineering each installation.

The digital distribution frame may be located at any point along the station connection cables so that the digital signal levels are not defined by the CCITT at the digital distribution frame.

On the other hand, from the standpoint of network organization, equipments can only be connected to the digital distribution frame, which is therefore the termination of a digital line section or a digital radio section.

Note 1b. — For systems based on the 1544 kbit/s hierarchy, the signals and levels are generally defined at the digital distribution frame. Therefore, the interface conditions as defined in Recommendation G.703 coincide with the termination of a digital line section or a digital radio section.

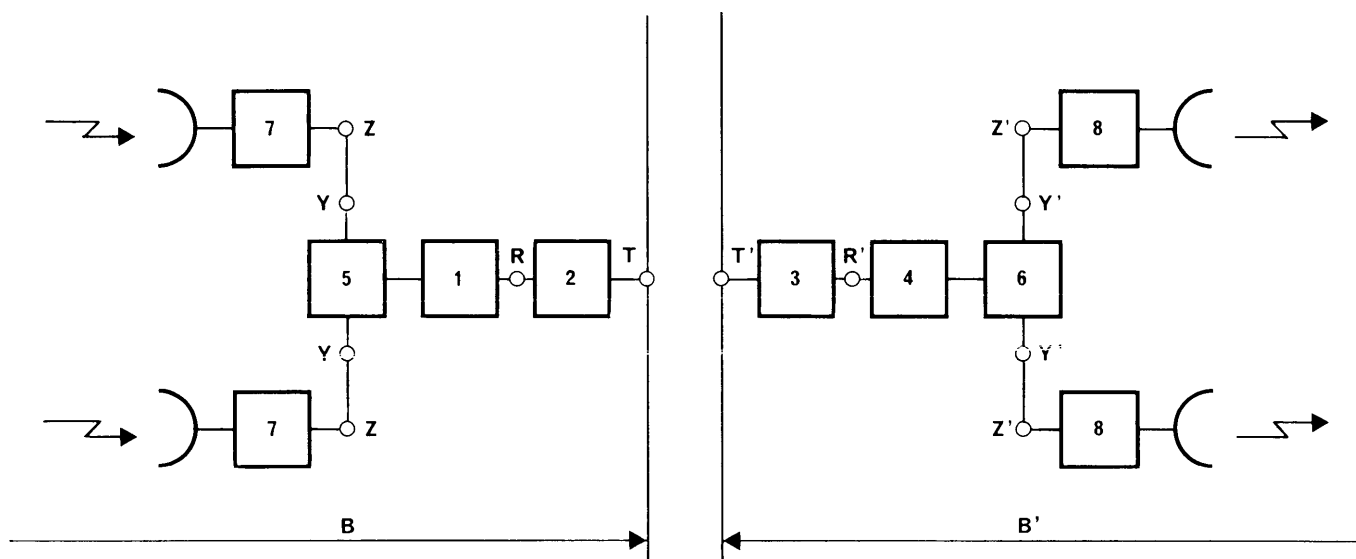


FIGURE 1

- B, B'*: digital radio section
R, R': possible interconnection points between radio-relay systems within a digital radio section
T, T': output and input ports or in-jacks and out-jacks (as defined by CCITT Recommendation G.703)
Y: input of the receive end of the switching equipment
Y': output of the transmit end of the switching equipment
Z: output of the terminal receiver
Z': input of the terminal transmitter
 1, 4: possible signal processing units
 2, 3: possible signal processors and interface units
 5, 6: possible receive and transmit ends of protection switching equipment
 7: receiver (including demodulator) and possible signal processing units
 8: transmitter (including modulator) and possible signal processing units

2. Baseband digital signal processing

2.1 Multiplexing

Only when the digital bit rate carried over the radio system is an integral multiple of a hierarchical bit rate, as recommended by the CCITT in Recommendation G.703, is multiplexing usually necessary. This function may be carried out in one of the pair of boxes:

- in boxes 2 and 3 of Fig. 1;
- in boxes 1 and 4 of Fig. 1;
- in boxes 5 and 6 of Fig. 1;
- in boxes 7 and 8 of Fig. 1.

2.2 Bit insertion

Bit insertion for BER monitoring, service channels or other purposes can be included in any of the boxes.

Where multiplexing is required, the bit insertion may be performed in the same units in which the multiplexing processing is carried out.

2.3 *Scrambling*

The sequence of digital pulses at the input of the modulating circuit must be such that, after modulation, a reliable timing signal can be derived from the radiated signal and the radiated signal spectrum does not contain intense spectral components which might cause harmful interference to other systems, particularly to co-channel or adjacent channel analogue systems.

Most modulation methods provide a reliable timing signal if it is ensured that sufficient transitions occur in the signal at the input of the modulating circuit. Similarly, intense spectral components are avoided by removing undesirable periodic sequences from that point.

If the alarm indication signal specified by the CCITT appears at point T' and is applied unchanged to the radio modulator, it has been found that undesirable spectral characteristics are produced.

Before being modulated, the signal may therefore be processed so that proper operation of the digital radio-relay system is not dependent in any way upon the incoming bit sequence at point T' . This can be accomplished by using a scrambling device.

Set-reset scrambling may be used but requires the addition of extra bits to synchronize the scrambler and descrambler. If a non-hierarchical bit rate is transmitted in which reframing is necessary, the frame alignment signal may be used for this purpose. Descrambling and scrambling at each radio repeater for the insertion and extraction of supervision and control signals might be avoided by using a frame length equal to an integral multiple of the scrambler sequence.

Self-synchronous scrambling is also possible and requires no additional bits, but incurs the disadvantage of error extension.

Scrambling processing may be carried out in the various boxes shown in Fig. 1, as categorized in § 2.1. The choice between the different solutions involves system considerations.

2.4 *Code conversion*

Code conversion processors are usually required, at least in two of the boxes shown in Fig. 1, as categorized in § 2.1.

3. *Interconnection between switching and radio equipments*

3.1 *Characteristics of points Y , Y' , Z , Z'*

The choice of a non-hierarchical bit rate at these interface points would necessitate the definition of a new set of parameters similar to those already defined by the CCITT for the hierarchical bit rates (bit rate, frame structure, etc.) and would not permit sufficient freedom to manufacturers in the choice of the quality detection method. On the other hand, the choice of a hierarchical bit rate may give rise to difficulties in some cases.

3.1.1 *Interconnection between multi-line or twin path switching and radio equipments*

In this case a hierarchical bit rate could be defined for Y , Y' , Z , Z' points. As a consequence, eventual multiplexing and bit insertion should be performed only in boxes 7 and 8 of Fig. 1. This may also have consequences on the choice of the boxes where scrambling has to be carried out; however boxes 7 and 8 seem to be the most appropriate locations.

3.1.2 *Interconnection between space diversity switching and radio equipments*

In this case, it may be difficult to define a common value for the bit rate.

3.2 *Quality detection*

The choice of the quality detection method and of its location has direct consequences on the definition of the interfaces between switching and radio equipments, and on the design of the radio-relay system. Harmonization of the different viewpoints of administrations seems to be difficult. Two proposals of two administrations are contained in [CCIR, 1978-82a and b].

4. *Conclusion*

This Report gives a preliminary answer to Study Programme 12H/9. In § 1, the interface points for possible interconnection between radio-relay systems and between radio equipment (terminal transmitters and receivers) and protection switching are identified.

It has also been recognized that, in many cases, it will be difficult to define interconnection points between radio-relay systems (RR'), which are different from TT' . If, in the future, no specific requirement for interface points RR' can be found, these interfaces should be deleted from this Report.

Standardization of the characteristics of the interconnections between switching and radio equipments necessitates the choice of the position (boxes in Fig. 1) where signal processing examined in § 2 shall be performed, as well as the definition of all the parameters listed in § 1. Attention must also be paid to the fact that this interconnection between switching and radio equipments would be possible only if all the characteristics of these parameters are clearly specified. The specification of those characteristics which would be of interest seems to be difficult due to the different viewpoints of administrations. In addition it is not at present clear whether the concept of protection switching for digital radio-relay systems adopted in this Report should be the one defined in Report 787, including multi-line, twin path and space diversity switching, or whether space diversity switching should be excluded.

In order to try to solve the problems in the early stage of introduction of digital radio relay into the transmission network, administrations are requested to submit contributions.

REFERENCES

CCIR Documents

[1978-82]: a. 9/288 (Italy); b. 9/307 (Germany (Federal Republic of)).

RECOMMENDATION 275-3

PRE-EMPHASIS CHARACTERISTIC FOR FREQUENCY MODULATION RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

(Question 1/9)

(1959-1966-1970-1982)

The CCIR,

CONSIDERING

- (a) that the pre-emphasis characteristic should preferably be such that the effective (r.m.s.) deviation due to the frequency-division multiplex telephony signal is the same with and without pre-emphasis (Recommendation 404);
- (b) that, in a frequency-modulation system for frequency-division multiplex telephony, the thermal noise is highest in the top channel and decreases with decreasing baseband frequency;
- (c) that, in a phase-modulation system, or in a frequency-modulation system with pre-emphasis of 6 dB per octave, the thermal noise is constant over the whole baseband;
- (d) that the thermal noise in the highest channel of a phase-modulation system is approximately 4.8 dB better than the corresponding channel of a frequency-modulation system, assuming that the two types of system are adjusted to have the same total frequency deviation;
- (e) that the reduction in frequency deviation with decreasing baseband frequency in a phase-modulation system makes such a system more sensitive to low frequency interference and to the effects of non-linearity in the system;
- (f) that the loss of advantage in the top channel is quite small and the effects due to non-linearity are not excessive if the range of pre-emphasis is restricted to about 8 dB;
- (g) that agreement on the pre-emphasis characteristic is desirable to facilitate international connection at radio frequencies or intermediate frequencies;
- (h) that the pre-emphasis network may be inserted at different places in various types of equipment,

UNANIMOUSLY RECOMMENDS

1. that, where pre-emphasis is used in radio-relay systems for frequency-division multiplex telephony, the same normalized attenuation-frequency characteristic should be used for systems with capacities up to and including 2700 channels;

2. that the preferred pre-emphasis characteristic is given by the expression:

$$\left. \begin{array}{l} \text{Relative deviation} \\ \text{produced by the} \\ \text{test-tone (dB)} \end{array} \right\} = 5 - 10 \log_{10} \left[1 + \frac{6 \cdot 90}{1 + \frac{5 \cdot 25}{\left(\frac{f_r}{f} - \frac{f}{f_r} \right)^2}} \right] \quad (1)$$

where f_r (the resonant frequency of the network) = $1.25 f_{max}$, f_{max} is the highest telephone channel baseband frequency of the system, and f is the baseband frequency.

The variation of deviation with frequency is shown in Fig. 1. Table I shows f_{max} and f_r for the frequency-division multiplex systems which are the subject of Recommendation 380 and which are mentioned in Recommendation 404.

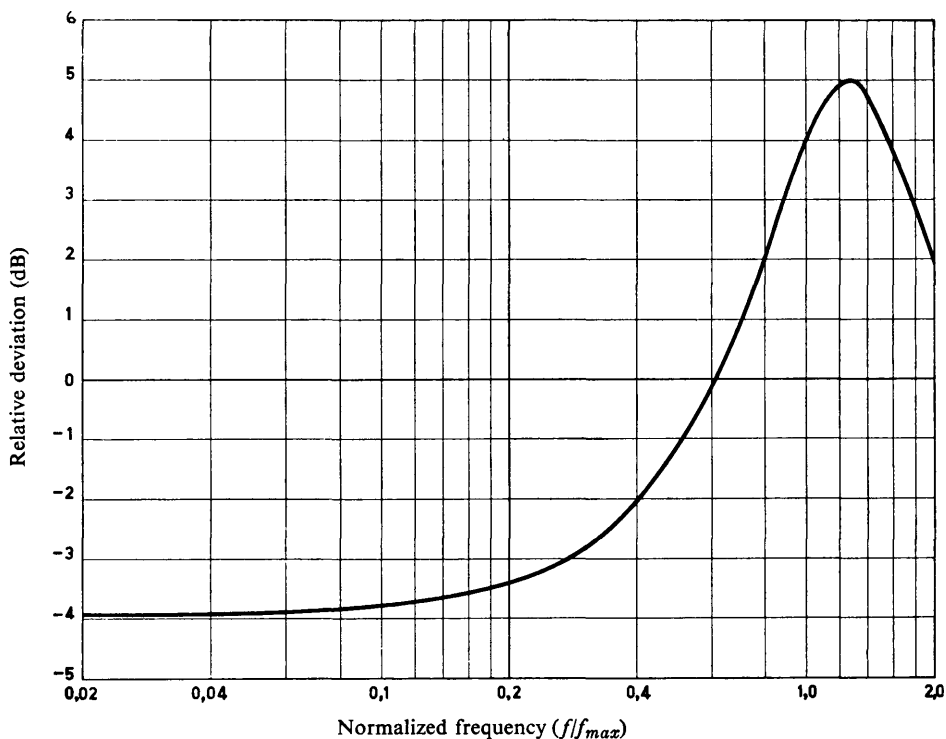


FIGURE 1

Pre-emphasis characteristic for telephony

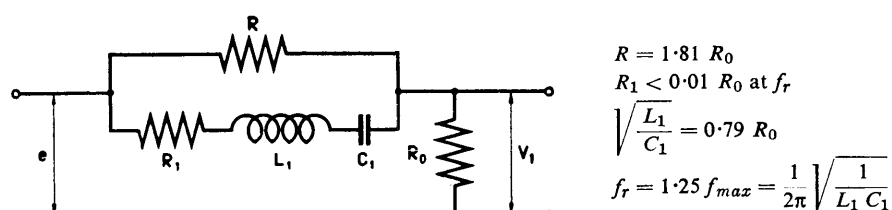
TABLE I — Characteristic frequencies for pre-emphasis and de-emphasis networks for the frequency-division multiplex systems which are the subject of Recommendation 380 and which are mentioned in Recommendation 404

Maximum number of telephone traffic channels ⁽¹⁾	f_{max} ⁽²⁾ (kHz)	f_r ⁽³⁾ (kHz)	f_c ⁽⁴⁾ (kHz)
24	108	135	66.226
60	300	375	183.96
120	552	690	338.49
300	1 300	1 625	797.16
600	2 660	3 325	1 631.1
960	4 188	5 235	2 568.1
1 260	5 636	7 045	3 456.0
1 800	8 204	10 255	5 030.7
2 700	12 388	15 485	7 596.3

- (1) This figure is the nominal maximum traffic capacity of the system and applies also when only a smaller number of telephone channels are in service.
 (2) Nominal maximum frequency of the band occupied by telephone channels.
 (3) Nominal resonant frequency of the pre-emphasis or de-emphasis network.
 (4) Cross-over frequency at which the deviations with pre-emphasis and without pre-emphasis are equal.

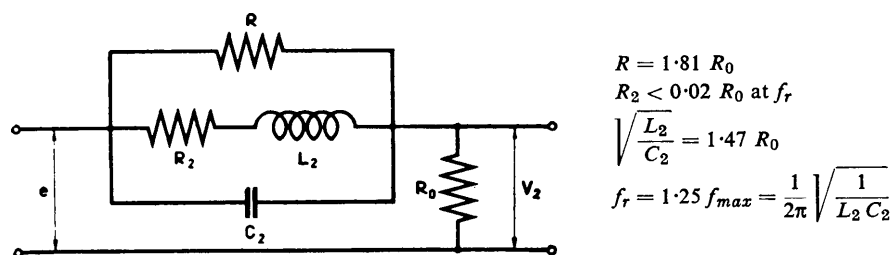
3. that the tolerance on the frequency response of the pre-emphasis characteristics, and also on the de-emphasis characteristics should be such that, within the nominal upper and lower limits of the baseband, the departure of the characteristic of a practical network from the theoretical characteristic should be confined within a variation of $\pm (0.1 + 0.05 f/f_{max})$ dB, f being the baseband frequency, and f_{max} the nominal maximum frequency of the baseband. This corresponds to component tolerances of about $\pm 1\%$ for resistors and about $\pm 0.5\%$ for capacitors and inductors. Further, the magnitude of the departure should exhibit no rapid variations within this frequency range.

Note 1. — It is recognized that it may be desirable to achieve the pre-emphasis characteristic by inserting a network at different places in various types of equipment. An example of a pre-emphasis and de-emphasis network, to work between a constant-voltage source and an open-circuit load, is shown in Figs. 2(a) and 2(b), respectively, and to work between matched resistive input and output impedances is shown in Figs. 3(a) and 3(b), respectively.



Where f_{max} is the highest baseband frequency

(a) Pre-emphasis network



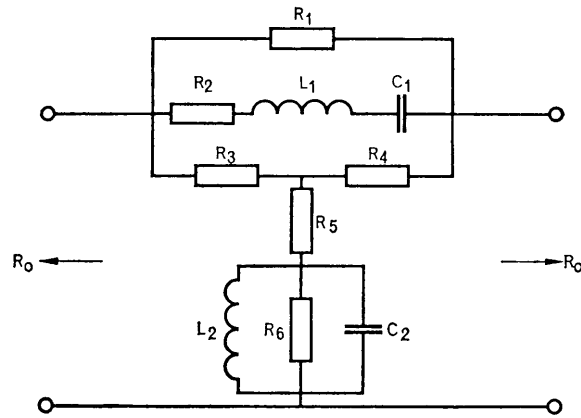
(b) De-emphasis network

FIGURE 2

Pre-emphasis and de-emphasis networks to work between a constant-voltage source and an open-circuited load

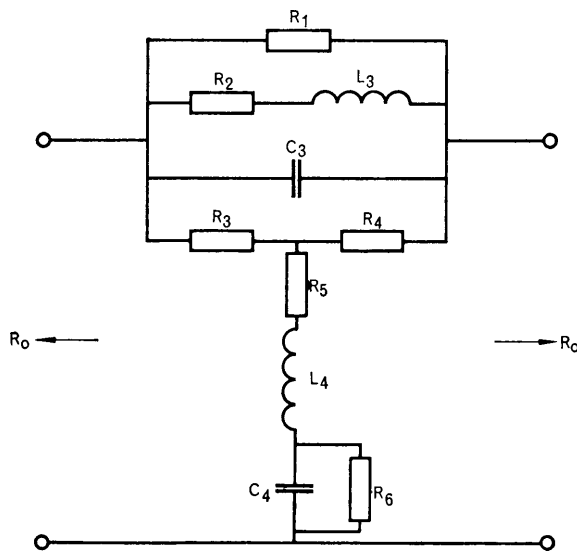
Note 2. — In the expression for the relative deviation as indicated in § 2, it should be noted that the frequency at which the deviation with pre-emphasis corresponds to that without pre-emphasis (Recommendation 404) is $0.61320 f_{max}$. It may be convenient to adopt this frequency for testing the loss between baseband terminal points of systems when these are not in service.

Note 3. — It is recognized that it may sometimes be desirable to use a different pre-emphasis characteristic by agreement between the administrations concerned.



(a) Pre-emphasis network

$$\begin{aligned}
 R_1 &= 1.81 R_0 \\
 R_2 &< 0.01 R_0 \\
 R_3 &= R_4 = R_0 \\
 R_5 &= \frac{R_0}{1.81} \\
 R_6 &> 100 R_0 \\
 f_r &= 1.25 f_{max} = \frac{1}{2\pi} \sqrt{\frac{1}{L_1 C_1}} \\
 &= \frac{1}{2\pi} \sqrt{\frac{1}{L_2 C_2}} \\
 \sqrt{\frac{L_1}{C_1}} &= 0.79 R_0 \\
 \sqrt{\frac{L_2}{C_2}} &= 0.79 R_0
 \end{aligned}$$



(b) De-emphasis network

$$\begin{aligned}
 R_1 &= 1.81 R_0 \\
 R_2 &< 0.01 R_0 \\
 R_3 &= R_4 = R_0 \\
 R_5 &= \frac{R_0}{1.81} \\
 R_6 &> 100 R_0 \\
 f_r &= 1.25 f_{max} = \frac{1}{2\pi} \sqrt{\frac{1}{L_3 C_3}} \\
 &= \frac{1}{2\pi} \sqrt{\frac{1}{L_4 C_4}} \\
 \sqrt{\frac{L_3}{C_3}} &= 1.47 R_0 \\
 \sqrt{\frac{L_4}{C_4}} &= 1.47 R_0
 \end{aligned}$$

FIGURE 3

Pre-emphasis and de-emphasis networks to work between matched resistive input and output impedances

RECOMMENDATION 404-2 *

**FREQUENCY DEVIATION FOR ANALOGUE RADIO-RELAY SYSTEMS
FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX**

(Question 1/9)

(1956-1959-1963-1966-1970)

The CCIR,

CONSIDERING

- (a) that frequency-division multiplex systems for telephony using frequency modulation may form part of an international circuit;
- (b) that it may at times be desirable to make international connections between such systems at intermediate or radio frequencies;
- (c) that, to economize in the use of the frequency spectrum, it is desirable to use the smallest satisfactory frequency deviation;
- (d) that the use of pre-emphasis allows a more uniform distribution of signal-to-noise ratio in the various channels of a multi-channel telephony system,

UNANIMOUSLY RECOMMENDS

that, as far as practicable, radio-relay systems for telephony using frequency-division multiplex forming part of an international circuit should conform to the following characteristics:

1. Frequency deviation without pre-emphasis

Maximum number of channels	R.m.s. deviation per channel ⁽¹⁾ (kHz)
12	35
24	35
60	50, 100, 200
120	50, 100, 200
300	200
600	200
960	200
1260	140, 200
1800	140
2700	140

⁽¹⁾ For 1 mW, 800 Hz tone at a point of zero reference level.

Larger capacity systems are not excluded.

Note. — It is recognized that it may sometimes be desirable to use other deviations by agreement between the administrations concerned. This applies in particular to trans-horizon radio-relay systems.

2. Frequency deviation with pre-emphasis

Where pre-emphasis is used, the pre-emphasis characteristic should preferably be such, that the effective (r.m.s.) deviation due to the multi-channel signal is the same with and without pre-emphasis.

* This Recommendation applies to line-of-sight and near line-of-sight radio-relay systems and, where appropriate, to trans-horizon radio-relay systems.

RECOMMENDATION 405-1

**PRE-EMPHASIS CHARACTERISTICS FOR FREQUENCY MODULATION
RADIO-RELAY SYSTEMS FOR TELEVISION**

(Question 3/9)

(1959-1963-1970)

The CCIR,

CONSIDERING

- (a) that it is generally preferable for the major intermediate-frequency and radio-frequency characteristics of international radio-relay systems for television to conform to those of large capacity systems for multi-channel telephony;
- (b) that the flexibility of radio-relay systems would be further increased if the modulators and demodulators could be used interchangeably for either television or frequency-division multiplex telephony;
- (c) that the high-level, low-frequency components in the video-frequency waveform, which are a barrier to the achievement of this flexibility, can be greatly reduced by attenuation of these components, i.e. by means of a pre-emphasis network before modulation, a corresponding de-emphasis network being inserted after demodulation;
- (d) that pre-emphasis enables a simple control of the mean carrier-frequency to be used both for television and frequency-division multiplex telephony;
- (e) that pre-emphasis can reduce differential gain and differential phase distortion in a radio-relay system and may be particularly advantageous if the transmission of colour television signals, or a sound channel by means of a sub-carrier, is envisaged;
- (f) that, in determining the pre-emphasis characteristic, its effect on the overall weighted signal-to-noise ratio * and on adjacent-channel interference must be taken into account;
- (g) that excessive attenuation of the low-frequency components of the video signal can cause difficulties due to hum and microphony;
- (h) that the optimum pre-emphasis characteristics for television and frequency-division multiplex telephony will not be the same;
- (i) that, to achieve readily reproducible characteristics, the pre-emphasis network, and the corresponding de-emphasis network, should be simple;
- (k) that it is operationally desirable that the same shape of pre-emphasis characteristic is used for monochrome and colour television signals,

UNANIMOUSLY RECOMMENDS

1. that the use of pre-emphasis is preferred for the transmission of television signals by radio-relay systems;
2. that a minimum phase shift network should be used for pre-emphasis;
3. that the idealized preferred pre-emphasis characteristic be given by the expression:

$$\text{relative deviation (dB)} = 10 \log [(1 + Cf^2)/(1 + Bf^2)] - A, \quad (1)$$

where:

A is the attenuation (dB) at a low frequency (< 0.01 MHz),*B* and *C* are constants which determine the shape of the pre-emphasis characteristic,*f* is the frequency (MHz).

* See Recommendation 567.

The preferred values of A , B and C for 525-, 625-, and 819-line systems are shown in Table I. The shapes of the characteristics are shown in Fig. 1;

TABLE I
Values of coefficients of pre-emphasis characteristics

Number of lines	525	625	819
A	10.0	11.0	7.0
B	1.306	0.4083	0.1021
C	28.58	10.21	2.552
Cross-over frequency (MHz) . .	0.7616	1.512	1.402
Deviations (peak-to-peak) at low frequencies (MHz)	2.530	2.255	3.573

4. that the tolerance on the pre-emphasis characteristics, and also on the de-emphasis characteristics referred to in Note 2, should be such that, within the frequency range of 0.01 MHz to the nominal upper limit of the video-frequency band, the departure of the characteristic of a practical network from the appropriate theoretical characteristic should be confined within a variation of $\pm (0.1 + 0.05 f/f_c)$ dB, f being the video-frequency, f_c being the nominal upper limit of the video-frequency band. This corresponds to tolerances of the network components (resistors, capacitors, inductors) of about $\pm 1\%$. Further, the magnitude of the departure should exhibit no rapid variations within this frequency range.

Note 1. — In accordance with Recommendations 276 and 567, a peak-to-peak signal of 1 V at a point of video-frequency interconnection produces, in the absence of pre-emphasis, a peak-to-peak deviation of 8 MHz. When there is pre-emphasis, a sinusoidal wave of 1 V peak-to-peak at a video-frequency corresponding to 0 dB relative deviation (cross-over frequency) produces a peak-to-peak deviation of 8 MHz. The cross-over frequencies are shown in Table I. At a low frequency (< 0.01 MHz) the corresponding deviation is reduced in accordance with the factor A . These low frequency deviations are also shown in Table I.

Note 2. — When television signals are to be transmitted between countries with radio-relay systems designed for different numbers of lines, the administration of the country receiving the signals should provide de-emphasis networks corresponding to the pre-emphasis network of the originating country; however, if preferred, other arrangements may be adopted by agreement between the administrations concerned.

Note 3. — An example of a pre-emphasis network is shown in Table II and Fig. 2. Table III and Fig. 3 give an example of a corresponding de-emphasis network.

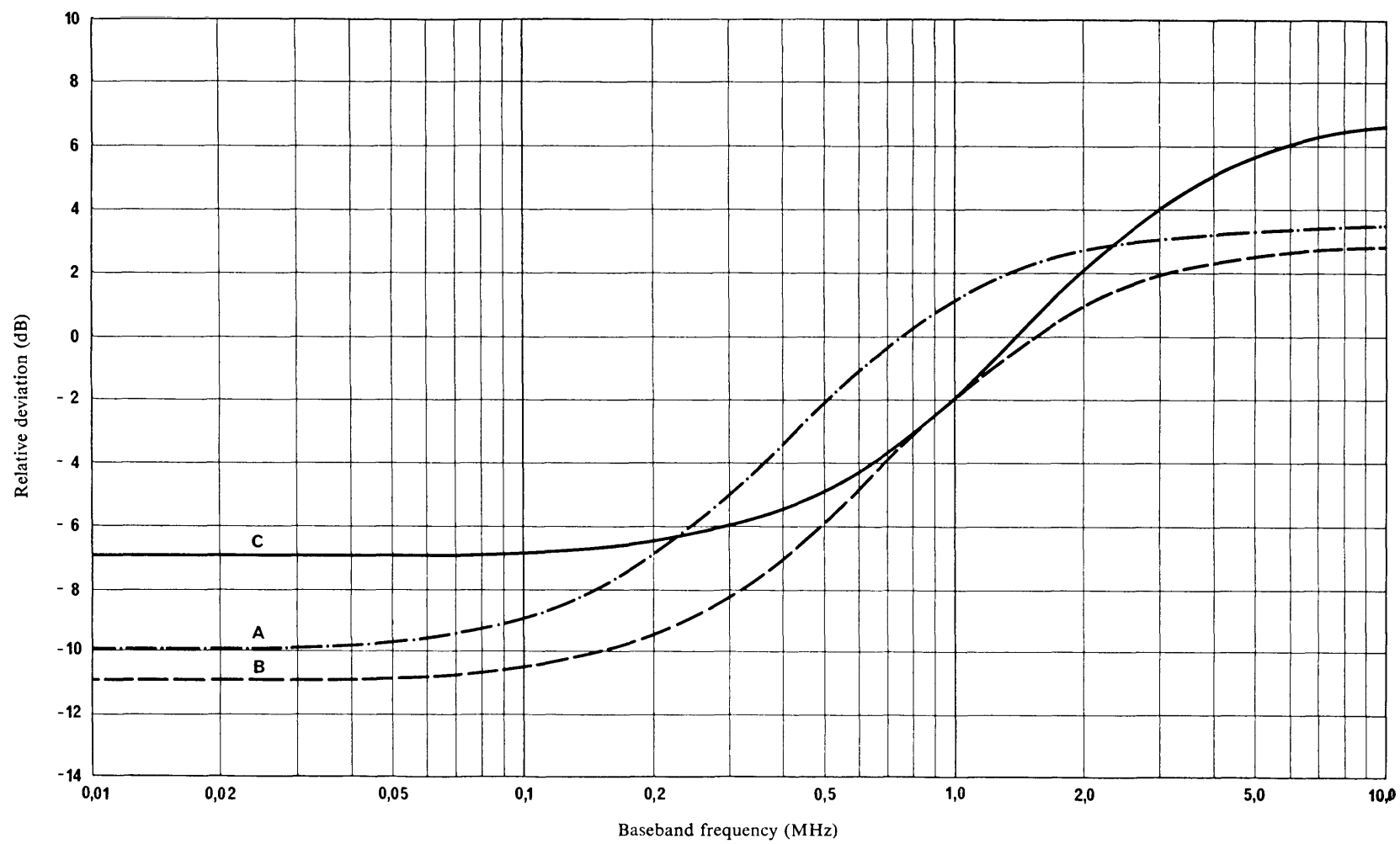


FIGURE 1

Pre-emphasis characteristic for television on 525-, 625-, and 819-line systems

Curve A: 525-line system
 B: 625-line system
 C: 819-line system

TABLE II
Component values of pre-emphasis network for television

Number of lines	525	625	819
L (μH)	17.35	9.54	4.77
C (pF)	3085	1695	847.5
R_1 (Ω)	275.8	300	300
R_2 (Ω)	75	75	75
R_3 (Ω)	20.4	18.75	18.75

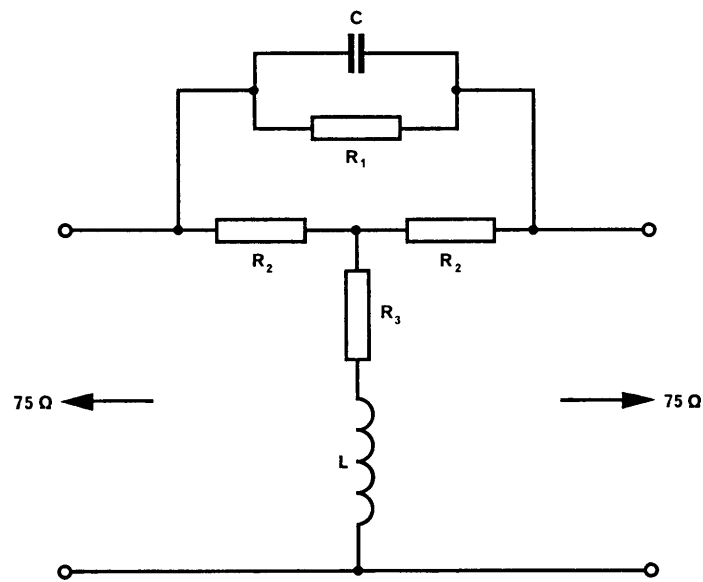


FIGURE 2
Pre-emphasis network for television

TABLE III
Component values of de-emphasis network for television

Number of lines	525	625	819
L (μH)	50.16	30.53	15.26
C (pF)	8917	5424	2712
R_1 (Ω)	275.8	300	300
R_2 (Ω)	75	75	75
R_3 (Ω)	20.4	18.75	18.75

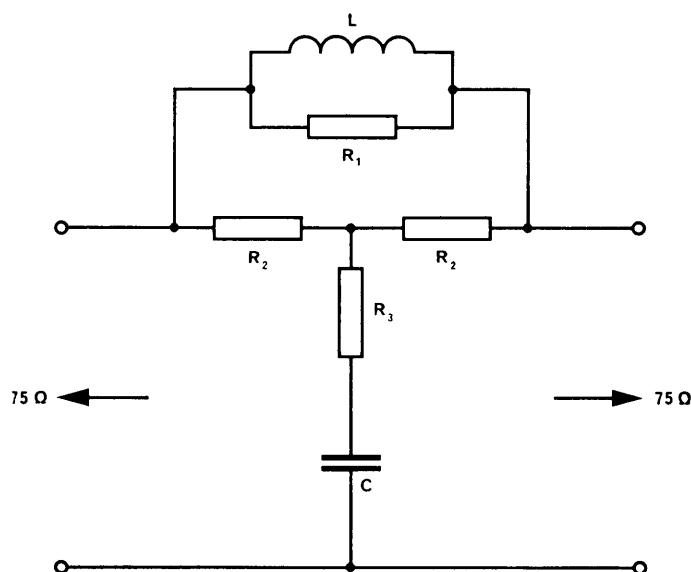


FIGURE 3

De-emphasis networks for television

RECOMMENDATION 276-2

**FREQUENCY DEVIATION AND THE SENSE OF MODULATION
FOR ANALOGUE RADIO-RELAY SYSTEMS FOR TELEVISION**

(Question 3/9)

(1956-1959-1970-1974)

The CCIR,

CONSIDERING

- (a) that radio-relay systems for television using frequency modulation may form part of an international circuit;
- (b) that international connections of such systems may at times have to be made at intermediate or radio frequencies;
- (c) that the use of too large a frequency deviation results in an unnecessarily wide band of transmitted radio frequencies and should be avoided, because of the need for economy in the use of the radio frequency spectrum;
- (d) that, for various reasons, the use of pre-emphasis may be desirable (see Recommendation 405),

UNANIMOUSLY RECOMMENDS

1. that the value of the frequency deviation without pre-emphasis in radio-relay systems for television should be 8 MHz peak-to-peak, referred to the nominal peak-to-peak amplitude of the video-frequency signal (see Recommendation 567);
2. that when pre-emphasis, in accordance with Recommendation 405, is used, the relative deviation of 0 dB in Fig. 2 of that Recommendation should correspond to the value of the deviation without pre-emphasis given in § 1;
Note. — This value of deviation was established for the transmission of monochrome television signals and was subsequently adopted for colour television signals.
3. that the sense of modulation at the point of international connection should be the subject of agreement between the administrations concerned.

RECOMMENDATION 403-3 *

INTERMEDIATE-FREQUENCY CHARACTERISTICS FOR THE
INTERCONNECTION OF ANALOGUE RADIO-RELAY SYSTEMS

(Question 1/9)

(1956–1959–1963–1966–1970–1978)

The CCIR,

CONSIDERING

- (a) that radio-relay systems for television and frequency-division multiplex telephony may form part of an international circuit;
- (b) that it may at times be desirable to make international connections between such systems at intermediate frequencies;
- (c) that, to facilitate international connections at intermediate frequencies, systems of the same channel capacity (independent of their radio frequencies), should preferably have the same intermediate frequency;
- (d) that, to facilitate the best choice for a radio-frequency channelling arrangement, it is desirable to adopt a preferred value for the intermediate frequency;
- (e) that incorrect interconnection may have harmful consequences (noise in radio-relay systems for telephony, and linear or non-linear distortion in radio-relay systems for television),

UNANIMOUSLY RECOMMENDS

that, as far as practicable, frequency-division multiplex radio-relay systems, forming part of an international circuit, should have intermediate-frequency circuits which, at a point of international connection, conform to the preferred values listed below:

1. Centre value of the intermediate frequency

Nominal centre values of intermediate frequency (MHz)	Maximum channel capacity
35 (for radio frequencies up to about 1.7 GHz) ⁽¹⁾ 70 (for radio frequencies above about 1 GHz)	12, 24, 60, 120
70	300, 600, 960, 1260, 1800
140	2700

⁽¹⁾ The intermediate frequency of 70 MHz may also be used in some radio-relay systems.

The tolerance relative to the nominal centre value of the intermediate frequency may well prove to be a function of a specific system, and is the subject of further studies. Until a final recommendation can be set up, the tolerance should be agreed between the administrations concerned.

* This Recommendation applies to line-of-sight and near line-of-sight radio-relay systems and, where appropriate, to trans-horizon radio-relay systems.

2. Output and input voltages of the intermediate-frequency signal

Nominal values

Output: 0.5 V r.m.s. (+ 5.2 dBm)

Tolerances

+ 1.0 dB
– 1.5 dB

The voltage at the output of a receiver corresponds to that of nominal radio-frequency level at the receiver input.

Input: 0.3 V r.m.s. (+ 0.8 dBm)

+ 1.0 dB
– 1.5 dB

Variations in levels which exceed the above range and which are either due to variations of the receive signal or to phenomena which are independent of propagation, should be the subject of agreement between the administrations concerned.

Connection between an output and an input may be made at an input voltage range of between 0.5 V r.m.s. to 0.3 V r.m.s. by agreement between the administrations concerned. Any necessary level adaptation should be made at the input point by the administration concerned.

3. Impedance of the intermediate-frequency circuit

Nominal impedance: 75 Ω (unbalanced).

Return loss: ≥ 26 dB within a frequency band including the baseband and the continuity pilot frequency on both sides of the centre frequency, for systems with a capacity of more than 600 telephone channels, or the equivalent.

Values greater than 26 dB may be necessary depending upon the characteristics of the junction cables used, especially their length, and the bandwidth transmitted (a large number of telephone channels or television and sound broadcasting signals).

The matching conditions for systems with a capacity of 600 channels or less, remain under study.

4. Intermediate-frequency characteristics at harmonic frequencies

The generation of harmonics (particularly the second harmonic) should be controlled as these may recombine with the fundamental frequency and cause distortions which could impair the transmission quality. As an example equipment-generated harmonics propagated through a junction cable may be reflected from the cable terminations to produce intermediate-frequency signals which are delayed with respect to the main signal and so result in intermodulation distortion noise.

Administrations should consider the level of harmonics and the impedance at harmonic frequencies of the cable termination, with a view to applying appropriate remedies, pending agreement upon a Recommendation.

Note 1. – When diversity reception is used, the preferred values quoted above for impedance and output level apply to the combined output of the receivers used.

Note 2. – It is recognized that in certain cases and in certain regions, it may be desirable to use, by agreement between the administrations concerned, intermediate-frequency characteristics other than those given above.

Note 3. – The precise definition of the point of international connection is the responsibility of the administrations concerned.

REPORT 788

CHOICE OF INTERMEDIATE FREQUENCIES FOR HIGH-CAPACITY DIGITAL RADIO-RELAY SYSTEMS

(Study Programme 12B/9)

(1978)

1. Introduction

The choice of intermediate frequency for a radio-relay system influences the feasibility, size, cost and reliability of such sub-systems as modulators, amplifiers, mixers and demodulators. In addition the IF for a high-capacity digital radio-relay system (gross bit-rate greater than 100 Mbit/s) is likely to directly affect the unwanted radiation and interference characteristics of the system and hence influence the channel filter characteristics.

Though small and medium capacity digital systems have been developed with an IF compatible with FDM-FM systems, the use of these intermediate frequencies for high-capacity digital systems may be impracticable, but is preferable in some cases, as outlined in § 2.2. As a consequence it is desirable to consider the practical factors affecting the choice of IF for such systems.

2. Equipment considerations

2.1 *Transmit modulator*

The IF output of the modulator contains the phase-modulated IF signal whose frequency spectrum spreads down to baseband frequencies, with components folding about zero frequency to produce unwanted signals in the IF passband. The baseband components can be adequately suppressed by filters, but the in-band fold-over components when using a switched modulator cannot be filtered out and may be of sufficient amplitude to make a contribution to the overall channel distortion. In addition, the higher harmonics of the baseband signal leak into the IF passband.

Any action to suppress the above-mentioned sources of interference is likely to be easier at high values of IF. In view of this, the value of transmitter IF should preferably satisfy the following relationship:

$$f_{IF} > \text{about } 3S \quad (1)$$

where S is the digital symbol rate.

The use of double-balanced switched modulators or the use of linear modulators with suitable pre-modulator filtering, may further reduce the interference in the IF passband. The use of an RF modulator has the same advantages as the use of a high IF, in respect to this baseband interference.

2.2 *Receiver demodulator*

A similar interference problem exists in the demodulator, but since the IF signal presented to the demodulator is band limited, the only significant distortion is leakage of the IF signal into the baseband. This can be overcome by the use of baseband filters in the case of a high IF, or alternatively, the leakage can be rejected by the use of a well-balanced demodulator. This technique enables the use of a standard analogue IF (such as 140 MHz) in the receiver.

2.3 *Other factors*

It is desirable for the efficient design and operation of IF amplifiers and carrier-recovery circuits to use a low value of IF. On the other hand IF circuits, for example hybrids, circulators and filters, can be designed without great difficulty for high intermediate frequencies and have the advantage that the occupied bandwidth is small compared with the centre value of the IF.

3. Interference considerations

3.1 *Channel frequency spacing*

The IF used in FDM-FM systems was chosen to allow interleaving of carrier frequencies and local oscillators thereby reducing potential interference. This arrangement is not so beneficial when applied to a high-capacity digital system since the ratio of signal bandwidth to channel spacing is much higher and in-band oscillators therefore pose a possible interference problem. Some administrations may however, wish to choose the IF as given by:

$$f_{IF} \approx \frac{2n-1}{2} \Delta F \quad (2)$$

where:

ΔF : channel frequency spacing and

n : an integer.

A consideration in the choice of IF is therefore one of interference to and from adjacent channels and local transmitters, a factor which depends on the rejection provided by the channel filter whose primary function is the determination of the digital channel performance. The design of the channel filter can, however, be eased by the use of additional filters such as half- or quarter-band filters or flanking filters.

3.2 *Interference into a digital channel*

The frequencies at which interference may enter a system from outside the allocated RF band (from radar, fixed and mobile radio systems, etc.) are,

- receiver local oscillator;
- receiver image channel; and
- intermediate frequency.

The image channel is generally the most sensitive of these three and in the absence of adequate protection by means of channel filters it may be necessary to protect the image frequency by suitable choice of IF. To totally protect both the image channel and the local oscillator from out-of-band interference it would be necessary to choose an IF so that these frequencies fell within the occupied band. On the other hand this recourse exposes the image channel to increased interference from local in-band transmitters. The situation can again be eased by the use of additional filters which makes the choice of IF less dependent on interference criteria.

3.3 *Out-of-band radiation*

Possible sources of out-of-band radiation are:

- transmitter local oscillator; and
- transmitter unwanted sideband.

These radiations can be controlled by rejection in the transmit-channel filter, which is aided by the use of a high IF and by the use of additional filters.

4. **General observations**

It is preferable to associate recognized digital hierarchies with a particular IF, however, the choice of IF may be influenced by interference considerations.

Table I lists some values of IF used in operational and development systems in Japan and the UK.

TABLE I

IF (GHz)	RF (GHz)	Digital symbol rate <i>S</i> (Mbaud)	Modulation
0.14	11 and 15	33.1 ⁽¹⁾	QPSK
0.14	11 and 15	49.4	QPSK
0.36	11	60	QPSK
1.2	19	132	QPSK
1.25	11	66	QPSK
1.7	20	199	QPSK

⁽¹⁾ Although this systems is not a high-capacity digital system, it is included for the purpose of information.

REPORT 284-2

**INTERCONNECTION OF ANALOGUE AUXILIARY RADIO-RELAY SYSTEMS OPERATING IN
A FREQUENCY BAND OTHER THAN THAT OF THE MAIN SYSTEM
AND AT FREQUENCIES BELOW ABOUT 2 GHz ***

(Study Programme 4A/9)

(1963-1966-1970-1982)

1. Frequency bands available

According to Recommendation 400, auxiliary radio channels can be provided either in the same band as the main system, or in a different band following the same route as the main system.

1.1 *Auxiliary systems operating in a band other than that of the main system*

Frequencies were proposed in the band of 400-470 MHz and discussion showed that there would be frequencies available in the band of 2 GHz.

In the Radio Regulations, the bands 401 to 430 MHz and 440 to 470 MHz have been allocated to fixed (and mobile) services in all three Regions, with many restrictions set out in the appropriate footnotes. The 2 GHz band is also allocated to the fixed (and mobile) services in all three Regions, and frequencies may be available in the band 1710 to 2690 MHz.

Propagation conditions in the 400 MHz range are very stable, light-weight antennas and low-loss flexible coaxial cables simplify the installation. Inexpensive crystal-controlled transmitters allow narrow frequency spacing.

In the 2 GHz range, narrow-beam antennas are available with greater side-lobe attenuation than in the lower range. This property, and the fact that these waves are not normally propagated beyond the line of sight, reduces the number of frequency pairs necessary for a given network compared with that for the 400 MHz range.

It was stated, however, that in the latter range, a frequency offset of about 50 kHz could double the available pairs of frequencies for a given radio-frequency band.

2. Necessary number of frequencies for auxiliary system operating in a band other than that of the main system

It was stated that the necessary number of pairs of frequencies would depend on the number of radio-relay systems crossing the border between the administrations concerned. With regard to the changing of frequencies between adjacent hops, the minimum requirement would be one or two pairs, but the number might often be greater, for instance, six pairs for more extended networks. With a baseband of, for example, 20 kHz bandwidth, the spacing for the 400 MHz range with a frequency stability of 20×10^{-6} (Radio Regulations, Geneva, 1979), would be about 250 kHz at crossing points and about 500 kHz on parallel routes. For the 2 GHz range, a stability of 20×10^{-6} seems to be feasible (the Radio Regulations give 100×10^{-6}); the corresponding figures would be about 0.5 MHz and 1 MHz respectively. For the sake of frequency conservation, the channel spacing should be reduced to the minimum practicable.

3. Characteristics at baseband frequencies

3.1 *Width of baseband*

The baseband may extend from 300 Hz to 60 kHz. Several telephone channels can be set up in this band, the precise arrangement of the channels being a matter for agreement between the administrations concerned.

In accordance with Recommendation 400, the telephone channels can be used to provide at least one omnibus speaker circuit and one main (express) speaker circuit.

The upper part of the baseband can be used for supervisory channels of high-speed switching signals and for extra telephone channels.

3.2 *Interconnection levels*

3.2.1 For the omnibus speaker circuit:

Input and output: between -3 and -4.3 dBr.

* Auxiliary radio-relay systems operating in the same frequency band as the main systems are dealt with in Recommendation 389 and Report 374.

3.2.2 For the 4-60 kHz band (per telephone channel):

Input: -45 dBr

Output: -15 dBr.

3.3 *Impedances*

3.3.1 For the omnibus speaker circuit:

600 Ω balanced.

3.3.2 For the remaining baseband (4-60 kHz):

150 Ω balanced.

4. **Modulation characteristics at radio frequencies**

Frequency modulation is used for the omnibus speaker circuit and for the low-speed digital channels. The r.m.s frequency deviation is 10 kHz.

Additional telephone channels and fast-switching channels are accommodated in a group within the baseband extending from 4 to 60 kHz. Pre-emphasis at baseband frequencies within this group is provided by a network, with a time constant of 5 μ s, the characteristics of which are such that the deviation increased with increasing frequency. The r.m.s. frequency deviation within this group is about 20 kHz, at a frequency of 36.5 kHz, for an input of 1 mW at a point of zero relative level.

5. **Quality**

The mean noise power in any telephony channel up to 280 km long, used for the transmission of auxiliary signals, should not, in accordance with Recommendation 400, exceed a value of 20 000 pW0p psophometrically weighted at a point of zero relative level.

6. **Continuity pilot**

Should it prove necessary to use a continuity pilot, its frequency deviation should be 7 kHz (r.m.s).

The frequency of this pilot should be determined by agreement between the administrations concerned. At present, a frequency of 5 kHz is used.

REPORT 374

INTERCONNECTION OF ANALOGUE AUXILIARY RADIO-RELAY SYSTEMS OPERATING IN THE SAME FREQUENCY BAND AS THE MAIN RADIO-RELAY SYSTEM *

(Study Programme 4A/9)

(1966)

The characteristics set out below are for angular modulation of the auxiliary carrier **.

They are applicable to auxiliary systems associated with main systems of a capacity greater than 300 telephone channels per radio-frequency channel.

1. **Characteristics at baseband frequencies**

1.1 *Width of baseband*

The baseband can occupy from 300 Hz to 60 kHz.

Several telephone channels can be set up in this band, the precise arrangements of the channels being a matter for agreement between the administrations concerned; in particular, for practical reasons, the voice-frequency telephony channel may be omitted and the baseband can start at 4 kHz.

In accordance with Recommendation 400, the telephone channels can be used to provide at least one omnibus speaker circuit and one main (or express) speaker circuit.

The top part of the band can be used for supervisory or high-speed switching signals and for extra telephone channels.

* See Recommendation 389 and Report 284.

** Some administrations also use these characteristics for below-baseband transmission on the main radio-relay system. In addition, some administrations make use of other types of modulation of the carrier.

1.2 *Interconnection levels*

1.2.1 *For the omnibus speaker circuit*

Input and output: between -3 and -4.3 dBr.

1.2.2 *For the 4-60 kHz band (per telephony channel)*

Input: -45 dBr;

Output: -15 dBr.

1.3 *Impedances*

1.3.1 *For the omnibus speaker circuit*

$600\ \Omega$ symmetrical.

1.3.2 *For the baseband (4-60 kHz)*

$150\ \Omega$ symmetrical.

2. **Characteristics at radio frequencies**

2.1 *Modulation characteristics*

Frequency modulation is used for baseband frequencies above 4 kHz.

Frequency-, phase- or intermediate angular-modulation can be used in the 0.3 - 4 kHz band; the conditions of interconnection will be determined by agreement between the administrations concerned.

2.2 *Frequency deviation*

In the baseband frequencies between 4 and 60 kHz, the frequency deviation for a 1 mW signal at a point of zero relative level is 50 kHz (r.m.s.) *.

3. **Quality**

The mean noise power of any telephony channel up to 280 km in length, which is used for the transmission of auxiliary signals should, whenever possible, not exceed $20\ 000$ pW0p psophometrically weighted at a point of zero relative level (in accordance with Recommendation 400).

4. **Continuity pilot**

When it proves necessary to use a continuity pilot, its frequency deviation should be 17.5 kHz (r.m.s.).

The frequency of the pilot will be determined by agreement between the administrations concerned. Frequencies between 4 and 5 kHz are used at present.

Note. — It may be desirable to have a high-speed pilot. Attention is drawn to the fact that there is a relationship between multi-channel switching equipment and control signal distribution.

REPORT 939

INTERCONNECTION OF TRANS-HORIZON RADIO LINKS

(Question 7/9)

(1982)

1. **Interconnection at baseband frequencies**

For interconnection at baseband frequencies, application of Recommendation 380 is suggested.

2. **Interconnection at intermediate frequency**

Where interconnection at intermediate frequency is desired, centre frequency, passband, impedance characteristics, levels, etc. should be specified.

* The frequency deviation of 35 kHz (r.m.s.) is also used.

Interconnection at the intermediate frequency is not as appropriate in trans-horizon systems as in line-of-sight radio-relay systems. This is due to the following facts:

- increasing use of frequency compression techniques;
- limitations imposed by the use of diversity reception, particularly baseband combining;
- due to the poor carrier-to-noise ratios usually experienced, the deviation for each system is generally chosen as the optimum for that system, rather than using a standardized deviation; however, interconnection cannot be easily achieved unless all systems use the same deviation;
- the intermediate-frequency bandwidths, pre-emphasis, etc., are usually chosen as a function of the number of channels actually in use and a compromise is undesirable.

Whereas the above circumstances may not prohibit intermediate-frequency interconnection, its desirability is likely to become marginal in many instances.

Nevertheless, where intermediate-frequency interconnection is desired, for frequency-modulation systems, the centre frequency, the voltage and impedance characteristics should be those as specified in Recommendation 403.

Note. — The interconnection frequency may be attained by single heterodyning, multiple mixing, multiplication (particularly in frequency compression receivers), a combination of these or similar techniques. Considerations of receiver noise figure and selectivity may also justify using double (or higher order) mixing (see Annex I).

3. Interconnection at radio frequencies

Interconnection at radio frequencies requires specification of the carrier frequencies employed, baseband characteristics (such as number and allocation of channels, modulation and demodulation characteristics, pre-emphasis, pilots, channel levels), order and type of diversity and polarization used, antenna characteristics (gain, bearings and polarization), radio-frequency power levels, receiver sensitivities, and system passband characteristics.

For the reasons given under § 2, as well as additional reasons (particularly noise, selectivity, and gain) interconnection at radio frequencies within a station is not desirable and there seems no purpose in preparing recommendations for such interconnection. Nevertheless, radio-relay systems are frequently interconnected by direct reception in one system of the radio-frequency emission from the other.

ANNEX I

THE CHOICE OF INTERMEDIATE FREQUENCIES FOR TRANS-HORIZON RECEIVERS

The following notes concern the choice of intermediate frequencies for trans-horizon receivers of the angular modulation type only. For single-sideband equipment some of the considerations are different and are not considered here.

1. Choice for the first intermediate frequency

When parametric amplifiers (or other low-noise input circuits) are used, the choice of intermediate frequency has no predominant influence on the noise factor of the receiver.

Otherwise, the choice of intermediate frequency becomes a compromise between the noise factor of the receiver and the radio-frequency filter losses. This may lead to the choice of a lower intermediate frequency than in the first case.

2. Double conversion receivers

In the interest of image rejection, as high a first intermediate frequency as possible should be used (consistent with noise figure requirements). However, there are a number of reasons why the use of a double conversion receiver is often desirable. These include the following factors:

- the large gain needed in a trans-horizon receiver is sometimes difficult to obtain with only one intermediate frequency;
- in a trans-horizon receiver, the intermediate-frequency bandwidth is generally less than in a line-of-sight receiver carrying the same number of channels, in order to obtain the best compromise between threshold and intermodulation; hence, rather narrow intermediate-frequency bandwidths may be needed, which can be best obtained at a relatively low frequency;
- the bandwidth at intermediate frequency is often varied for different channel capacities to obtain the optimum compromise between threshold and intermodulation in each case. This can most economically be done by making the intermediate-frequency bandwidth suitable for the larger number of channels for which the set is to be used, and inserting a filter for lower capacities. These filters may be built more cheaply for a lower frequency.

In a receiver employing an intermediate-frequency combiner, it is necessary to have a voltage-variable oscillator in one or more of the receivers, which can be used to phase-lock the signals to one another, or to a common standard for effective combining. If this oscillator operates at a frequency below about 100 MHz, the use of relatively simple modulator techniques is possible. It can conveniently be the second local oscillator in a dual conversion receiver.

In a “compression” type receiver, a dual intermediate frequency is desirable, to avoid the need for duplicating the microwave local oscillators for space or angle diversity, and it is also necessary to avoid the application of feedback over too long a loop.

For receivers using “phase lock” detectors, it is desirable to operate the detector at as low a frequency as possible. Although operation at frequencies of the order of 70 MHz is possible, there would be advantages from the receiver design standpoint if they could be operated at lower frequencies. If compression is combined with the phase-lock detector, the use of two intermediate frequencies is mandatory to avoid trying to apply feedback over a long path.

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

SECTION 9D: MAINTENANCE

Recommendations and Reports

RECOMMENDATION 290-3

**MAINTENANCE MEASUREMENTS ON RADIO-RELAY SYSTEMS FOR
TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX**

(1959-1970-1974-1978)

The CCIR,

CONSIDERING

that the operation of frequency-division multiplex radio-relay systems for telephony would be facilitated by maintenance procedures similar to those in existence for line networks,

UNANIMOUSLY RECOMMENDS

that the following routine maintenance measurements should be made on radio-relay regulated line sections in accordance with CCITT Recommendation M.500. These measurements should be made in the radio equipment terminal stations of the radio-relay system. Readjustment should be carried out in accordance with CCITT Recommendation M.510.

1. At intervals to be determined by agreement between the administrations concerned and based on experience of the reliability of the system:

- measurement of the loss/frequency distortion at frequencies in the baseband relative to the reference frequency * or multi-frequency check (permissible limits ± 2 dB except under abnormal propagation conditions);
- when there is no continuous recording of noise, measurement of the total noise level on the noise-measurement channels outside the baseband in accordance with Recommendation 398 ** this measurement can be made without causing any interference in the transmission channel;
- further measurements, e.g. group delay measurement, may be appropriate to obtain more detailed information.

2. When the measurement mentioned in § 1 gives unacceptable high noise values, or more often, when the reliability of the system makes it desirable, check the following measurements in accordance with the appropriate CCIR recommendations for the radio-relay system concerned, the radio-frequency channel being switched to the stand-by equipment. Measurement results should be compared with the results of the reference measurements required by CCITT Recommendation M.450, § 3.3:

- the deviation of the frequency at which the level is unchanged by pre-emphasis;
- the pilot-frequency deviation;
- the nominal value (control position) of the intermediate frequency in the non-modulated condition of the system;
- the level of the baseband reference frequency * where applicable (single-frequency check);
- the baseband amplitude variation with frequency relative to the reference frequency * where applicable (multi-frequency check);
- the level of individual interfering signals in the baseband in the non-modulated condition of the system.

3. So as to enable the overall limits for the variations of transmission equivalent (see under § 1) to be met, the difference in baseband response between two systems in diversity reception or between working and protection systems should not exceed 2 dB.

Note. – The variation of ± 2 dB applies to all types of switching including baseband. The actual variation may be less for intermediate-frequency switching or for diversity switching on a single radio hop.

In order to achieve this figure consistently, it may be necessary for the amplitude/frequency response of each radio channel to be adjusted to tighter limits than those given in Recommendation 380, Note 7.

* The baseband reference frequency may be different from the frequency at which the level is unchanged by pre-emphasis and may be selected from one of the frequencies specified in § 3.1.2 of CCITT Recommendation M.450 for each transmitted bandwidth.

** Where a protection channel is provided, and if administrations so desire, noise measurements may be made on that channel with artificial loading, in accordance with Recommendation 399.

Administrations may find it advisable to adjust the transmission equivalent of all radio channels in the same switching system to close limits at a single mutually agreed reference frequency.

RECOMMENDATION 305

**STAND-BY ARRANGEMENTS FOR RADIO-RELAY SYSTEMS
FOR TELEVISION AND TELEPHONY**

(1956-1959)

The CCIR,

CONSIDERING

- (a) that, in radio-relay systems, it is indispensable to have stand-by arrangements to decrease the time when the circuit is out of action as a result of a fault in equipment, or to facilitate periodical maintenance operations;
- (b) that for this purpose, it is generally advisable to use a stand-by channel replacing the channel normally in service along the entire length of a switching section;
- (c) that, for technical or operational reasons, it may be desirable to use, in certain cases, stand-by installations of a different type such as stand-by equipment with switching at each station on the same carrier frequency;
- (d) that a distinction should be made according to whether the system is intended for the transmission of telephone channels, of telephone and television channels possessing very similar radio characteristics, or of telephone and television channels with differing characteristics,

UNANIMOUSLY RECOMMENDS

1. that, when several radio-frequency channels possessing the same characteristics are used for multiplex telephony, it is preferable to use a stand-by channel common to the channels in service (or several such stand-by channels, if necessary);
2. that, when some of the radio-frequency channels are utilized for multiplex telephony and others for television and all the radio channels possess very similar characteristics, it is preferable to use a stand-by channel common to the channels in service (or several such stand-by channels, if necessary);
3. that, in certain specific cases, such as when some of the radio-frequency channels are utilized for multiplex telephony and others for television and when the characteristics of such channels are substantially dissimilar, the administrations concerned may, by mutual agreement and if they so desire, use stand-by arrangements differing from those specified in §§ 1 and 2 of the present Recommendation, such as stand-by equipment operating on the same carrier frequency as the equipment in service and which can be substituted for that equipment station by station.

RECOMMENDATION 401-2 *

**FREQUENCIES AND DEVIATIONS OF CONTINUITY PILOTS FOR FREQUENCY MODULATION
RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY**

(1956-1959-1963-1966-1970)

The CCIR,

CONSIDERING

- (a) that special pilots are required on radio-relay systems to indicate the continuity of the circuit;
- (b) that these pilots should be situated outside the range of frequencies occupied by the telephony or the television signals (Recommendation 381);
- (c) that typically, a frequency about 10% higher than the upper limit of the transmitted baseband is desirable depending upon the necessary suppression desired (see Recommendation 381);

* This Recommendation applies to line-of-sight and near line-of-sight radio-relay systems and also, where appropriate, to trans-horizon radio-relay systems.

- (d) that, in determining the upper frequency limit of continuity pilots, compatibility with radio-relay channel arrangements, and equipment passband characteristics need to be taken into account;
- (e) that some administrations wish to use the same continuity pilot characteristics in various radio-relay systems for multi-channel telephony and television;
- (f) that, to reduce intelligible cross-talk, the continuity pilot should, when possible, have a frequency of $(4n - 1)$ kHz, where n is an integer,

UNANIMOUSLY RECOMMENDS

1. that for frequency-division multiplex telephony and television radio-relay systems, when the continuity pilot is above the baseband, its frequency and deviation should be that shown in Table I;

TABLE I

System capacity (channels)	Limits of band occupied by telephone channels (kHz)	Frequency limits of baseband (kHz) ⁽¹⁾	Continuity pilot frequency (kHz)	Deviation (r.m.s.) produced by the pilot (kHz) ⁽²⁾ ⁽³⁾
24	12-108	12-108	116 or 119	20
60	12-252 60-300	12-252 60-300	304 or 331	25, 50, 100 ⁽³⁾
120	12-552 60-552	12-552 60-552	607 ⁽⁴⁾	25, 50, 100 ⁽³⁾
300	60-1300	60-1364	1499, 3200 ⁽⁵⁾ or 8500 ⁽⁶⁾	100 or 140
600	60-2540 64-2660	60-2792	3200 or 8500	140
960 } 900 }	60-4028 } 316-4188 }	60-4287	4715 or 8500	140
1260 } 1200 }	60-5636 } 60-5564 } 316-5564 }	60-5680	{ 6199 8500	100 or 140 140
1800	312-8204 316-8204	300-8248	9023	100
2700	312-12 388 316-12 388	308-12 435	13 627	100
Television			{ 8500 9023 ⁽⁷⁾	140 100

⁽¹⁾ Including pilot or other frequencies which might be transmitted to line.

⁽²⁾ Other values may be used by agreement between the Administrations concerned.

⁽³⁾ Alternative values dependent on whether the deviation of the signal is 50, 100 or 200 kHz (Recommendation 404).

⁽⁴⁾ Alternatively 304 kHz may be used by agreement between the Administrations concerned.

⁽⁵⁾ This deviation does not depend on whether or not a pre-emphasis network is used in the baseband.

⁽⁶⁾ For compatibility in the case of alternate use with 600-channel telephony systems and television systems.

⁽⁷⁾ The frequency 9023 kHz is used for compatibility purposes between 1800 channel telephony systems and television systems, or when the establishment of multiple sound channels so indicates.

2. that a continuity pilot situated below the baseband may be used after agreement between the administrations concerned;

3. that the frequency stability of the continuity pilot should be better than 5 parts in 10^5 .

RECOMMENDATION 444-3

PREFERRED CHARACTERISTICS FOR MULTI-LINE SWITCHING ARRANGEMENTS
OF ANALOGUE RADIO-RELAY SYSTEMS

(Study Programme 5A/9)

(1966-1970-1978-1982)

The CCIR,

CONSIDERING

- (a) that protection arrangements for wide-band telephony and television radio-relay systems may be required to meet availability objectives;
- (b) that international agreement on the major characteristics required for interconnection of such systems appears to be desirable and feasible for baseband-frequency and intermediate-frequency multi-line switching systems;
- (c) that many characteristics of multi-line switching systems are still under study, while others represent areas of agreement;
- (d) that an objective of multi-line switching arrangements is to facilitate compliance with Recommendations 393 and 567,

UNANIMOUSLY RECOMMENDS

that, as far as practicable, the characteristics of multi-line switching systems should conform to the following:

1. the criteria for protection switching and restoration should be based on:
 - 1.1 the level of the continuity pilot (see Recommendation 401);
 - 1.2 the evaluation of noise power within a frequency band in the vicinity of the pilot frequency (see Table I, Recommendation 401);
 - 1.3 the received carrier level;
2. seizure and restoration of a protection channel should depend on the following criteria:
 - § 1.1 alone
 - § 1.2 alone
 - § 1.3 in combination with § 1.1
 - § 1.3 in combination with § 1.2
 - § 1.1 in combination with § 1.2;
3. the threshold levels should be adjustable, and the actual threshold should be chosen so that switching occurs only when essential for reasons of performance and reliability;
4. in each switching section, recognition of a failure of a regular radio-frequency channel should initiate changeover to a protection radio-frequency channel *within* the section involved. Unnecessary switchover and re-set operations in other sections should be avoided;
5. the following control signals should be provided:
 - 5.1 from the main traffic receive-end to the transmit-end, a signal for bridging or switching. This signal includes identification of the degraded channel, and, where appropriate, a preference for a particular protection channel. The signal should comprise voice frequency telegraph tones which conform in frequency with the relevant CCITT Recommendations. Other types of signal and levels may be used by agreement between the administrations concerned. A service channel should be used (see Recommendation 400) to convey this signal. A failure of the control signal information should freeze the situation as it was immediately preceding the failure. In certain cases where priority is used, it may be desirable to change the situation to some preferred configuration;
 - 5.2 from the main traffic transmit-end to the receive-end, confirmation that bridging or switching has taken place. This may be transmitted, for instance, by suitably modulating the continuity pilot of the protection channel, or by changing its frequency, or by other means;
6. the protection channels should be made available as much as possible. If the operational requirements make it necessary, it should be possible to give priority to any regular channel;

7. the operate time of the entire automatic switching system should not exceed 40 ms. An operate time of 10 ms can be achieved by using a wide-band signalling channel;
8. the effective transfer time in most cases depends on the switching element used. Reduction of this time below 2 ms and down to 10 μ s may be realized by using modern design techniques;
9. the noise allocated as a contribution by the switching equipment should generally be a small fraction of the total allowable noise of the link (see Recommendations 393 and 395);
10. conformity with CCIR Recommendations relating to interconnection and characteristics at baseband and intermediate frequencies should, in no way, be affected by the use of multi-line switching equipment.

REPORT 137-5

PREFERRED CHARACTERISTICS FOR MULTI-LINE SWITCHING ARRANGEMENTS OF ANALOGUE RADIO-RELAY SYSTEMS

(Study Programme 5A/9)

(1959-1966-1970-1974-1978-1982)

1. Protection arrangements

Multi-line switching systems constitute one type of service protection used in radio-relay systems. Another, related approach, consists of single-line protection (see Report 443).

2. General description

A multi-line switching system includes all the apparatus necessary for effecting successful transfer of traffic on any one of two or more regular channels transmitted over radio-relay systems to one or more protection radio channels in the event of transmission impairments. Functions necessary for the successful operation of such an arrangement include fault detection and recognition, control-signal initiation via possible logic circuitry, switching-request transmission and acknowledgement, switching or bridging at transmit and receive points at baseband or intermediate frequency.

3. Criteria for switching

Criteria for switching are based on the nature as well as on the extent of the degradation and any special interrelationship between them. Furthermore, priority relations between channels may be established by the switching logic circuitry. The extent of degradation is indicated by so-called switching thresholds.

The switching threshold is generally defined by a specified drop in the level of the continuity pilot and/or by a specified increase in the noise level monitored in the vicinity of the pilot (see Recommendations 401 and 444), or, in some cases, in a slot usually in the upper part of the baseband.

There are certain arrangements in which the level of the received carrier can be used as a switching criterion, but if it is measured only at the end of a switching section, then unlike the pilot and noise levels which separately can initiate a change-over, the information on the state of the received carrier level must be combined with that of the pilot or noise level to form a switching criterion.

Drops in pilot level from 4 to 8, or even to 15 dB, have been suggested as a threshold for initiation of switching. The smaller values would apply to pilots with frequencies below the baseband and above the baseband when sufficiently close to it. The larger values may be more appropriate when the pilot frequency is considerably higher than the baseband. Many other factors also influence the choice of the threshold point.

For telephony, noise level thresholds ranging from 10 000 pW0p (−50 dBm0p) to 500 000 pW0p (−33 dBm0p) have been suggested. For television, the minimum criteria suggested is a weighted signal-to-noise ratio in the range 45 to 48 dB at the switch threshold. There is considerable evidence that when the fade depth to the switch threshold is large, as may be the case in high-capacity systems using only a thermal noise criterion, severe video signal distortions may occur under multipath fade conditions prior to the initiation of the switch. In order to avoid this distortion, a method of switch initiation has been proposed, by one administration, in which switching is initiated for not only a drop, but also an increase, in pilot level. Limited experiments using this technique with an 8.5 MHz continuity pilot have proved to be effective in causing the initiation of switching to initiate during multipath fading. This method should be studied further in order to establish the relationship between propagation conditions and the optimum upper threshold limit for switch initiation. Also the effects of reduced protection channel availability caused by the increase in switching activity should be studied further.

By means of the switching-logic circuitry, preference can be given to one criterion over another, or to different levels of the criteria. It is common practice to provide adjustment to accommodate thresholds to varying system needs. Fading rates of 100 dB/s and operate times up to 40 ms would suggest that the noise level causing initiation of switch-over should be at least 4 dB above the degradation noise level value.

In some current multi-line switching arrangements, the switching logic can be arranged such that a switch to the protection channel which has occurred due to an increase in noise level, may be pre-empted by a subsequent complete failure on another channel. This provides a preference for access to the protection channel, for a completely failed channel over a degraded channel.

4. Switching cycle

Both the basic cycle as well as the resultant outage time (see Report 443) depend heavily upon the reason for switch-over, whether caused by fades or by equipment degradation.

4.1 Sequence

Typically, such a sequence consists of the following time elements:

- recognition of fade or failure, at receiving end;
- construction of a control signal to be sent to transmitting end;
- transmission of control signal to transmitting end;
- recognition at transmitting end (check for inhibit instructions, if appropriate);
- bridging or switching time at transmitting end;
- transmission of signals over control line to receiving end;
- time to examine signal received over control line;
- decision on whether the switch should be operated;
- actual switch operation (transfer).

4.2 Interruption time

In the case of fading, transmission quality will probably continue to deteriorate but the signal may not completely fail after the instant that request for switching is initiated. If the operate time and the noise level which cause switching to be requested are properly proportioned to the maximum rate of increase in path loss due to fading, it is possible to eliminate transmission errors due to fading. The actual outage is thus governed by the performance of the switching element itself.

There are several designs of switching elements in use, including electronic and mechanical configurations at intermediate and baseband frequencies. Mechanical switches usually exhibit longer transfer times, generally considered to be about 2 ms, compared to 10 μ s or even less for electronic switches. Use of certain “make-before-break” configurations essentially produce further reduction of transfer times (assuming favourable signal presence on both channels).

Optimum switch-over conditions can be achieved by means of amplitude and phase equalization of both channels.

In the case of equipment failure or malfunction, most, if not all of the switching sequence (§ 4.1) will contribute to the interruption time. On a 280 km section propagation time alone will account for 1 ms, and additional delay time will be introduced by the operation of circuitry etc. Actual delay times of between 10 ms and 40 ms have been reported.

In order to minimize the operate time for one preselected channel, the channel may be bridged at the transmit end to the protection channel during the whole time that the protection channel is not otherwise occupied.

5. Likelihood of failure

Since with the use of modern, quality equipment, a preponderance of outages are associated with fades, primary consideration should be given to transfer times and secondary consideration to fault recognition and control tone transmission times in evaluating interruptions.

6. Characteristics of multi-line switching equipment

To obtain agreement on the characteristics of multi-line switching equipment for an international interconnection certain characteristics are more important than others. In particular, the control signals used between the transmitting and receiving ends and the noise detection bands need to be agreed. Additionally factors relating to the priority of channels and to the number of protection channels must also be considered by administrations. This section summarizes the practice adopted by some administrations. It is not intended to be complete, but can be considered as a possible basis for future international agreement.

6.1 *Signalling from transmitting to receiving end*

The following methods of transmission of the control signal from the transmitting to the receiving terminals of the multi-line switching system were reported:

- an offset continuity pilot frequency;
- modulation of the continuity pilot;
- a control signal which uses a voice-frequency channel. This channel is also used for the signals in the receiving to transmitting direction.

6.2 *Signalling from the receiving to transmitting end*

The signalling arrangements between the receiving and transmitting end are given for baseband switching systems. Intermediate-frequency systems have additional considerations, some of which are given in § 7 of this Report. The control signal should comprise voice frequency telegraph signals which conform in frequency with the relevant CCITT Recommendations.

Modulation methods

The following modulation methods are in current use or are being considered:

- on-off keying modulation,
- 2-level frequency-shift keying,
- 3-level frequency-shift keying,
- time-division modulation.

Coding methods (excluding TDM signals)

The coding methods of the voice frequency telegraph tones can depend upon the complexity of the switching system, i.e. the number of main and protection channels, the degree of protection required against false operation, etc. The following coding methods are in current use:

- the change of state of a single tone. There are n tones provided corresponding to n main channels, i.e. “1 out of n ”;
- either a “2 out of 4” or a “2 out of 5”.

In addition, the level of voice frequency telegraph tones and the transmission bandwidth associated with each tone require agreement.

6.3 *Protection of the control signal between the receiving and transmitting end*

Protection of the control signal between the receiving and transmitting end to avoid simulation of the signal by random noise, cross-talk or breaks in transmission, is necessary. This is best achieved by a suitable coding of the signal, the use of a muting device on the main radio-frequency channel, and a suitable choice of logic. Back looping of the control signal to the receiving end for comparison with the transmitted signal, may also be used as a measure to monitor any malfunctioning. In the event of unwanted disturbances in the transmission channel, the switching system should remain in the position of the last command or in a predetermined position.

6.4 *Priority of radio-frequency channels*

Priority of radio-frequency channels in the switching system should be at the discretion of the administration concerned.

The following points are relevant:

- that the priority function, where used, shall be determined by the receive logic and shall be independent of the transmitting terminal;
- that some administrations prefer not to use a priority arrangement;
- that, in general, where a priority arrangement is used, it is restricted to a single radio-frequency channel. However, for systems with a large number of regular channels and two protection channels, two priority channels may be used;
- in the case of some developing countries where two radio-frequency channels are used in a “1 + 1” switching arrangement with television on the protection channel, the telephony circuits have priority over the television signals.

6.5 *Number of protection channels*

Current multi-line switching equipment is used with either one or two protection channels. The following views exist:

- that in some circumstances the availability of circuits is only slightly improved with the use of a second protection channel, therefore one protection channel may be sufficient;
- on high traffic density routes there might be a requirement for a radio-frequency channel to provide facilities for alternative routing, for cable circuits or to ensure a high availability during maintenance periods. This is met by some administrations by the use of an “ $n + 2$ ” switching system and by others with the use of an undedicated main radio-frequency channel within the switching system.

6.6 *Test access feature*

Some existing multi-line switching arrangements are designed to provide access to a working radio-frequency channel for test purposes, such that in the event of a failure of the protection channel or any regular channel during the testing period, testing is automatically discontinued and the traffic reverts to its original radio-frequency channel.

6.7 *Service band switching at repeater stations*

Service channel circuits dropped and inserted at intermediate repeater stations can be provided in several ways (Report 444). When a main channel carrying the service channel circuits either as a sub-baseband signal or as a signal above the baseband, fails, provision should be made at the repeater to switch to another channel which also carries the service channel signal.

The following methods are in current use:

- a service channel, carried normally by the priority channel, is switched to the protection channel in the event of a failure of the main channel by means of a control tone from the receive logic. The method can also be used on a “1 + 1” switching system;
- if two radio-frequency channels are used to carry the service band signals, which are applied to the channels after the transmit switch, switching (automatic or manual) or combining, is used at the repeater station to obtain the service band signals.

6.8 *Stop filters at system input*

Stop filters may be necessary at the input of radio systems. This is to ensure satisfactory protection of the continuity pilot and the noise detection band. The noise detection band is either centred around the continuity pilot or displaced from the continuity pilot. Thus adequate protection should be given to both the continuity pilot and the appropriate bandwidth of the noise detection band. The noise detection band frequency allocation requires agreement.

7. *Subsidiary effects*

If not properly designed, a multi-line switching arrangement at intermediate frequency, associated with a section of a radio-relay system, may have harmful effects on other sections by initiating false switching, either during protection switch-over or restoration. Means to avoid this include:

- retention of the unsatisfactory carrier as well as transmission of an inhibition instruction to the succeeding sections;
- in each switching section, monitoring and comparison of the signal at the receiving end, after bridging the normal and stand-by channels at the transmitting end, and inhibiting switching at the receiving end in the switching section when the quality of both signals is comparable;

- insertion of a substitute carrier with pilot modulation. This is not recommended for switching due to fades in order to limit such interruptions to the actual transfer time;
- a combination of the above.

8. Disturbances due to switching

The switching equipment, like the other constituents of a radio link, makes a contribution to the noise and distortion of the system, and due allowance for this must be made in determining system performance.

8.1 Noise

When traffic is switched from a regular channel to a protection channel, there may be a change in the noise and distortion to which it is subject, even though propagation conditions within the switching section are normal. This is due partly to a change in the noise introduced by the switching equipment itself, and partly to the fact that the noise contributed by the protection channel is not identical to that contributed by the regular channel.

The following values have been reported for a switching section of 280 km:

- switching equipment contribution:
less than 50 pW for any telephone channel,
differential gain, less than 0.3%,
differential phase, less than 0.3°;
- change caused by switch-over:
less than 150 pW for any telephone channel.

8.2 Transmission equivalent

The following maximum values of variation in transmission equivalent when switching between a main channel and a protection channel under normal propagation conditions can be expected:

- total variation $\leq \pm 2$ dB,
- contribution of the switching equipment itself about ± 0.5 dB (included in the value above).

However, during periods of abnormal propagation, greater variations may occur but at present cannot be quantified.

8.3 Phase changes due to switching

During the switching a phase change will occur. The maximum allowable value of this change should be studied, taking into account the baseband frequency and the type of traffic.

BIBLIOGRAPHY

ZATSEPINA, V. E., KAMENSKY, N. N., RODIONOV, V. M. and SHOSHENKOV, V. D. [1977] Avtomaticheskoe rezervirovanie stvolov v unifitsirovannykh radioreleinykh sistemakh svyazi (Automatic channel switching in unified radio-relay systems). *NIIR Proc.*, 3, Moscow, U.S.S.R.

CCIR Documents

[1978-82]: 9/32 (Canada); 9/45 (U.S.S.R.); 9/46 (U.S.S.R.); 9/236 (Japan).

REPORT 443-1

TRANSMISSION INTERRUPTIONS DUE TO THE SWITCHING OF ANALOGUE RADIO-RELAY SYSTEMS

(Question 5/9)

(1970-1978)

1. Interruption and degradation

In considering transmission interruptions it appears useful to interpret interruptions in the broader sense of "impairments" due to the switching or combining process as posed by the above Question. It also seems appropriate to consider the likelihood of occurrence, when evaluating the relative merits of system approaches leading to different degrees of impairment (in duration as well as type). The choice could well lead to acceptance of a less desirable switching degradation if justified by a reasonably low rate of occurrence.

1.1 Two aspects of the duration of the switching operations need to be recognized:

1.1.1 *The transfer time* of the switch element (or sub-system) during which service degradation occurs (§ 1.2 and Report 137).

1.1.2 *The operate cycle* of the entire automatic switching system, from the instant that transmission is degraded sufficiently to initiate the cycle, to the instant when normal quality service is restored (see Report 137).

1.2 *Types of baseband degradation*

Such degradations may take several forms. These include sudden variations in the level of the baseband signal with either slowly-correcting or sudden-restoration characteristics. A common variant is the effective though temporary removal of the baseband signal. Introduction of noise bursts (alone or in conjunction with level variations) as well as phase changes within the baseband constitute other common accompanying phenomena.

2. Types of system

There are many similar considerations between multi-line and single-line and switching systems. In the case of single-line switching systems, a prior selection of the protected and protecting channel permits certain system arrangements conducive to less annoying impairments. However, the design of multi-line switching systems and improved equipment reliability have progressed to the point where the advantages of single-line switching are seldom important enough to outweigh the economic and other benefits of multi-line switching.

2.1 *Causes and effects of switch-over*

There are generally two types of causes for switch-over: those related to equipment malfunction, and those related to fades. In the case of the latter, transfer impairment duration and characteristics are dependent upon the switching element itself (see also Report 137). Use of reliable equipment can substantially reduce the relative frequency of malfunctions.

2.1.1 *Equipment failure*

Equipment failure has a different effect depending upon the configuration used. In the case of multi-line switching, the "operate time" of the switching cycle can be governing (see Report 137). Effects of single-line transfer systems depend on the type used: single-line switching or single-line combining.

2.1.2 *Single-line switching*

In the case of single-line switching, operate time due to equipment malfunction consists of that necessary for fault recognition and transfer. Additional time — depending on equipment design — may be necessary to accommodate circuits for "false switching inhibit" functions. Fault recognition times, including loss of continuity pilot, can generally be held to less than 1 ms. Overall operate time, just slightly in excess of this, is also practical when used in conjunction with a 10 μ s electronic switch. (Service interruptions caused by fades correspond to the transfer time of the switching element.)

2.1.3 *Single-line combining*

Single-line combining substitutes a baseband (or sometimes an intermediate frequency) combiner in place of the switch element. For fade situations, there is no outage since there is essentially no transfer time ("make-before-break" switch configurations can achieve a similar effect) (see also Report 137).

Occurrence of a fault, however, could result in a temporary change (or even loss) of the combined output signal level, dependent upon the relative noise levels of the two channels at the instant of failure. Restoration of the signal level takes place after a duration governed by the fault recognition time and the time required by the combiner to cut off the faulty channel. Again, for electronic combiners, this operate time is generally less than 1 ms; for mechanical-type combiners, about 3 ms.

3. Equipment maintenance

Periodic maintenance checks performed on multi-line or single-line systems necessitate manual operation of the system switching elements. Outage times associated with these checks correspond to the transfer times of the switching elements. Since the frequency of maintenance checks is generally greater than the occurrence of faults, primary consideration must once again be given to transfer time of switching elements as opposed to fault recognition times and transmission times of control signals.

4. Effects of interruptions on service

Current documentation relating switching interruptions and effects on transmission requirements suggests that the time elapsing between the start of each change (primarily, loss of signal) and service restoration (in amplitude and phase) can be characterized by the following maximum limits:

- 1 ms to preclude errors in 50-baud amplitude- or frequency-modulation telegraphy;
- 50 to 100 μ s to preclude errors in 1200-baud data transmission;
- 40 ms to avoid seizure of common equipment in toll dialling offices, although 20 ms has also been reported as a maximum for certain transmissions and signalling systems;
- 10 μ s has been quoted as a usable interruption limit without loss of television synchronization and 0.5 s to 2 s as “noticeable” to viewers. These figures are given only for information — more precise figures, relevant to the switching of television and sound programme circuits, are studied by the CMTT.

5. Summary Tables

Tables I, II and III present:

- the relative frequency of occurrence;
- outage time determinant;
- outage time;
- effect on system performance associated with various forms of degradation;

for multi-line (I), single-line with switch (II) and single-line with combiners (III) switching systems.

TABLE I – Multi-line systems

Form of degradation	Frequency of occurrence	Determinant of outage time	Range of outage time	Effect on transmission			
				Data at		Telephony	Television
				50 bauds	1200 bauds		
1	2	3	4	5	6	7	8
1. Fade	High	Transfer time of switch element	2 ms mechanical switch 10 μ s electronic switch	Possible errors None	Outage None	None None	Loss of line synchronism None
2. Equipment failure	Low	System switching operate time ⁽¹⁾	10 ms to 40 ms	Outage	Outage	See § 4	Loss of synchronism
3. Power failure	Low/ medium	Start-up time of auxiliary power source	10 s or more	Outage	Outage	Outage	Outage
4. Maintenance (Manual switching)	Medium	Transfer time of switch element	2 ms mechanical switch 10 μ s electronic switch	Possible errors None	Outage None	None None	Loss of line synchronism None

⁽¹⁾ Includes fault recognition, control transmission, propagation and transfer times.

TABLE II – *Single-line systems with switches*

Form of degradation	Frequency of occurrence	Determinant of outage time	Range of outage time	Effect on transmission			
				Data at		Telephony	Television
				50 bauds	1200 bauds		
1	2	3	4	5	6	7	8
1. Fade	High	Transfer time of switch element					
2. Equipment failure	Low	System switch operate time ⁽¹⁾	3 ms electronic switch 1 ms electronic switch	Possible errors None	Outage Outage	None None	Loss of line synchronism Loss of line synchronism
3. Power failure	Low/ medium	Start-up time of auxiliary power source					
4. Maintenance	Medium	Transfer time of switch element					

⁽¹⁾ Includes fault recognition time and transfer time.

TABLE III – *Single-line systems with combiners*

Form of degradation	Frequency of occurrence	Determinant of outage time	Range of outage time	Effect on transmission			
				Data at		Telephony	Television
				50 bauds	1200 bauds		
1	2	3	4	5	6	7	8
1. Fade	High	(No outage time)		None	None	None	None
2. Equipment failure	Low	Combined fault recognition and cut-off time	0 to 3 ms mechanical switch 0 to 1 ms electronic switch	Possible errors None	Possible outage Possible outage	None None	Possible loss of line synchronism Possible loss of line synchronism
3. Power failure	High	Transfer time of switch element					
4. Maintenance	Medium	Transfer time of switch element					

REPORT 787-1

**PREFERRED METHODS AND CHARACTERISTICS FOR THE SUPERVISION
AND PROTECTION OF DIGITAL RADIO-RELAY SYSTEMS ***

(Study Programme 12J/9)

(1978-1982)

1. Introduction

In this Report, the broad principles of methods and characteristics for supervision and protection are outlined.

2. Methods and characteristics of supervision**2.1 Link quality monitoring**

In digital radio-relay systems, continuous monitoring of channel quality is necessary for initiating protection switching under conditions of channel failure. However, under an intermittent failure mode condition that results in high error ratio, or frame loss persisting for a few microseconds, initiation of a protection switch, in a multi-line protection switching system, would not appear to be practical or desirable. It is, however, considered desirable to provide the capability to detect interruptions of such short duration and to advise maintenance personnel that such a condition exists. Information should also be provided on the cause of the intermittent condition and its location. Corrective maintenance action may then be initiated when the condition is deemed to be unacceptable. It is desirable that the monitoring system should not rely on information contained in the traffic signal.

In digital cable line systems a redundant level is generally added. This redundancy can be used for bit error monitoring, the number of violations of the coding rules being a measure of the bit error ratio. However, such techniques are not convenient for use in digital radio systems as they make inefficient use of the radio spectrum as recognized in Considering (f) of Study Programme 12H/9.

In Report 613, several methods of continuously monitoring the bit error performance over a radio section are described.

2.2 Alarms

Monitoring of the radio channel may be achieved by providing:

- equipment alarms for either individual items or for groups of equipment, and
- system alarms and indications.

Equipment alarms normally give local visual indications associated with the equipment itself, and facilities usually exist to enable alarms to be extended to a staffed point.

System alarms for the radio system comprise traffic fail and channel fail alarms which are extended to a control point.

2.3 Supervisory indications

In addition to system alarms, visual indications of the status of the protection switching equipment are necessary. These indications are required at the terminal station where the protection switching equipment is housed. They may also be extended to the radio system control point.

2.4 Service channels

The proposals to provide service channels to carry the supervision and control signals (SC) are of three types:

- Transmitting by inserting SC signals into the main signal pulse sequence.
- Transmitting separately from the main signal pulse sequence. This includes using additional modulation of the main carrier.
- Transmission means other than the main signal path.

* A general maintenance philosophy for digital networks has been described in CCITT Recommendation G.704. Administrations are advised to study this Recommendation and its application to digital radio systems and provide comments and contributions.

For supervising and controlling intermediate repeater stations, insertion and detection of the SC signal must be accomplished at each station. The required capacity of the in-band service channel will be a function of the number of control and supervisory signals, their speed of transmission and the number of engineering speaker circuits. These factors will depend on those aspects of system design arising from the service techniques and philosophy of the administration concerned. The capacity so required would be a factor in determining which of the methods would be the most appropriate to adopt.

The second method proposed above can be suitable in some cases for the transmission of small capacity SC. In particular, additional FSK or FM modulation of the main carrier has been employed as described, for instance, in [Kuwabara *et al.*, 1977].

2.5 *Radio channel identification*

Generally, digital radio-relay systems are designed to have a large fade margin in order to cope with multipath fading or rainfall attenuation. Under normal propagation conditions, thermal noise is negligibly small. Interference from cross-polarized channels or from different routes may be larger than thermal noise. In such a case, when the wanted signal is lost at the receiver output due to transmitter failure, etc., there may be some situations where one of the predominant interfering signals is received and demodulated in place of the wanted signal. To avoid such wrong reception, the identification of the wanted signal from these possibly interfering sources is necessary.

One method of identification would be to use in the case of bit insertion, different frame synchronization pulse sequences on each radio channel.

3. **Methods and characteristics of protection**

3.1 *General*

Protection switching equipment is characterized mainly by:

- the service to be provided (improvement of availability or quality, switching time, etc.),
- the point at which switching is carried out,
- the switching criterion to be taken into account,
- the transmission mode of the switching instructions.

3.2 *Need for protection*

The main purpose of protection switching is to improve circuit availability by switching to available standby channels in the event of equipment malfunction or failure. The additional benefit of some degree of protection against outages caused by frequency selective fading, may result in systems employing multi-line protection switching. Space diversity protection may also be used to improve system performance during these poor propagation conditions.

Dual route diversity protection facilitates the use of greater hop lengths in frequency bands where attenuation due to precipitation becomes appreciable.

3.3 *Types of protection arrangements*

Single route systems may be protected in one of three ways:

- multi-line and single line switching with a dedicated protection channel,
- multi-line and single line switching with a non-dedicated protection channel,
- space diversity operation.

In theory, the switch may operate at RF, IF or baseband, but in practice, baseband switching is preferred since this may protect the complete channel from input port to output port with a minimum duplication of equipment outside the switched path.

Dual route protection involves the use of switching at the terminal receiver. It may be necessary to equalize the difference in transmission time between the path lengths of each route, in order that the signal on both routes may be aligned at the instant of changeover.

3.4 *Factors influencing the choice of switching criteria*

The switching criteria are influenced by the main role of the protection switching.

If switching is used to protect against equipment failure, relatively slow recognition of the switching criteria, transmission of the switching instructions and switch changeover can be tolerated. This will result in loss of synchronization downstream, and provision may be required to minimize the number of interruptions to service caused by these switching operations.

If switching is used to improve performance during poor propagation conditions, this would require the rapid recognition of switching criteria and it is desirable to switch to a stand-by channel without loss of synchronization. It should be noted that the addition or loss of a bit, due for instance to switching without prior arrangements to ensure coincidence or to a spurious impulse affecting the timing, may completely desynchronize the downstream transmission chain and cannot be considered an isolated error. This phenomenon affects system performance and should be studied further. To realize this, the following should be considered:

3.4.1 Synchronization of bit and frame pulses between either:

- all channels, or
- the stand-by and the working channel experiencing a BER exceeding the switch threshold, depending on the length of time required to establish frame synchronization and the length of time between the experiencing of the threshold BER and the misframe BER.

3.4.2 Static equalization of the difference in steady transmission time between the stand-by channel and the working channels.

3.4.3 Dynamic equalization of the fluctuations in transmission time between the stand-by channel and the working channel or working channel during multipath fading.

4. Conclusion

This Report has discussed some principles associated with methods and characteristics for the supervision and protection of digital radio-relay systems. Many of these aspects are related to the service policies of each administration and further work will be required before the preferred methods and characteristics can be established.

REFERENCES

KUWABARA, M., YAMAMOTO, H., YOKOYAMA, S. and TAGASHIRA, Y. [15 June, 1977] Design and performance of 20 GHz digital radio repeater. IEEE International Conference on Communications (ICC '77), Chicago, Ill., USA, Conf. Rec., Vol. 3, Session 40: High capacity microwave systems, 40.4-93-40.4-97.

RECOMMENDATION 398-3

MEASUREMENTS OF NOISE IN ACTUAL TRAFFIC OVER RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

(1959-1963-1966-1970-1974)

The CCIR,

CONSIDERING

- (a) that measurements by means of a generator producing white noise (according to Recommendation 399) are only possible when the radio-frequency channel is not carrying traffic and that channels used for these measurements can lie within the frequency range occupied by telephone channels *;
- (b) that systems carrying multi-channel telephony cannot be withdrawn from service at will for measurement;
- (c) that protection channels are not always available for maintenance purposes;
- (d) that maintenance measurements of the total noise (thermal and intermodulation noise) are used for determining the quality of a system and must be made while the system is carrying traffic;
- (e) that it is convenient to place the channels used for this kind of measurement outside the total bandwidth of the multiplex signal;
- (f) that, when these measuring channels are located outside the total multiplex signal band, they should be positioned as near the limits of the total signal band as possible, to measure the intermodulation products due to the non-linearity of the system;
- (g) that, on the other hand, to facilitate and to minimize the cost of filter construction, the measuring channels should not be positioned too near these limits;

* In this Recommendation the words "frequency range occupied by telephone channels" are intended to mean the part of the baseband actually transmitted, when a system is used below its maximum capacity.

(h) that measurements in channels above the multiplex signal band are generally more sensitive to changes of thermal and intermodulation noise in the radio-frequency and intermediate-frequency circuits of the equipment, whereas measurements in channels below this band are generally more sensitive to changes in the modulators and demodulators;

(j) that it is usually necessary to use band-stop filters at the input of a system, to minimize noise on the incoming circuit in the bands occupied by the measuring channels and that it will be necessary to specify the minimum performance of these filters, both in the stop band of these filters and at the edges of the total multiplex signal band;

(k) that the specification of frequencies, situated about 10% above the upper limit of the total multiplex signal band for continuity pilots (Recommendation 401), suggests the use of the same frequencies as centre frequencies for the measuring channels. On the other hand, measuring equipment with a heterodyne receiver, which is independent of the pilot and can also be used for measurements in accordance with Recommendation 399, will suffer interference from a pilot transmitted during the measurement, so that a shift of the measuring channel will be necessary;

(l) that the following factors have to be taken into account when the centre frequency of noise measuring channels is shifted in accordance with § (k):

- the difference in frequency between the measuring channel and the total multiplex signal band should be as small as possible (§ (f)),
- intermodulation products between the pilot and the lower end of the baseband should not fall within the measuring channel,
- in view of spurious responses which might occur with crystal band-stop filters, the measuring channel should be shifted upwards when use is made of these;

(m) that it may be of use to combine the evaluation of the power of the continuity pilot with the measurement of the noise around it;

(n) that it may be of use to employ the measuring channels outside the multiplex signal band also for measurements with white noise, according to Recommendation 399,

UNANIMOUSLY RECOMMENDS

1. that noise occurring in radio links while actual traffic is being carried should be measured at the output of the system in relatively narrow bands situated outside (below and/or above) the total multiplex signal band;

2. that the centre frequencies of the noise measuring bands should be those shown in Table I:

- the centre frequencies given in column (a) should preferably be used in conjunction with the measuring equipment considered in § (m);
- the centre frequencies given in column (b) are for use with measuring equipment similar to that described in Recommendation 399 (also considered in § (n));

3. that the attenuation of the band-stop filters at the input of the system should exceed 50 dB over a minimum frequency band of $\pm (0.005 f + 2)$ kHz * (f being the centre frequency in kHz of the measuring channel). The additional attenuation, caused by the insertion of the band-stop filters at the lower and at the upper edges of the total multiplex signal band, shall not exceed 0.3 dB referred to the additional attenuation caused in the centre of the multiplex signal band;

4. that the effective bandwidth of the filters in the receiving equipment should be small enough for use with the input band-stop filter mentioned above;

5. that, in all cases where different frequency bands are used, or where there are differences between the measurement techniques, special agreements should be made.

Note. – In certain telephone channels and in combinations of them, harmonic distortion may be produced, which may make it necessary to leave these channels disconnected, e.g. if the second or third harmonics coincide with the centre frequencies of the noise measuring channels.

* Except when the centre frequency is 10 kHz; the minimum frequency band is then 10 ± 1 kHz.

TABLE I

System capacity (number of channels)	Limits of band occupied by telephone channels (kHz)	Frequency limits of baseband ⁽¹⁾ (kHz)	Centre frequencies (<i>f</i>) of noise measuring channels (kHz)		
			Below	Above	
				(<i>a</i>)	(<i>b</i>)
24 60	12-108 12-252 60-300	12-108 12-252 60-300	10 10 50	116 or 119 304 331	(²) (²) (²)
120	12-552 60-552	12-552 60-552	10 50	607 607	600 600
300	60-1300 64-1296	60-1364	50	1499	1549
600	60-2540 64-2660	60-2792	50	3200	3250
960	60-4028	60-4287	50	4715	4765
900	316-4188	60-4287	270	4715	4765
1260	60-5564 60-5636	60-5680	50	6199	6300
1200	316-5564	60-5680	270	6199	6300
1800	312-8204 316-8204	300-8248	270	9023	9073
2700	312-12 388 316-12 388	300-12 435	270	13 627	13 677

⁽¹⁾ Including pilots or frequencies which might be transmitted to line.

⁽²⁾ These values will be indicated after more practical experience has been gained.

RECOMMENDATION 399-3

MEASUREMENT OF NOISE USING A CONTINUOUS UNIFORM SPECTRUM SIGNAL ON FREQUENCY-DIVISION MULTIPLEX TELEPHONY RADIO-RELAY SYSTEMS

(1956-1959-1963-1966-1974-1978)

The CCIR,

CONSIDERING

- (*a*) that it is desirable to measure the performance of radio-relay systems for frequency-division multiplex telephony under conditions closely approaching those of actual operation;
- (*b*) that a signal with a continuous uniform spectrum (white noise) has statistical properties similar to those of a multiplex signal, when the number of channels is not too small;
- (*c*) that the use of a signal with a continuous uniform spectrum to measure the performance of such radio-relay systems is already widespread;
- (*d*) that it is necessary to standardize the frequencies and bandwidths of the measuring channels to be used for such tests;
- (*e*) that it is necessary to standardize the minimum attenuation and the bandwidth of the stop filters which may have to be used in the white-noise generator;
- (*f*) that the CCITT has indicated, for the planning of telephone circuits, a mean value of speech power in a telephone channel to be taken into consideration during the busy hour (CCITT Recommendation G.223, Vol. III, Fascicle III.2),

UNANIMOUSLY RECOMMENDS

1. that the performance of frequency-division multiplex radio-relay systems should be measured by means of a signal of a continuous uniform spectrum in the frequency band used for the telephone channels;
2. that the nominal power level of the test signal with a uniform spectrum should be in accordance with the conventional load, specified in CCITT Recommendation G.223. If applied at the point of interconnection of the system corresponding to T' of CCIR Recommendation 380, the absolute power levels of interest are shown in column 4 of Table I;
 - 2.1 that the sending equipment should be capable of providing, at the output of an inserted band-eliminating filter, a loading level at least up to +10 dB relative to the nominal power level as defined above;
 - 2.2 that, within the bandwidth corresponding to the baseband of the system under test, the r.m.s. voltage of the white-noise spectrum measured in a band of about 2 kHz should not vary by more than ± 0.5 dB. This degree of spectrum regularity should be met in the level range up to +6 dB relative to the power level indicated in Table I, column 4. This is to ensure reliable calibration of the receiver by means of the test signal;
 - 2.3 that the white-noise test signal should be available at the output of the sending equipment with a peak factor of about 12 dB with respect to the r.m.s. value;

TABLE I

(1)	(2)	(3)	(4)
Number of telephone channels	Relative power level at point T' (dBr)	Level of the conventional load (dBm0)	Nominal power level of the test signal at point T' (dBm)
60	-36	6.1	-29.9
120	-36	7.3	-28.7
300	-36	9.8	-26.2
600	-36 -33	12.8	-23.2 -20.2
960	-36 -33	14.8	-21.2 -18.2
1260	-33	16.0	-17.0
1800	-33	17.5	-15.5
2700	-33	19.3	-13.7

3. that the nominal effective cut-off frequencies (the cut-off frequencies of hypothetical filters having ideal square cut-off characteristics and transmitting the same power as the real filters) and tolerances, for the band-limiting filters proposed for the various bandwidths of systems to be tested, should be as specified in Table II. (To reduce the number of filters required, compromises have been made between the nominal effective cut-off frequency and the system bandwidth-limiting frequency in some cases. The tolerances ensure that consequent calibration errors do not exceed ± 0.1 dB and errors in measurement of intermodulation noise do not exceed ± 0.2 dB, assuming system pre-emphasis conforming to Recommendation 275) *;

* Study Group 9 of the CCIR has noted that the CCITT refers to a pre-emphasis of 10 dB and understands that this is valid for cable systems only.

TABLE II

System capacity (channels)	Limits of band occupied by telephone channels (kHz)	Effective cut-off frequencies of band-limiting filters (kHz)		Frequencies of available measuring channels (kHz)
		High-pass	Low-pass	
60	60-300	60 ± 1	300 ± 2	70 270
120	60-552	60 ± 1	552 ± 4	70 270 534
300 {	60-1300 64-1296	60 ± 1	1296 ± 8	70 270 534 1248
600 {	60-2540 64-2660	60 ± 1	2600 ± 20	70 270 534 1248 2438
960 {	60-4028 64-4024	60 ± 1	4100 ± 30	70 270 534 1248 2438 3886
900	316-4188	316 ± 5	4100 ± 30	534 1248 2438 3886
1260 {	60-5636 60-5564	60 ± 1	5600 ± 50	70 270 534 1248 2438 3886 5340
1200	316-5564	316 ± 5	5600 ± 50	534 1248 2438 3886 5340
1800 {	312-8120 312-8204 316-8204	316 ± 5	8160 ± 75	534 1248 2438 3886 5340 7600
2700 {	312-12 336 316-12 388 312-12 388	316 ± 5	$12\ 360 \pm 100$	534 1248 2438 3886 5340 7600 11700

3.1 that the discrimination of a low-pass filter should be at least 20 dB at a frequency more than 10% above nominal cut-off and at least 25 dB at frequencies more than 20% above nominal cut-off. The discrimination of a high-pass filter should be at least 25 dB at frequencies more than 20% below nominal cut-off;

3.2 that, to limit discrimination against measuring channels, the spread of losses introduced by any pair of high-pass and low-pass filters should not exceed 0.2 dB over a range of frequencies which includes the outer measuring channels;

4. that values of the provisional characteristics for the discrimination in each stop band at the output of a sending equipment are given in Table III; these characteristics are intended to apply over a temperature range from 10 °C to 40 °C;

TABLE III

Centre frequency f_c (kHz)	Bandwidth (kHz), in relation to f_c , over which the discrimination should be at least				Bandwidth (kHz), in relation to f_c , outside which the discrimination should not exceed	
	70 dB	55 dB	30 dB	3 dB	3 dB	0,5 dB
70	± 1.5	± 2.2	± 3.5	—	± 12	± 18
		± 1.7	± 2.0	—	± 5	± 10
270	± 1.5	± 2.3	± 2.9	—	± 8	± 24
534	± 1.5	± 3.5	± 7.0	—	± 15	± 48
1248	± 1.5	± 4.0	± 11.0	—	± 35	± 110
2438	± 1.5	± 4.5	± 19	—	± 60	± 220
3886	± 1.5	± 15.0	± 30.0	—	± 110	± 350
	± 1.5	± 1.8	± 3.5	± 8.0	± 12	± 100
5340	± 1.5	± 2.2	± 4.0	± 8.5	± 14	± 150
7600	± 1.5	± 2.4	± 4.6	± 9.5	± 16	± 200
11 700	± 1.5	± 3.0	± 7.0	± 11.0	± 20	± 300

Note 1. — The discrimination values quoted are relative to the minimum attenuation of the band-stop filters within the baseband frequency range defined by high-pass and low-pass filters in Table II. This implies that a band-stop filter suitable for measurements on one system is not necessarily suitable for measurements on a system of larger bandwidth.

Note 2. — The characteristics recommended for the filters 70 kHz to 2438 kHz inclusive are based on coil-capacitor type filters. Those characteristics recommended for the filters at 5340 kHz and above are based on crystal-type filters. Optional characteristics are recommended for the 3886 kHz filter to permit a choice of design between a coil-capacitor type or crystal-type filter.

Note 3. — The design of the receiver selectivity of 3886 kHz should be related to the characteristic of the crystal-type band-stop filter.

Note 4. — Due to spurious resonances, narrow spikes of discrimination may occur in the upper passband of crystal-type band-stop filters. When resonators are operated in a higher harmonic mode, narrow spikes can also appear in the lower passband. Those spikes of about 10 dB peak attenuation within 1 to 5 kHz bandwidth are admissible because they do not affect the measuring accuracy.

5. that, when the receiving equipment is connected directly to a sending equipment provided with band-stop filters which only just meet the requirements of § 4, the ratio of the noise power indicated by the receiving equipment when the band-stop filter is by-passed, to that indicated when the filter is in circuit, should be a minimum of 67 dB; this requirement applies when a conventional load is applied. The minimum effective bandwidth of the receiver should be 1.7 kHz. The maximum reading of absolute noise power arising from leakage given by a receiver of 1.74 kHz effective bandwidth and which just meets the foregoing leakage requirement, is -85.6 dBm0p ;

6. that additional measuring channels may be provided by agreement between the administrations concerned.

Note. — An overall accuracy of $\pm 2 \text{ dB}$ or better, is assumed for the measurement of radio-relay systems in operation. Attention is drawn to CCITT Rec. G.228, Annex A and Annex B, which discuss the method of measurement and the measuring accuracy.

REPORT 612-1

MEASUREMENTS OF EQUIPMENT NOISE PERFORMANCE OF ANALOGUE RADIO-RELAY SYSTEMS

(Question 2/9 and Study Programme 2C/9)

(1974-1978)

1. Introduction

This Report is concerned with analogue line-of-sight radio-relay systems for television and telephony having a capacity of more than 60 telephone circuits and operating on frequencies below about 10 GHz.

The noise requirements for radio-relay links are given in Recommendations 393 (telephony) and 555 (television) in terms of the hypothetical reference circuit. In Note 7 of Recommendation 393 designers are asked to indicate the assumptions they have made regarding a number of performance characteristics of radio-relay links incorporating their equipment.

Some of the assumptions that have to be made apply to the equipment alone, whilst others are concerned with the overall planning of a route. However, since equipment performance and system planning are often dealt with by different organizations and since any one type of equipment may be used on routes having a wide range of conditions it is desirable to have an agreed method of expressing the noise performance of the equipment in terms which can be used by system planners.

The terms should be so expressed that equipment designers can test their equipment under conditions which simulate a link having the stated characteristics. Information derived in this way could then be used by system planners for overall system design. However, it should be noted that the tests proposed in this Report are not comprehensive and that tests of other equipment parameters are also relevant to system design. For example, this Report does not deal with intermodulation noise, such as may arise in feeders, nor with distortion noise as may arise during periods of multipath fading. In addition, the calculations which follow do not allow for possible changes in receiver noise factor with changes in carrier input level nor for other noise sources, such as co-channel interference or adjacent channel interference.

2. Assessment of noise powers in radio equipment under simulated path conditions

The total noise power in a telephone channel, measured or calculated, includes the following three components:

N_1 : residual noise, independent of path attenuation and loading

N_2 : thermal noise for a defined path attenuation P dB

N_3 : intermodulation noise

and this Report proposes a method whereby six-hop noise contributions can be determined for a variety of different radio-relay equipments.

3. Proposed measuring arrangements

3.1 Number of repeater sections (hops)

It is desirable that the simulated radio-relay system should represent one direction of transmission of a homogeneous section of the hypothetical reference circuit, i.e. it should correspond to a baseband-to-baseband section whose length is one ninth of the 2500 km hypothetical reference circuit.

It is recommended that the simulated homogeneous section of the hypothetical reference circuit should comprise six repeater sections ("hops"). *

The tests should permit the assessment of the noise arising in equipments which include baseband modulation and demodulation, such as terminal equipments and demodulating repeaters; as well as the assessment of the noise arising in non-demodulating repeaters. This will assist the planning of real radio-relay systems where the number of hops between terminal stations may differ from that assumed here.

3.2 Simulated path attenuation

The simulated path attenuation per hop is defined as the insertion loss P dB provided between the point where a transmitter is connected to the radio-frequency multiplex equipment (circulators, filters, etc.) and the corresponding point for the receiver. It will usually be necessary to include some radio-frequency multiplexing equipment in the test arrangement and its insertion loss should be considered as forming part of P .

3.3 Measurements

Noise power ratio measurements on the simulated links should be made at several baseband frequencies using white noise test signals and equipment in accordance with Recommendation 399. The measured noise power ratio should be converted into weighted noise power at a point of zero relative level (pW0p).

* This Report is concerned only with systems operating on frequencies below about 10 GHz; the composition of homogeneous sections of the hypothetical reference circuit for systems operating on frequencies above 10 GHz is a subject for further study.

3.3.1 With the simulated system loaded with a white noise test signal at a level of either $(-1 + 4 \log N)$ dBm or $(-15 + 10 \log N)$ dBm (see Note 9 of Recommendation 393 and also Recommendation 399), each of the simulated radio-frequency paths should be adjusted to have an attenuation of P_0 dB such that the greatest weighted noise level (A pW0p) in any measuring channel at the end of the homogeneous section is 833 pW0p, that is, the noise power appropriate to each of the nine homogeneous sections of the hypothetical reference circuit in accordance with Recommendation 393. The attenuation P_0 dB should be noted.

3.3.2 With the path attenuations remaining at P_0 dB, remove the white noise test signal and measure the remaining weighted noise power which will be B pW = $N_1 + N_2$; note the value of B .

3.3.3 With no white noise loading, increase the attenuation of all paths by Q dB and measure the weighted noise level C pW = $N_1 + RN_2$ where $R = 10^{0.1Q}$. Note the value of $(P_0 + Q)$ dB.

The information derived from § 3.3.1, 3.3.2 and 3.3.3 can then be used to determine N_1 , N_2 and N_3 as shown in § 4.

3.3.4 Further information concerning the equipment characteristics at differing received radio-frequency signal levels and of the residual noise can be obtained as follows: with all path attenuations restored to P_0 dB and with the white noise test signal applied, change the attenuation of the last path, i.e. that immediately preceding the receive terminal, from P_0 dB to $(P_0 + S)$ dB. Where a common radio-frequency attenuator is used for all six paths, it will be necessary to transfer the modulator from the transmitter of the first path to that of the last path. A suitable choice of values for S should be made from the range -20 dB to $+40$ dB and the values chosen should be stated. The noise level in each measuring channel should be measured and noted, for each chosen value of S . Particular note should be made of the values of $(P_0 + S)$ dB which result in (1) a weighted noise level of 47 500 pW, and (2) an unweighted level of 10^6 pW at a point of zero relative level. The latter value may not be achievable for values of S of 40 dB or less, in which case the unweighted noise level for $S = 40$ dB should be noted.

When the radio-frequency path attenuation is decreased and with no white noise loading, the noise in a measuring channel tends towards the residual noise of one hop plus one modulator/demodulator.

4. Determination of N_1 , N_2 and N_3 for a six-hop system

From § 3.3.1, 3.3.2 and 3.3.3 above:

$$A = 833 \text{ pW} = N_1 + N_2 + N_3$$

$$B = N_1 + N_2$$

$$C = N_1 + RN_2 \text{ where } R = 10^{0.1Q}$$

and,

$$N_1 = \frac{RB - C}{R - 1}$$

$$N_2 = \frac{C - B}{R - 1}$$

$$N_3 = A - B.$$

If appropriate, the tests A and B should be repeated, with IF interconnection of the modulator and demodulator, to permit determination of N_1 and N_3 for the modulating and demodulating equipment alone.

5. Summary of information to be recorded

The following test results should be obtained:

- Value of P_0 in decibels – see § 3.3.1. This value is the maximum gross path attenuation, with equal and simultaneous fading on all paths, over which the simulated link will provide a noise performance of 3 pW/km. It should be noted that P_0 does *not* correspond to the free-space value of path attenuation. System planners should make an allowance for feeder intermodulation noise, for interference noise and for fading.
- Value of $(P_0 + Q)$ dB and Q dB, where Q dB is a value chosen to enable C to be determined – see § 3.3.3 and 4.
- Value for N_1 , N_2 and N_3 for the six-section system – see § 4.
- Value for N_1 and N_3 for the modulator and demodulator modems – if required – see § 4.
- Value for S dB, together with corresponding baseband noise levels – see § 3.3.4.

6. Measurements of noise performance for television

The simulated radio-relay system should be identical to the system used to define the components of overall noise power in a telephone channel.

It should represent one direction of transmission and should be comprised of six sections; i.e. it should correspond to 1/9 of a 2500 km hypothetical reference circuit.

The path attenuation between the transmitter and the receiver of the simulated radio-relay system should be adjusted to have a value of P_0 , such that the ratio (in dB) of the peak-to-peak signal, excluding synchronizing pulses, to r.m.s. value of the weighted noise is:

$$(X + 4) + 10 \log 9 = X + 13.5 \text{ dB},$$

where:

$(X + 4)$ is taken from Recommendation 555.

The attenuation P_0 dB should be noted.

The total noise voltage at the output of a video channel will be:

$$U = \sqrt{U_1^2 + U_2^2}$$

where:

U_1 voltage of residual noise independent of path attenuation,

U_2 voltage of thermal noise determined by path attenuation.

The values of U_1 and U_2 can be determined in accordance with the measurement of weighted noise power components N_1 and N_2 as given in § 3 and 4.

In defining noise components the voltage at the video channel output $U = \sqrt{U_1^2 + U_2^2}$ must be measured after establishing the path attenuation P_0 dB.

Additional attenuation Q dB is introduced and the output voltage is measured again with a path attenuation of $P_0 + Q$ dB:

$$U_Q = \sqrt{U_1^2 + RU_2^2}$$

where:

$$R = 10^{0.1Q}$$

Thermal noise voltage U_2 controlled by path attenuation may be determined from the expression:

$$U_2 = \sqrt{\frac{U_Q^2 - U^2}{R - 1}}$$

Similarly, the voltage of residual noise independent of path attenuation will be:

$$U_1 = \sqrt{\frac{RU_Q^2 - U^2}{R - 1}}$$

7. Conclusion

Information in the form as suggested above will make available to system planners some aspects of the noise performance of equipment in which they are interested. It should be noted that the simulated system proposed above is a basic uni-directional system comprising six hops and is not subject therefore to the potential interference arising within the system due to the presence of other radio-frequency channels operating in the same frequency band.

BIBLIOGRAPHY

CCIR Documents

[1974-78]: 9/72 (U.S.S.R.).

REPORT 613-2

BIT ERROR PERFORMANCE MEASUREMENTS FOR DIGITAL RADIO-RELAY SYSTEMS

(Study Programme 12H/9)

(1974-1978-1982)

1. Introduction

This Report deals with error ratio measurements in digital radio-relay systems, both under out-of-service conditions and under normal traffic loading.

Main items considered in this Report are:

- the bit error performance assessment for a complete digital radio-relay system, or for a single regenerative section of it;
- the methods for out-of-service error performance measurements when the entire transmission channel is available for sending a known test sequence;
- the methods for in-service error detection and performance evaluation. The suitability of such methods depends upon the operational requirements of digital radio-relay systems, i.e. protection switching operation, maintenance, recording, etc. The performance recording may be required on a single regenerative section or possibly on the whole system.

2. Basic criteria for bit error performance evaluation

The parameter used to describe the digital system performance is the bit error probability, that is the probability of incorrect reception of a single bit. Experimentally the most-used parameter is the so-called error ratio, defined as:

$$\text{Error ratio} = \frac{N_e}{N_t} = \frac{N_e}{Bt_0} \quad (1)$$

where:

N_e : number of bit errors in time interval t_0

N_t : total number of transmitted bits in the time interval t_0

B : bit rate of binary signal at the point where the measurement is performed

t_0 : measuring time interval (error counting time).

When the error generation process is random and stationary and the errors are counted in a sufficiently long interval t_0 , the expression (1) can give an estimate of the error probability. The accuracy of this estimation increases as N_e increases, but practical requirements on the measuring time interval usually limit the values of N_e .

The minimum acceptable value of N_e seems to be about 10 and in this case the true error probability is contained in a range equal to $\pm 50\%$ around N_e/N_t with a confidence coefficient of 90%.

The data required in the basic formula (1) may be obtained by means of different procedures. In particular, measurement could be made of:

- the number of errors detected in a fixed time interval t_0 ;
- the time interval required to detect exactly N_e errors (or, more conveniently, the number N_t of bits transmitted in such an interval).

Each of the described procedures to measure the bit error ratio has specific advantages so the procedure to be preferred should be chosen in relation to the application.

The first criterion presents the advantage that the measured data can be expressed easily in figures of availability.

The second criterion presents the advantages of:

- a nearly constant measurement accuracy for any value of the error ratio;
- a minimum time to perform the measurement with the required accuracy.

In certain cases it seems more convenient to measure the bit error ratio over a sufficiently large number of 1 s time intervals following each other. *

* The results of sufficiently extensive bit error ratio measurements over each 1 s time interval make the calculation of availability factor (in accordance with Recommendation 557) and bit error ratio performance (in accordance with Recommendation 594) easy. These calculations are readily provided by using the computer technique.

Transmission errors may also occur in a burst mode, i.e. in groups of short duration with relatively high error frequency, separated by much longer intervals with a much lower error rate. The occurrence probability of such a phenomenon, the statistical characteristics of it (burst duration, error density during the burst, low-error interval duration, etc.), and the effect on the services carried by the digital link, in particular any framing structures which might be necessary, require further study to arrive at a definition of a suitable performance parameter.

3. Error performance measurement under out-of-service conditions

Most measurement methods and equipments use a pseudo-random test sequence, obtained by a shift-register generator [Golomb, 1964]. Main characteristics of such a sequence, when obtained by a register of n bits, and when the structure of the generator is the best one, are:

- a repetition period equal to $2^n - 1$;
- the presence of every possible sub-sequence made up by combinations of n bits, each sub-sequence once in the period; *
- a good balance among the sets of sub-sequences of lengths lower than n .

To have a reliable measurement on the intersymbol interference effects, the register length n should be much greater than, or equal to, the number of pulses which are affected by the channel response to a single pulse. As this requirement depends on characteristics of the transmission channel which are often unknown, a conservative value of n should be chosen.

Another way of checking the suitability of the test sequence could be obtained by comparing the error rates measured with different register lengths.

The coding operations should also be considered, as they are likely to modify the symbol sequence in the modulated signal. On the other hand the increase in detected errors due to decoding or self descrambling operations must also be taken into account in the evaluation of the measurement accuracy.

The test sequence period, equal to $(2^n - 1)$, gives rise to a frequency spectrum with discrete components and with a fundamental frequency $S/(2^n - 1)$, where S is the line symbol rate. Care must be taken to ensure that the test sequences applied to the input of the digital modulator do not generate undesirable RF-spectra, especially when making interference measurements.

Note 1. — As a test pattern, at least for first- and second-order digital systems, the CCITT recommends the use of pseudo-random sequence with the repetition period $2^{15} - 1 = 32\,767$ bits (CCITT Recommendation O.151).

Note 2. — In carrying out measurements on digital paths by means of a test pattern, it is important to distinguish between error bursts and slip, since they may have a different effect on the digital multiplex equipment. Further study is required on the effect of slip on the operation of digital multiplex equipment.

4. In-service bit error ratio measurements

The main problem in this case is the detection of bit errors in the unknown digital pulse stream. Some methods for error detection are described, which make use of the "a priori" knowledge of some characteristics of the received signal. Other problems are the measurement duration and the error ratio estimation accuracy.

The measurement duration may have to be limited by the following factors:

- necessity of an immediate action (for instance, in protection switching initiators);
- non-stationary behaviour of the transmission channel, when a recording of error ratio is performed.

The estimation accuracy depends on the number of independent events counted.

All types of bit error ratio monitoring methods described below would ideally require nearly stationary error rate statistics. The behaviour of the various methods and the errors in estimation of the instantaneous BER should be tested in practical conditions when the received signal and thus the BER are rapidly varying. Such signal characteristics occur during multipath fading. It is expected that the monitoring methods which require less time to give an estimate of the BER will be less affected by such phenomena.

* One of these sequences, usually that containing n zeros, is not allowed.

4.1 Test sequence interleaving

The error performance may be estimated by inserting sample pulses into the digital pulse stream at a rate of $1/N$ of the clock rate. At the receiver these pulses are extracted and their errors counted. The error performance of the system is estimated from this count of the errors within the sample pulses. Using this method the time taken to recognize a specific error ratio is N times that required by counting the errors of all the transmitted pulses. The error performance of the radio-relay circuit can be estimated independently of the signal content at the line interconnection interface TT' of Fig. 1 of Report 787.

A separate synchronizing frame is not always needed to extract the sample pulses at the receiver. The interleaved pulses should be independent of the digital multiplexer frame.

4.2 Parity-check coding

The error performance of a digital radio system can be estimated by using a parity-check technique. At the transmit end a parity-check symbol is added to each group of γ symbols. The value of the added symbol equals the sum of the γ symbol modulo M where M is the number of possible symbol values, i.e. the numbered levels being transmitted. This can be expressed mathematically as:

$$\text{value of parity symbol} = \sum_{n=1}^{n=\gamma} S_n \text{ modulo-} M \quad (2)$$

where:

S_n : value of the n th symbol of the group of γ symbols.

At the receiver the modulo- M sum of the γ group of received symbols is compared to the value of the received parity check symbol. It is assumed that if there is agreement, no errors have occurred, whereas if there is disagreement an error has occurred.

For low error probability (below about 10^{-3}) the number of disagreements obtained from the parity check comparison is approximately equal to the total errors of all the pulses in the digital signal. Therefore the error performance of the radio-relay circuit can be estimated by counting the number of disagreements.

This method requires a synchronizing frame.

4.3 Code-violations detection

The same criteria used in baseband digital transmission may be usable in some cases also on radio-relay links.

Bipolar or partial response line codes have an intrinsic redundancy that can be used to detect line errors. Obviously the choice of such coding and modulation methods is made on the basis of considerations other than the error ratio measurement.

Synchronization of the receiver output sequence is not required.

4.4 Pseudo-error detectors

These methods make use of "secondary" decision devices [Calandrino and Crippa, 1975; CCIR, 1974-78; Sant'Agostino, 1975] which are connected in parallel with the main signal path, and which have an intentionally degraded performance. Such devices give rise to digital output sequences affected by an error ratio much greater than the error ratio (unknown) of the main receiver.

A measurement of these "amplified" error ratios may be obtained by taking the main output sequence as a reference, and counting the number of disagreements between it and a secondary output sequence. Every disagreement is called "pseudo-error" because it does not necessarily correspond to an error on the main output sequence.

There are different ways of introducing a controlled degradation of the secondary receiver performance, e.g. by modifying the decision regions, with respect to the optimal ones. It may then be possible, by means of a previous calibration to relate the pseudo-error ratio to the error ratio on the main receiver. However, measurement error can be caused by multipath fading and interferences from adjacent channel and/or co-channel signals. Ideally in such circumstances the accuracy of this method of measurement should be verified for the particular application in mind.

A theoretical analysis of the accuracy of such indirect measurements of error ratio is presented in [Sant'Agostino, 1975]. From this it can be seen that the influence of the difference in the probability density functions will be low for adjacent channel and co-channel interference in a practical situation. The effect of multipath fading requires detailed study.

The main advantage of the method is the possibility of performing the measurement in a shorter time, and for smaller error rates, than with the previous methods considered, particularly in the case of one regenerative section. Also it is not necessary to insert extra bits thereby eliminating the need for bit-insertion facilities.

4.5 Conclusion

All the methods mentioned above need further study particularly concerning their specific advantages and disadvantages for the implementation of digital radio-relay systems; for their end-to-end supervision and for the acquisition of switching criteria.

5. Comment

The digital pulse stream from a digital multiplexer usually contains added bits as well as the information bits. These are, for example, used for framing. In general, error performance should be estimated independently of the format of the information signal. It follows that it is considered to be inadvisable in a digital radio-relay system to use such added bits for measuring the bit error performance.

REFERENCES

- CALANDRINO, L. and CRIPPA, G. [1975] Indirect method for error rate measurement in radio-relay systems. Telettra Internal Report.
- GOLOMB, S. W. [1964] *Digital Communications with Space Applications*. Prentice-Hall Inc., New York, NY, USA.
- SANT'AGOSTINO, M. [December, 1975] Performance monitoring devices for digital radio-relay links. *CSELT Rapporti Tecnici*, Vol. 3, 4, 13-29.
- CCIR Documents*
[1974-78]: 9/81 (Netherlands).

BIBLIOGRAPHY

- MINKIN, V. M. [1977] Vydelenie additivnogo signala iz ispytatelnoi M-posledovatelnosti (Separation of additive signal from test M-sequence). *NIIR Proc.*, 2, Moscow, U.S.S.R.
- MINKIN, V. M. [1979] Algoritm obrabotki ispytatelnoi M-posledovatelnosti v ustroistve vydeleniya oshibok (Algorithm for processing of test M-sequence in error separation). *NIIR Proc.*, 2, Moscow, U.S.S.R.
- CCIR Documents*
[1978-82]: 9/47 (U.S.S.R.).

RECOMMENDATION 400-2 *

SERVICE CHANNELS TO BE PROVIDED FOR THE OPERATION AND MAINTENANCE OF RADIO-RELAY SYSTEMS

(Question 4/9)

(1956-1959-1963-1966-1970)

The CCIR,

CONSIDERING

- (a) that service channels are required for the maintenance, supervision and control of radio-relay systems;
- (b) that if, for any reason, the radio-relay system itself fails to function, communication between various stations along the route, and from those stations to other points is likely to assume special importance;
- (c) that agreement is desirable on the number and function of the service channels to facilitate the planning of radio-relay systems;

* This Recommendation applies to radio-relay systems which will transmit at least 60 telephone channels or a television signal and comprise two staffed terminal stations, in which the signals are demodulated to baseband, and any number of unstaffed intermediate stations. This Recommendation applies, where appropriate, to trans-horizon radio-relay systems.

- (d) that service channels will be used to provide:
- omnibus voice circuits,
 - express voice circuits,
 - supervisory circuits,
 - control and operational circuits;
- (e) that service channels will not be connected to the public telephone network,

UNANIMOUSLY RECOMMENDS

that, on international radio-relay systems:

1. all staffed stations should be connected directly to the public telephone network;
2. when a radio-relay link is extended by means of short cable sections, and these cable sections and the radio-relay link taken together constitute a regulated line section, the terminal stations of the radio-relay link itself should have speaker circuits to the stations at the ends of the regulated line section;
3. a telephone service channel (omnibus voice circuit) should be set up to connect together all the stations on the system, whether staffed or not;
4. a second telephone service channel (express voice circuit) should be provided for direct telephonic communication between the staffed stations receiving supervisory signals;
5. provisions for the transmission of supervisory and control signals should be subject to agreement between the Administrations concerned;
6. the telephone service channels should possess, whenever possible, the characteristics (excluding noise power) recommended by the CCITT for international telephone circuits and, in particular, should be able to transmit the frequency band 300 to 3400 Hz;
7. all telephone service channels (including those used for supervisory and control circuits) up to a length of 280 km should, whenever possible, not exceed a mean noise power in any hour of 20 000 pW0p psophometrically weighted, at a point of zero relative level.

Note. — Service channels may be provided over an auxiliary radio-relay system, over the main radio-relay system, or by other unrelated means, either on a primary or stand-by basis. In the case of express voice circuits, the use of regular multiplex channels within the telephony baseband is acceptable, where this is possible.

REPORT 444-1

**SERVICE CHANNELS FOR ANALOGUE RADIO-RELAY
SYSTEMS**

(Question 4/9)

(1970-1978)

1. Introduction

A number of service communication requirements associated with the maintenance and operation of radio-relay systems for which special provisions should be considered have been identified. Generally these fall into two classes:

- functions to serve maintenance and operational personnel and network management. These involve omnibus and express service channels, display of system information, and may involve automatic processing,
- functions associated with the operation of the system. These involve channels required for the operation of multi-line switching equipments (see Report 137) and for the remote operation of regulating or switch-over equipment used for traffic control.

2. Express voice channels, requirements

The need for facilities to communicate between operating personnel of an international radio-relay system is an accepted fact. Thus, provisions to interconnect manned stations in a system need to be made. Such stations often correspond to terminals of modulation sections (see Recommendation 392) or in television systems where programme origination, switching or conversion warrants the stationing of personnel (see Recommendation 567).

Since in many cases the duties of operating personnel may be relevant to equipment other than merely radio-relay systems, service channel system design should allow provision for extension facilities. Generally, such systems should include selective calling. Since operation can extend over several sections, transmission quality is important.

3. Omnibus voice channels, requirements

Where personnel are not permanently stationed, the stations require voice communication access only during visits by maintenance personnel. Calling between these stations and to and from manned stations can usually be accomplished on a non-selective basis. To aid maintenance, service-channel equipment is generally located adjacent to the radio-relay equipment.

4. Supervisory requirements

Indications from unmanned stations are required for determining the status of the equipment at the site and indicating the maintenance action required. Reporting of conditions peripheral to the equipment may also be indicated. One arrangement is to divide the system into maintenance sections with site status indicators. The status indications from a number of maintenance sections may be required to be extended to a network control centre.

5. Control and operational channels, requirements

In many systems, the need exists to transmit control information used internally to the radio-relay system. A typical requirement is the control channel for multi-line switching (see Report 137). Other requirements may include programme switching; switch-over from television to telephony, actuation of equipment to accomplish specific transmission tasks; and remote control of equipment associated with the radio-relay stations.

6. Transmission considerations

6.1 The transmission bandwidth and quality of the service channels may be lower than for the radio-relay systems being served. On the other hand, the availability of service channels tends to be most important when the radio-relay system itself is in trouble.

Some service functions are characterized by a need for rapid transfer of information, especially in the case of multi-line switching. Other functions may require less rapid transfer. Transmission techniques may have the same characteristics as multi-frequency voice-frequency telegraphy (see CCITT Recommendations R.35 and R.38A) or higher speed data transmission (see CCITT Recommendation V.23). The bandwidth required varies from a few hundred hertz to more than 10 kHz. Where the quantity of information is in excess of one telephone-type channel capacity, it may be convenient to divide the information into a number of such channels.

6.2 One approach is the utilization of the main radio-relay system.

Service availability of radio-relay systems has been improved substantially over recent years by better equipment design, provision of protection equipment and stand-by power sources. Thus, use of the main radio-relay system for the transmission of service channels has enjoyed increasing popularity.

Technically this can be readily accomplished on FDM telephony systems by employing the frequency spectrum below the telephony baseband where equipment design includes provision for such access. It is generally convenient to insert one telephone channel directly without frequency translation, whilst the remainder use single sideband modulation, as in low capacity multiplex systems.

For telephony systems using the sub-baseband for data signals, on television systems, and on mixed telephony television routes, service channels may be provided in the frequency band above the main baseband and in the neighbourhood of the continuity pilot. In such cases the service channels are provided by normal FDM techniques. Care should be taken that neither the continuity pilot, nor any noise detection band is affected by the service channels.

6.3 Auxiliary radio-relay systems overlaying the route served have been used successfully either in the same frequency band (Recommendation 389, Report 374) or in another one (Report 284) as a means of providing easy access and limited circuit capacity. Another method to achieve auxiliary channels has been the provision of independent means of communication (see Recommendation 400).

6.4 Table I relates the main types of service and functions performed for typical transmission feasibilities, some of which are the subject of further study.

TABLE I – *Typical transmission feasibilities*

Type of service	Function	Single-line or multi-line telephony or multi-line telephony and television	Single-line or multi-line television
Omnibus voice channel	Access to and from each site	Auxiliary or below telephone baseband (direct- or derived) or above the baseband (derived) ⁽²⁾	Auxiliary ⁽¹⁾ or above the television signal
Express voice channel	Interconnection of manned sites	Auxiliary or below or above telephony baseband (derived) ⁽²⁾	Auxiliary or derived above television signal ⁽¹⁾⁽²⁾⁽³⁾
Supervisory	System supervision, maintenance	Auxiliary or below or above telephony baseband or above television signal (derived) ⁽²⁾	Auxiliary or derived above television signal ⁽²⁾
Control and operational	Basic system operation	Auxiliary or below or above telephony baseband or above television signal (derived) ⁽²⁾	Auxiliary or derived above television signal ⁽²⁾

⁽¹⁾ "Auxiliary" in this sense means separate from the main radio-relay system, such as an auxiliary radio-relay system or other separate means.

⁽²⁾ In this Table, "direct" is understood to mean without frequency translation and "derived" with frequency translation.

⁽³⁾ A frequency modulated sub-carrier above the television signal can also be used with certain operational restrictions regarding the access at repeater stations.

SECTION 9E: RADIO-RELAY SYSTEMS FOR SPECIAL APPLICATIONS

Reports

REPORT 379-4 *

**CHARACTERISTICS OF SIMPLE RADIO-RELAY EQUIPMENT OPERATING
IN BANDS 8 AND 9 FOR THE PROVISION OF TELEPHONE TRUNK CONNECTIONS
IN RURAL AREAS**

(Question 9/9 and Study Programme 9B/9)

(1966-1970-1974-1978-1982)

1. Introduction

Question 9/9 deals with a system for use in national networks which is normally not intended for connections across a national boundary.

The following summarizes the conclusions as to the basic aspects of Question 9/9 which have been reached.

2. Special conditions in the developing countries

In view of the special conditions in which the new and proposed systems will have to be specified, installed and operated in the developing countries, and especially the need to provide circuits at minimum cost, the following points must be borne in mind:

2.1 The need for selecting the most advantageous basic solution and for the most careful planning of circuit paths so that establishment costs are reduced to a minimum.

2.2 The need to reduce to a minimum the cost of establishing the infrastructure required to receive the equipment. This infrastructure includes, in particular:

- the provision of adequate access roads,
- the provision of buildings to house the equipment and, if necessary, accommodation for maintenance personnel,
- the provision of accommodation for power supplies, together with fuel reservoirs, if necessary,
- the provision of antenna supports, etc.

In existing radio-relay systems, this infrastructure has often been found to account for a very high proportion of the expenditure.

2.3 The need to specify equipment for these circuits, the capacity of which is in strict accordance with requirements. In particular, efforts should be made to avoid an unnecessarily large margin for circuit capacity unless the necessity for such a margin is immediately evident.

2.4 The need for equipment which is easy to maintain so that this work may be done by semi-skilled staff.

2.5 In many cases, the equipment will operate far from any existing power sources. It should therefore have low consumption so that the necessary power supply installation, as well as its maintenance and replenishment, may be as simple as possible.

2.6 Because in many cases radio-relay systems operating in bands 8 and 9 provide the most economic solution, they are referred to in this Report as low-cost systems.

3. Transmission performance

In general the transmission performance should be in accordance with the Recommendations of the CCITT for international and national networks. It should be noted that this performance is a function of careful system planning as well as equipment performance [CCITT, 1976].

* This Report is brought to the attention of the Chairmen of GAS 3 and 7 because of its special relevance to developing countries.

3.1 *Analogue systems*

For circuits of length up to about 250 km, CCITT Recommendation G.123 (Geneva, 1972) "Circuit noise in national networks" § B.a.3, required that the mean (for all channels of a system) of the psophometric power at a zero relative level point should not exceed 1000 pW0p one minute mean power for more than 20% of any month. In no case could this noise power exceed a maximum of 2000 pW0p for any of the channels of the system.

Long-distance circuits (about 250-2500 km) should meet the requirements of CCITT Recommendation G.152.

From information submitted by several administrations it is evident that 24 channel systems operating in the 400 MHz band may meet the CCITT Recommendations for one or two hops only. However, for temporary use in developing countries some relaxation (3 dB) in the noise requirements may be allowed if a significant reduction in the system cost is obtained.

The high noise values are mainly due to thermal noise and intermodulation noise caused by long delayed side reflections.

One method of satisfying the noise requirement mentioned in CCITT Recommendation G.123 would be to use a compandor (CCITT Recommendation G.162) for each telephone circuit, provided a significant reduction in system cost is obtained (due regard should be paid to CCITT Recommendation G.143, § 2, which restricts the systematic use of compandors in long-distance national and international networks).

Since the improvement by using a compandor is effective for all the noise involved in signal transmission, external noise such as interference noise, man-made noise, etc. can be reduced as well as thermal noise and intermodulation noise.

A high equipment selectivity can be advantageous, to allow for an effective frequency plan.

3.2 *Digital systems*

The transmission performance of a digital transmission system is expressed in terms of bit error ratio. The permissible values for bit error ratio have not yet been established by the CCITT. The way in which the error ratio of a digital radio-relay system will be specified and the error-ratio objectives for long-distance systems, are given in Report 930. From these objectives and the characteristics of a digital radio-relay system it follows that the most significant is the higher error-ratio objective (defining system "outage") which may be exceeded for small percentages of the time.

The permissible error ratio which may be exceeded for small percentages of the time is determined on the basis of the required system availability. The values proposed in Report 930 for long-distance circuits may also be used as a guide to the values of permissible bit error ratio and to the percentage of time for circuits of length up to 250 km.

Because of favourable fading conditions in bands 8 and 9 digital radio-relay systems operating in the bands concerned may, in certain regions, be designed for higher hop attenuation than corresponding analogue systems in which the mean noise power is the dominant parameter to be considered. Furthermore, the effect of side reflections, which may produce relatively high intermodulation noise in analogue systems, is usually negligible in digital systems.

In the digital radio systems that regenerate the digital signal by the use of repeaters, the degradation of transmission quality caused by increased numbers of hops results in bit error accumulation, and not in noise power accumulation. The bit error ratio of any regenerative radio-relay system can be improved significantly by a slight increase of the carrier-to-noise ratio.

Digital radio-relay systems can economically provide for trunk circuits of 250 km or longer that meet the performance objectives specified in Recommendation 594.

3.3 *Need for further study*

Administrations are invited to continue studies of the noise performance of both analogue and digital systems, and of compatibility between analogue and digital systems, for use in developing countries.

4. **Modulation**

When the equipment uses angle modulation associated with frequency-division multiplex, the r.m.s. frequency deviation should be in accordance with Recommendation 404.

While a higher frequency deviation may be used to improve the ratio of signal-to-thermal noise under non-fading conditions, it will also raise the threshold of frequency-modulation noise improvement so that, other things being equal, any gain in signal-to-noise ratio will be obtained at the expense of lower service reliability when deep fading occurs. A very large frequency deviation is likely to increase the risk of intermodulation interference. Conversely, if a lower frequency deviation is used, it will improve the fading margin at the expense of signal-to-thermal noise ratio.

While current practice makes use of analogue systems of multiplexing and modulation, the rapidly increasing use of digital systems should be borne in mind, especially the effect that the use of digital systems of multiplexing and modulation may have on the cost of the equipment. Studies of systems using digital methods of modulation are being actively pursued in both the CCITT and the CCIR.

The system capacities considered in this Report correspond to those of primary PCM multiplex equipment operating at 1544 kbit/s for 24 PCM channels, and at 2048 kbit/s for 30 PCM channels or twice these capacities. Principal characteristics of primary PCM multiplex equipment have already been standardized by the CCITT (CCITT Recommendation G.730 series) and their use in cable systems is increasing rapidly.

Studies and experience indicate that it is possible to realize digital radio-relay systems in band 9 for capacities of 24 and 30 PCM telephone channels using the same radio-frequency channel arrangements as used for the corresponding analogue radio-relay systems. The principles of these economical and practical radio-frequency channel arrangements are given in Annex II. The compatibility thus achieved makes it possible, or at least much easier, to resolve interference problems between digital and existing analogue radio-relay systems using the same radio-frequency band.

In particular, for pulse-code modulation, some of the essential characteristics of multiplex equipment are mentioned in the CCITT G.730 series of Recommendations but a more complete international standardization is still being studied (CCITT Study Group XVIII). For national purposes, other techniques may offer advantages which require further study. One country (Finland) has indicated that better frequency economy may be obtainable in band 9.

5. Equipment

Solid-state equipment should be employed to reduce power requirements and maintenance. Reduction in the size of the equipment is possible with solid-state circuits; however, reduction in size should not be made at the expense of reliability and ease of maintenance.

It may be noted, however, that in certain cases (when crossing marshy land, deserts, mountainous regions or foreign territory) the use of trans-horizon radio-relay systems working in a relatively low frequency band may be advantageous, since this will avoid the provision of stations remote from important centres of population without necessitating a large installation. In these cases solid-state components might not be suitable for the transmitter power-amplifier.

6. Antennas

The antennas should be simple, sturdy and with a small surface exposed to wind. A Yagi antenna would be suitable below 470 MHz, a dipole-array, helical antenna or corner reflector in the 400 MHz band and a parabolic antenna at 400 MHz and above. The antenna should be close to the equipment building to minimize the length of transmission line. Foam dielectric and solid dielectric cables have the advantage of not requiring pressurization.

The use of the same antenna for transmission and reception is generally more economical, but in such a case a larger frequency separation must be adopted to avoid blocking the receiver (e.g., 3% to 5% of the mean frequency).

Where intermodulation due to long-delayed unwanted side reflections is met in systems operating in the lower bands, for example, in the 400 MHz band, some improvement can be expected by using antennas having narrower horizontal beamwidths. One method of reducing the beamwidth is to use two or more antennas coupled side by side.

7. Power supplies

Low-power requirements may be supplied by batteries that are replenished by line chargers connected to a commercial power supply when available.

The problems of primary power supply raised by systems of this kind have been studied by GAS 4, who have published a manual on this subject [CCITT, 1970].

8. Maintenance

As the equipment will have to be maintained by semi-skilled staff, maintenance procedures should be as simple as possible, particularly when adjustments, the location of faults and the replacement of defective parts are concerned. Maintenance visits will have to be kept to a minimum. Provided no increase in the basic cost of equipment is entailed, it may be advisable to design the various units to be easily interchangeable, so that a fault can be corrected by replacing the unit concerned and sending it for repair to a special workshop.

The use of a simple synthesized local oscillator could be advantageous to reduce the number of spare parts required, provided that a suitable channel arrangement is utilized.

9. Field of application and choice of system capacity

While it is generally difficult to forecast the long-term requirements for trunk circuits in developing countries, the choice of system capacity is an economic optimum based on such forecasts. An initial installation of equipment will be uneconomic if its final capacity exceeds future requirements. On the other hand, replacement of an initially installed smaller system, when its capacity becomes inadequate, should only be necessary after several years' growth. A higher capacity system will then be justified, and the initial equipment can be recovered for use on another light-traffic route.

The systems considered in this Report have a capacity of 6, 12 or 24/30 (exceptionally 48/60) circuits and usually only satisfy the traffic needs on routes between a major switching centre and an outlying area away from main traffic arteries. On such routes the degree of reliability usually does not need to be the highest possible and hence a simple design is sufficient.

For routes which in the near future are to carry traffic between major switching centres, an initial installation will usually be required with an appreciably higher capacity than that provided by systems considered here.

REFERENCES

CCITT [1970] GAS 4. Primary sources of energy.

CCITT [1976] GAS 3. Economic and technical aspects of the choice of transmission systems.

ANNEX I

TYPICAL CHARACTERISTICS OF LOW-COST ANALOGUE RADIO-RELAY SYSTEMS OPERATING IN BANDS 8 AND 9

Introduction

This Annex gives the essential typical characteristics of low-cost analogue radio-relay systems having capacities of up to 60 channels. Wherever possible the limits of the characteristics have been chosen to allow low cost construction and these systems may therefore enable economical domestic services to be established in developing countries.

1. Radio frequency bands

The following four frequency bands may be suitable:

400 MHz band
800 MHz band
1500 MHz band
2000 MHz band

The use of other frequency bands is not excluded.

Note. — A radio-frequency channel arrangement for the 2.3-2.5 GHz band, based on a homogeneous pattern suitable for small capacity systems in rural areas is contained in Report 933.

2. Channel capacities

The channel capacity in each radio-frequency band may be chosen from the table below, taking into account the initial cost of installation and the cost of future expansion.

TABLE I

Frequency band (MHz)	Number of channels
400	12, 24, 60
800	12, 24, 60
1500	24, 60
2000	24, 60

Note. — Radio equipment of lower channel capacity, for example 5 or 6 channels, is also available and may, at a lower overall cost, include, as an integral part of the radio equipment, special non-CCITT standard multiplexing equipment to derive the telephone channels.

The use of very low capacity systems in a rapidly developing network may, however, be unwise since traffic congestion could occur at an early stage in the life of the radio system.

The use of 60 channel equipment in the 400 MHz frequency band should only be considered for use in those areas where frequency congestion problems are unlikely to exist.

3. Interference

The techniques for the calculation of the interference between two terrestrial systems are given in Report 388.

3.1 Spectral characteristics of signals

The evaluation of baseband interference involves a knowledge of the spectral densities of the unwanted and the interfering signals.

In Fig. 1 the normalized power spectral densities of 24 and 60 channel carriers are plotted. The 0 dB value corresponds to the unmodulated carrier power. The typical parameters of each signal are reported in Table II, together with the value of the residual carrier power. The standard CCIR pre-emphasis has been assumed in the case of a 60 channel carrier.

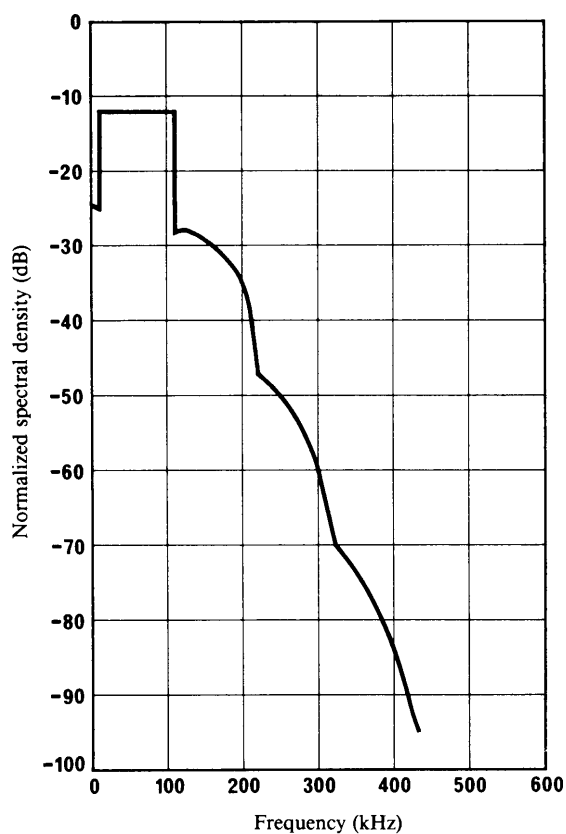


FIGURE 1a — Normalized power spectral density of a 24 channel signal ($\alpha = 0.2$ rad)

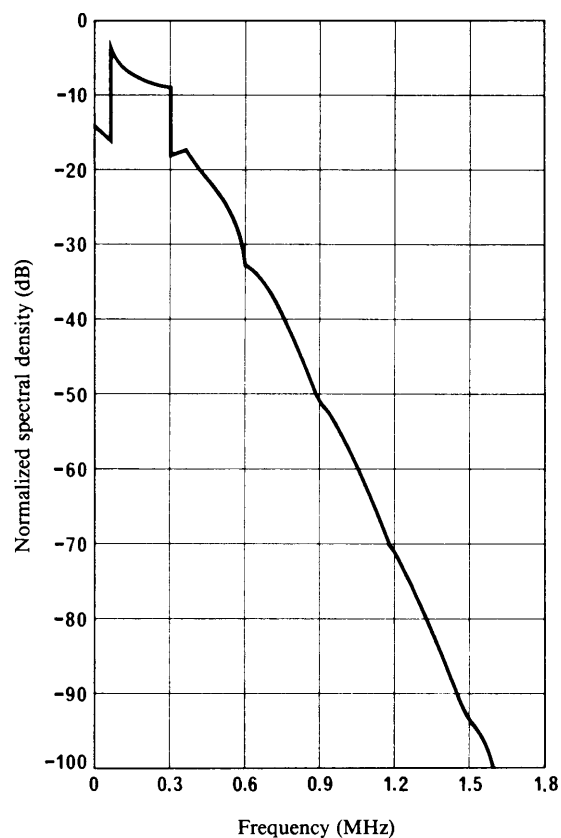


FIGURE 1b — Normalized power spectral density of a 60 channel signal ($\Delta f_0 = 50$ kHz).

TABLE II

Number of voice channels	Baseband limits		Modulation	Test tone frequency deviation Δf_0 (kHz)	Test tone phase deviation $\Delta \Phi_0$ (rad)	r.m.s. frequency deviation Δf_{rms} (kHz)	r.m.s. phase deviation $\Delta \Phi_{rms}$ (rad)	Mean square phase deviation α (rad ²)	Residual carrier power (dB)
	f_1 (kHz)	f_2 (kHz)							
24	12	108	Phase	—	0.2	—	0.337	0.113	-0.49
60	60	300	Frequency	50	—	101.1	—	0.417	-1.81

3.2 Examples of interference noise calculations

Theoretical calculations have been carried out using the same methods described in Report 780. The experimental results presented have been measured on a simulated hop with commercial equipment operating at 300 MHz in the Brazilian network.

3.2.1 Co-channel interference

The resulting equal level interference noise power N_{i0} (dBm0p) as a function of the baseband frequency is illustrated in Fig. 2. The interference noise between systems with different capacity and characteristics is not considered here, but it seems to be of interest in several practical situations.

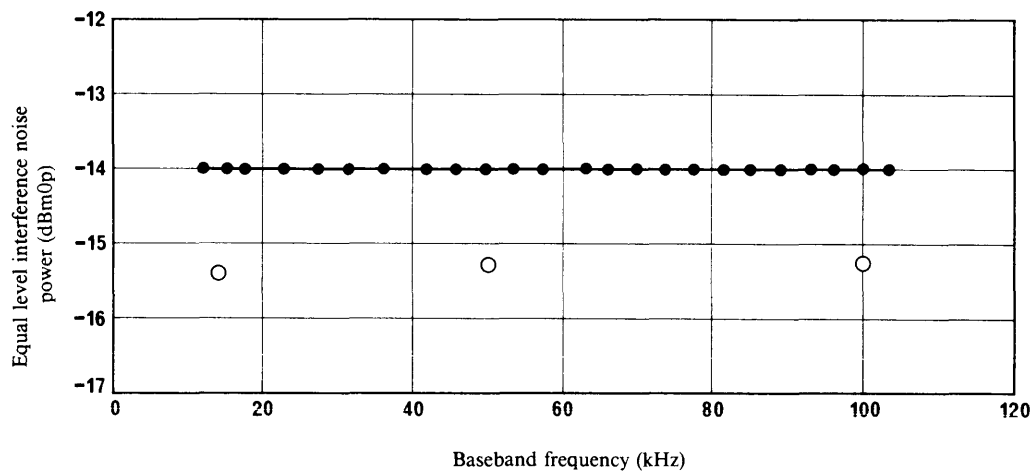


FIGURE 2a — Co-channel interference in FDM-PM 24-channel capacity systems: equal level interference noise power N_{i0} as a function of baseband frequency.

- Theoretical value
- Measured value

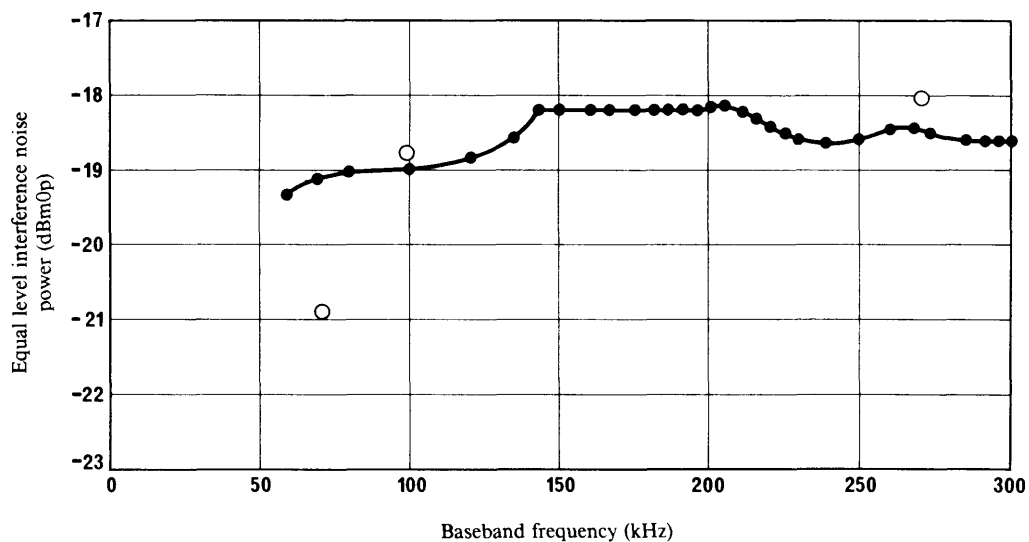


FIGURE 2b — Co-channel interference in FDM-FM 60-channel capacity systems: equal level interference noise power N_{i0} as a function of baseband frequency.

- Theoretical value
- Measured value

3.2.2 Adjacent channel interference

The resulting equal level interference noise N_{i0} (dBm0p) computed in the highest measuring channel in the baseband of the interfered signal is illustrated in Fig. 3.

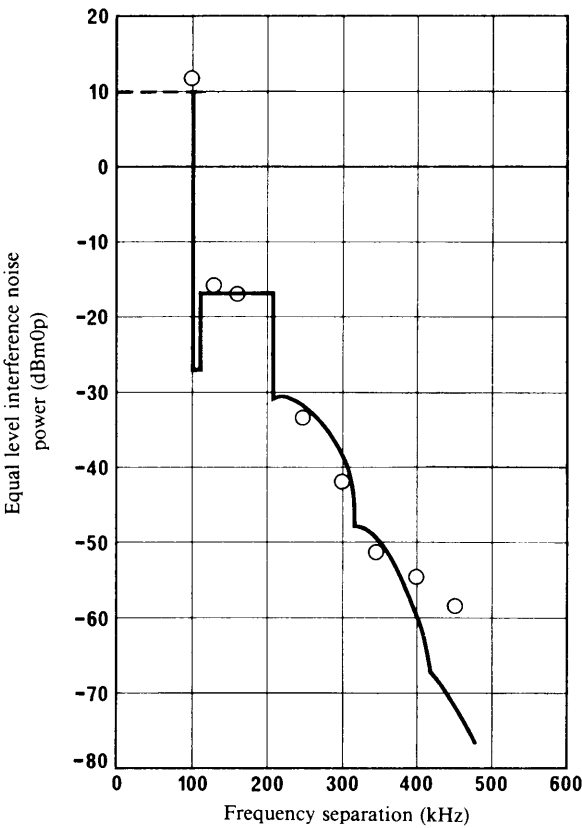


FIGURE 3a — Adjacent-channel interference in FDM-PM 24-channel capacity systems: equal level interference noise power N_{i0} as a function of baseband frequency

- : theoretical value (98 kHz frequency-channel)
- : measured value (98 kHz frequency-channel)
- - - - : theoretical value (worst frequency-channel)

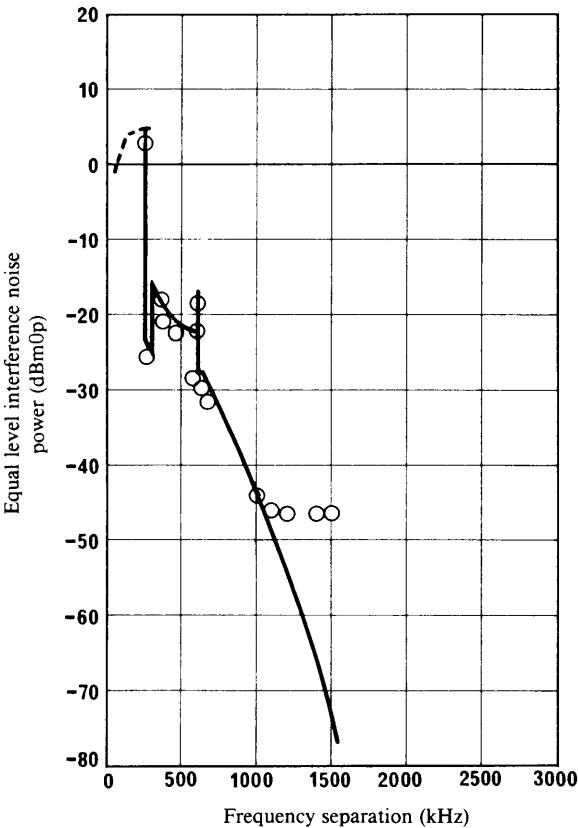


FIGURE 3b — Adjacent-channel interference in FDM-FM 60-channel capacity systems: equal level interference noise power N_{i0} as a function of baseband frequency

- : theoretical value (270 kms frequency-channel)
- : measured value (270 kms frequency-channel)
- - - - : theoretical value (worst frequency-channel)

3.3 Non-linear interference considerations

With reference to Report 780, it seems that, for this type of equipment, a 15 dB (at the demodulator input) ratio between desired and undesired signal should be a secure value as a minimum signal to interference ratio in order to protect the system from non-linear effects.

4. Radio-frequency separation between transmitter and receiver

The choice of frequency separation will depend upon the availability of frequency spectrum and the relative cost and practicability of using separate antennas and isolating filters for transmission and reception versus the use of a common antenna of suitable bandwidth and combining networks.

Typical values may range from 10 to 60 MHz.

5. Adjacent channel separation

The following adjacent co-polar channel separations are typical for the 400, 800, 1500 and 2000 MHz bands:

TABLE III

Number of voice frequency channels	RF channel separation (MHz)
< 12	0.5
12	1
24	2
60	4

6. Modulation

The use of frequency modulation with the following deviations is preferable:

TABLE IV

Number of channels	r.m.s. deviation per channel ⁽¹⁾ (kHz)
12	35
24	35
60	35, 50, 100, 200

⁽¹⁾ For 1 mW, 800 Hz tone at a point of zero reference level.

Where closer channel spacing is required, to conserve frequency spectrum, the lower frequency deviations should be used. Phase modulation may, however, be used for systems of low capacity. A modulation index in the range 0.2 to 0.8 is suggested.

7. Interconnection

Interconnection between two small capacity radio-relay systems is normally carried out at baseband frequencies and not at intermediate frequency. Nevertheless the intermediate frequency is important in making channel frequency plans and assignments in order to avoid interference between systems, and the following nominal centre values of intermediate frequency are preferred:

- 10.7 MHz for small capacity systems,
- 35 or 70 MHz for larger capacity systems.

8. Baseband frequencies

The following frequency ranges in the baseband are preferred:

TABLE V

Number of channels	Frequency range (kHz)
12	12 to 60 or 6 to 54
24	12 to 108 or 6 to 102
60	12 to 252 or 60 to 300

For small capacity systems the baseband may extend below 12 kHz.

9. Baseband impedance

Nominal impedance: 150 Ω (or 600 Ω balanced below 24 channels)
or: 75 Ω (unbalanced).

10. Baseband input level

–45 dBr.

11. Baseband output level

–15 dBr.

12. Service channel

A speech service channel is desirable on all systems; such a channel may be used for supervision where necessary.

ANNEX II

CHARACTERISTICS OF POINT-TO-POINT DIGITAL RADIO-RELAY SYSTEMS OPERATING IN BANDS 8 AND 9

This Annex presents, as an example, typical characteristics of low-cost digital radio-relay systems. The capacities of the systems are 24, 30, 48 and 60 PCM telephone channels.

1. Radio-frequency bands

The following four frequency bands may be suitable:

400 MHz
800 MHz
1500 MHz
2000 MHz

The use of other bands is not excluded.

Note. — A radio-frequency channel arrangement for the 2.3-2.5 GHz band, based on a homogeneous pattern suitable for small capacity systems in rural areas is contained in Report 933.

2. Channel capacities

The channel capacities are based on the capacities of the primary PCM multiplex equipment operating at 1544 kbit/s for 24 PCM channels and at 2048 kbit/s for 30 PCM channels as specified by the CCITT. 48 PCM channels and 60 PCM channels are transmitted because the bit streams from two mutually synchronized multiplex equipments can be transmitted without an extra multiplexer by using 4-phase modulation. Since the cost of a radio-relay system, in general, increases with radio frequency, the use of capacities of 2×24 PCM and 2×30 PCM channels are especially suitable for the 1500 MHz band and the 2000 MHz band.

3. Radio-frequency separation between transmitter and receiver

The choice of frequency separation will depend upon the consideration given in Annex I.

Typical values for digital systems are dependent on the modulation method. Typical values may range:

- from 10 to 60 MHz for 2-level FSK, with modulation index given in § 4 of this Annex;
- from 20 to 80 MHz for 4-level PSK.

4. Adjacent channel separation and modulation

Among the modulation methods used for small capacity simple relay equipments are 2-level FSK and 4-level PSK, for which some considerations are given below.

For a capacity of 24 PCM telephone channels with a bit rate of 1544 kbit/s, employing 2-level FSK to achieve compatibility with the radio-frequency channel arrangements for analogue systems given in Annex I, the modulation index of about 0.65, defined as the difference between the frequencies representing the two conditions of modulation divided by the bit rate, is a suitable value. At this modulation index the error ratio is near the optimum, the power spectrum density is flat across a frequency band equal to the bit rate, and the spectral width between the first zeros is either equal to 1.3 times the bit rate, or to 2 MHz.

For capacities of 24, 30, 48 and 60 channel PCM radio-relay systems, 4-level PSK provides a suitable modulation method that uses the spectrum efficiently. To limit the spectrum of the transmitted signal baseband shaping by the use of cosine roll off filters may be used. The power spectrum density is flat across a frequency band almost equal to the baud rate (half the bit rate).

In view of the above considerations, the following typical adjacent co-polar channel separations are suitable for the 400, 800, 1500 and 2000 MHz bands:

TABLE VI

Number of channels	Bit rates (kbit/s)	Modulation method	RF channels separation (MHz)
24	1 544	2-level FSK	2
24	1 544	4-level PSK	1.5
30	2 048	4-level PSK	1.75 or 2
2×24	3 088	4-level PSK	3
2×30	4 096	4-level PSK	3.5 or 4

5. Intermediate frequency

The same considerations apply as mentioned in Annex I, § 7 "Interconnection". The preferred nominal centre values are 35, 70 or 10.7 MHz.

6. Interconnection and baseband characteristics

Interconnection between radio-relay systems is normally made at digital baseband frequencies. The important baseband characteristics for a digital radio-relay system forming part of an international circuit and the characteristics of primary digital interfaces, are at present being studied by the CCITT. For national systems the regeneration and line terminating units of corresponding cable systems may be utilized to facilitate the interconnection of radio-relay equipment and multiplex equipment or radio-relay equipment and equipment of extension cable systems.

At radio repeater stations, or between radio-relay systems, simpler regeneration equipment may be used.

7. Service channel

A speech service channel is desirable and may be used for supervision where necessary. The operation of the service channel should preferably be independent of the signal from the PCM multiplex equipment.

ANNEX III

A POINT-TO-MULTIPOINT RADIO-RELAY SYSTEM FOR TRUNK CONNECTIONS IN RURAL AREAS

1. Introduction

This Annex describes a radio-relay system suitable for use as a bearer between a traffic concentrating switching centre, a radio-relay or cable station and distant rural or urban stations in various directions. Simple low capacity point-to-multipoint radio-relay circuits use a multi-direction time-division-multiplex method which makes efficient use of the frequency spectrum and provides an economical system [CCIR, 1978-82].

2. General description of the system

2.1 Relay circuit configuration

This system transmits a PCM-TDM signal with sufficient capacity for the traffic between the main traffic concentrating station (MTCS) and the many small traffic stations (STS) in the area. The system configuration is shown in Fig. 4.

Transmit and receive signals are shown in Fig. 5; each STS transmits its TDM signal in a burst mode with a frame length proportional to the traffic requirement.

2.2 Synchronization

The signals transmitted from each STS are received as a continuous signal at the MTCS's receiver. In low capacity line-of-sight radio-relay systems, variation in burst signal timing, caused by changes in the propagation time of the main carrier, is ignored.

The STS receives a continuous TDM signal transmitted from the MTCS and regenerates the frame synchronization signal contained within the received signal. The regenerated signal is used for frame synchronization of the transmitted TDM signals and for timing the burst carrier.

The propagation time between each STS and the MTCS is equalized at each STS and the burst signals at the MTCS are received in synchronism.

3. Transmitter and receiver

Transmit and receive equipments at the MTCS and STS are similar to point-to-point radio-relay equipment except for the inclusion of burst carrier control, clock and frame timing equalization circuits.

4. Antenna

The MTCS antenna has its directivity matched to the direction of the corresponding STS and its beam width should be as narrow as possible to minimize interference.

5. System economy

The equipment at the MTCS consists of one set of transmit and receive equipment. This results in an economical system compared with systems using individual low capacity radio-relay circuits to more than three stations. In the example shown in Fig. 4, ordinary low capacity radio-relay systems are utilized when many repeaters are required between the MTCS and STS.

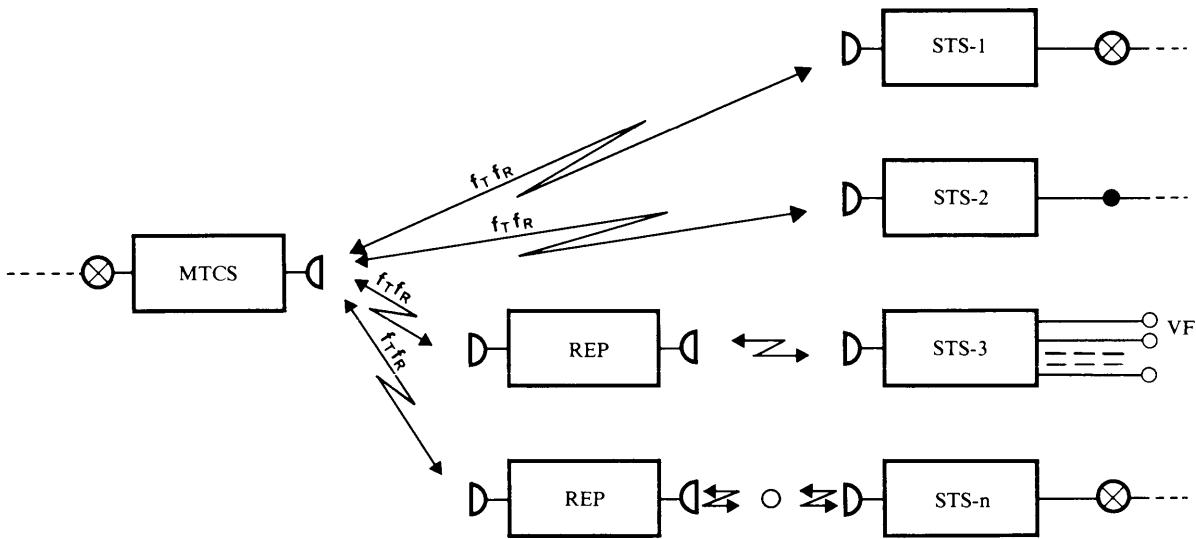


FIGURE 4 — A possible configuration of a point-to-multipoint TDM radio-relay system.

- Other repeater stations
- Equipment interface at non-hierachical bit rate
- ⊗ Equipment interface at hierachical bit rate
- VF: voice frequency telephone line interface
- MTCS: major traffic center station
- STS: small traffic station
- REP: repeater station
- f_T, f_R : transmit and receive carrier frequencies at MTCS

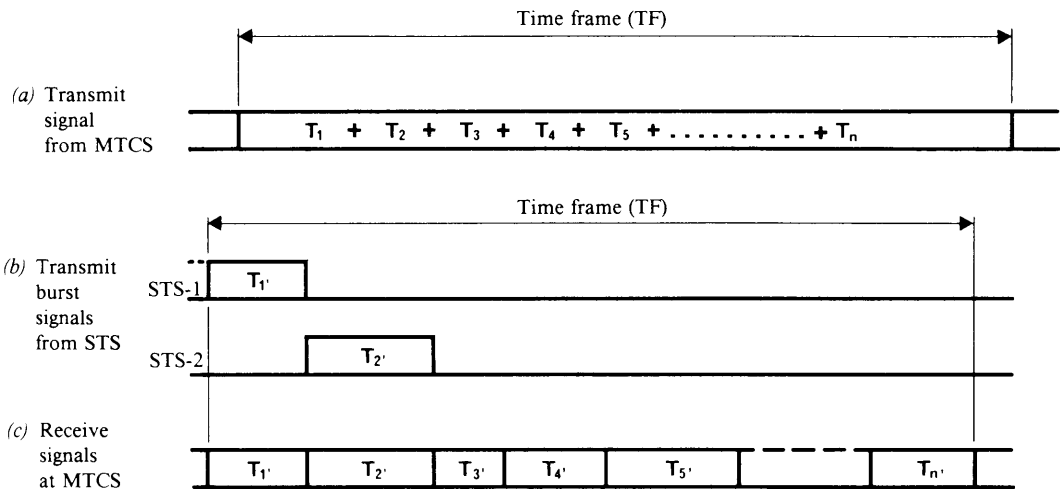


FIGURE 5 — Relation in allocated time slots at the MTCS
 T_n', T_n : time slot in PCM-TDM time frame for traffic of STS-n.

6. Frequency spectrum utilization

This system uses only one pair of radio frequencies for all stations which results in more efficient utilization of the frequency spectrum than a system constructed on an individual point-to-point basis.

7. Channel capacity

Typical STS channel capacity for this type of application can be up to 60 channels.

8. Modulation and RF channel separation

The modulation method usually used for the system is 2-level FSK or 4-level PSK. Typical RF channel separations are similar to those shown in Annex II.

9. Interconnections with other systems or equipment

Interconnection between this system and a TDM terminal equipment or another relay system at the MTCS, is made at the points T , T' or R , R' shown in Fig. 1 of Report 938.

Interconnections with other circuits at the STS stations are shown in Fig. 4, and must be made after the burst PCM-TDM signals have been converted to a continuous TDM signal.

REFERENCES

CCIR Documents

[1978-82]: 9/240 (Japan).

REPORT 380-1 *

RADIO SYSTEMS OPERATING IN BANDS 8 AND 9 FOR THE PROVISION OF SUBSCRIBER TELEPHONE CONNECTIONS IN RURAL AREAS

(Question 10/9)

(1966-1982)

1. Introduction

Question 10/9 relates to radiotelephone links that will provide telecommunication services to rural subscribers.

Special Autonomous Group 3 (GAS 3) (CCITT/CCIR) has prepared two handbooks, entitled "Economic and technical aspects of the choice of transmission systems" (1976 edition) and "Rural telecommunications" (1979 edition) which give detailed technical characteristics of radio equipment that may be used to provide service to rural subscribers. In particular, analogue single-channel and concentrator systems are described.

The use of the time division multiple access (TDMA) technique as a means of providing telephone services to rural subscribers has become widespread [Beaupre, 1980]. A further development of TDMA is the use of digital transmission and regenerative repeaters. Such equipment is planned for widespread introduction in rural areas of Australia [Sargeant and Steel, 1981].

2. General description of the systems

The basic purpose of these systems is to provide a radiotelephone that will extend services to rural subscribers. As far as practicable these services should provide a transmission quality and range of facilities that are normally provided to subscribers in urban areas.

In general, three types of systems may be envisaged: single channel systems, concentrator systems, and drop/insert systems.

* This Report is brought to the attention of the Chairmen of GAS 3 and GAS 7 because of its special relevance to developing countries.

2.1 Single channel systems

The single channel system involves the exclusive assignment of a radio circuit to each subscriber station. This system requires two transmitter-receiver units (one at each end of the link) to constitute a subscriber line.

2.2 Radio concentrator systems

Radio concentrator systems provide multiple access to subscribers by the use of either multiple frequencies (frequency division multiple access, FDMA) or by the use of multiple time slots (time division multiple access, TDMA). Digital radio concentrators naturally use TDMA.

Multiple access systems give subscriber stations access to several circuits, the number n of which is smaller than the number N of subscriber stations ($n < N$). As this is a concentrator system, a certain grade of service in respect of attempts to set up calls must be accepted, the grade of service depends on the number n of circuits, the number N of subscriber stations and the traffic that is originated.

The multiple access system requires a switching unit to provide for the concentration-expansion between the N subscriber stations and the n circuits. This unit is generally located in the telephone exchange to which the rural subscribers are connected, and where N subscriber lines are provided (see Fig. 1). The multiple access system must also include a base unit where all the subscribers are concentrated. This base unit may be located at some distance from the switching unit so that the desired coverage is easier to obtain.

From the radio standpoint the frequency division multiple access radio concentrator system (FDMA-RCS) consists of n single channel systems, with the difference that the subscriber stations have no fixed, exclusive assignment to a particular channel, but access to a specific channel is selected (generally automatically) from among the n channels. In the case of an analogue radio concentrator system as many transmitter-receiver units as there are radio circuits in the system must be installed at the base unit (see Fig. 1). A transmission medium with a capacity of n circuits will be required between the base unit and the switching unit whenever they are geographically separated.

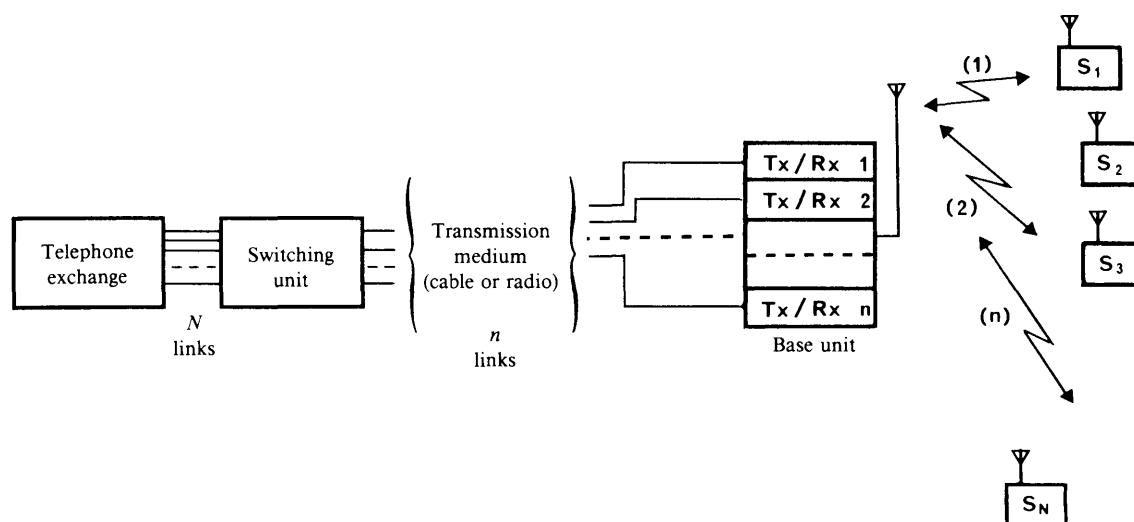


FIGURE 1 — Possible configuration of an FDMA radio concentrator system for rural subscribers.

S_i : subscriber station

A time division multiple access radio concentrator system (TDMA-RCS) consists of a single transmitter-receiver unit at the base unit and at each subscriber station. The transmitted signal consists of n time slots multiplexed in time, with each capable of providing a telephone channel. Any subscriber station has access to any of the n time slots which are allocated on a demand basis by the exchange switching unit.

In the case of the digital radio concentrator system (DRCS) it is possible to introduce regenerative repeater stations to extend the service from the exchange to far-distant subscribers. Repeater stations consist of two transmitter-receiver units connected back-to-back through two baseband regenerators. Repeaters serve local subscribers and operate as two-way RF translators that retransmit the signal into the adjacent radio zones (see Fig. 2).

Annex I to this Report illustrates a possible cell arrangement and frequency plan for a digital radio concentrator system.

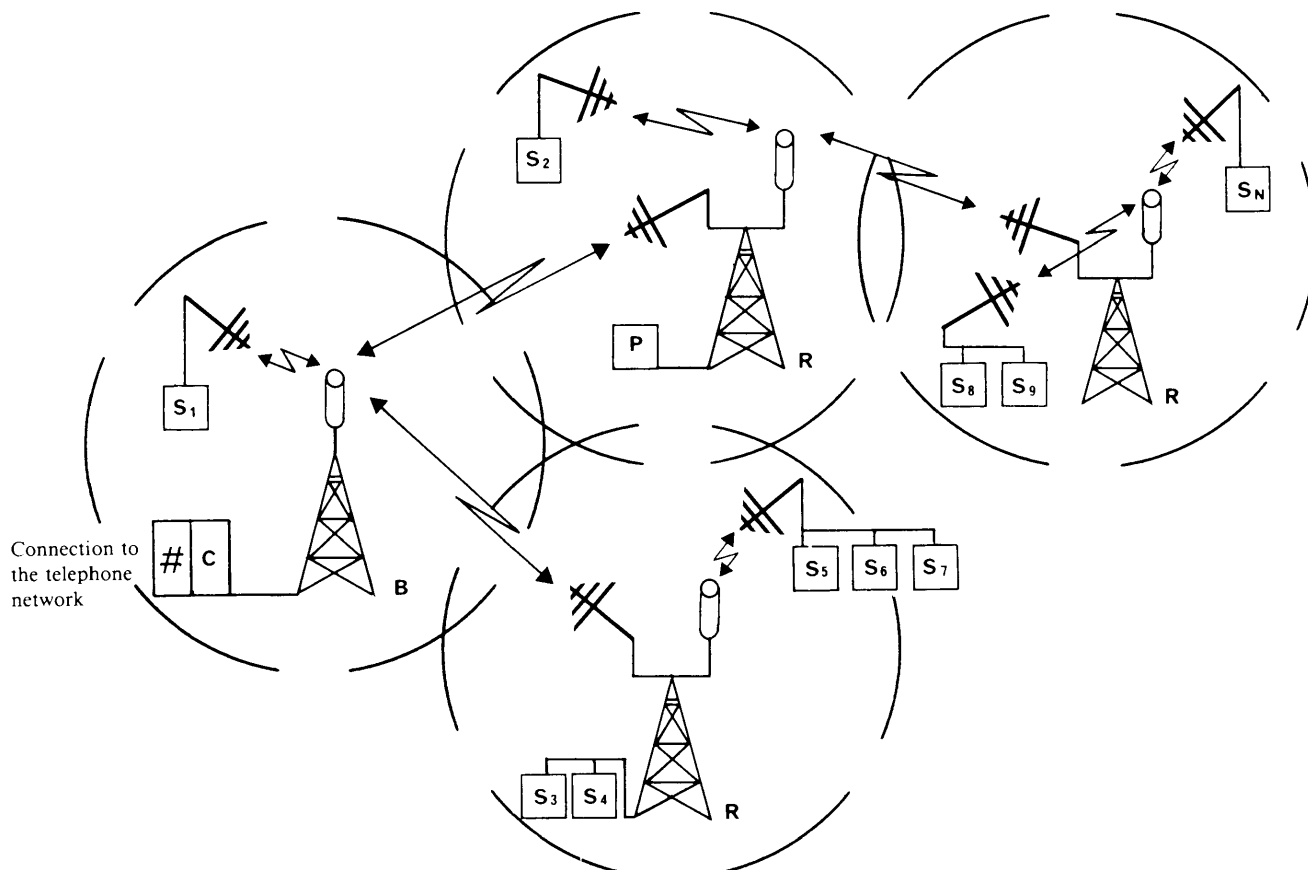


FIGURE 2 — A possible configuration for a TDMA radio concentrator system for rural subscribers.

- # : telephone exchange
- S_i : subscriber station
- R: repeater station
- B: base unit
- P: public telephone
- C: switching unit

2.3 Drop/insert systems

In drop/insert systems the signalling information, the routing requirements, and information on the operational status of the multiple access network are conveyed over supervisory channels which are continuously monitored and, if necessary, updated at all stations. Unutilized subscriber channels or time slots are allocated on demand on a drop and insert basis to the individual subscribers via the local switches and the supervisory channels are updated with information on new connections and disconnections. The same channel or time slot can be reused several times along the network due to the local switch facility. No central switch is required. A base station must be provided as a gateway to the public network. Figure 3 shows a possible configuration of drop/insert system with typical layouts of a repeater station and a base station.

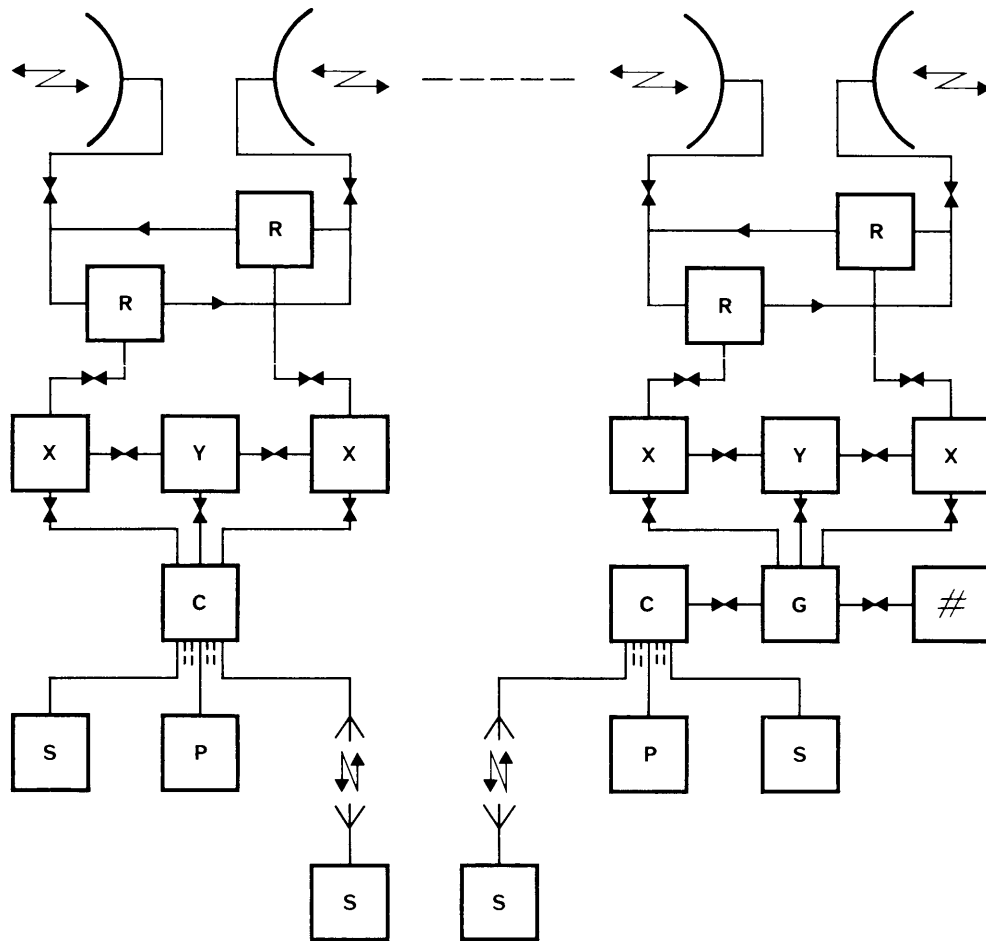


FIGURE 3 — A possible configuration for a drop/insert multiple access system for rural subscribers.

R: repeater
 X: drop and insert muldex for supervisory channels and traffic
 Y: supervisory processor
 C: local switch
 G: gateway switch
 #: telephone exchange
 S: subscriber station
 P: public telephone

3. Frequency range. Electromagnetic compatibility

With due regard to the mode of propagation and the present state of the art, the frequency band should be chosen from those parts of bands 8 and 9 that have been allocated to the fixed service. The lower bands are to be preferred mainly when propagation is by diffraction (mountainous regions) and the higher bands in cases where there is a risk of interference.

In multiple access systems, the frequencies of the radio channels should be chosen taking into account the bandwidth of the equipment and the limitations imposed by the various sources of interference.

When several radio systems are to be operated in the same rural area, frequency coordination will require careful analysis and multiple access systems will be found to have certain points in common with mobile systems. Reports 739, 740 and 741 contain useful information in this respect.

Reports 660 and 661 define and propose methods of measuring an electromagnetic compatibility figure of merit in analogue radio systems with a capacity of one telephone circuit.

4. Type of path and characteristics of the radio equipment

4.1 *General*

The three types of systems referred to in § 2 above have much in common as far as analogue radio equipment is concerned. For example, the transmitters and receivers at the subscriber stations and base units of the multiple access systems are the same for both the single-channel and the multiple access options.

The most economical solution appears to be a line-of-sight or near line-of-sight (diffraction) path, making it possible to use transistorized equipment with transmitter powers of about 0.5 W to 5 W. A higher transmitter output power may be necessary in certain cases, particularly at the base unit in the multiple access system.

In some cases, more complex equipment can be used at the most easily supervised terminal (telephone exchange and/or multiple access base unit) and simpler equipment at the other end of the circuit (subscriber station or public call telephone).

The use of microprocessing techniques could facilitate the supervision of multiple access systems, a factor which is of vital importance for the operation of such systems in rural areas. It would also be desirable for exchange supervision to include the possibility of monitoring the subscriber stations.

4.2 *Frequency stability*

The tolerance should be in conformity with the Radio Regulations. This should be possible preferably without the use of a thermostat.

4.3 *Modulation*

Frequency or phase modulation seem to be the systems preferred for analogue systems and frequency shift keying (FSK) or phase shift keying (PSK) for digital systems.

4.4 *Antennas*

The antennas at the subscriber stations should be simple, sturdy and with a small surface exposed to wind. However, they should also have sufficient directional gain. Yagi antennas are in most cases a good solution, but at higher frequencies other types of antennas, such as helix or dipole array with reflector, may be used depending on required gain and bandwidth.

The use of the same antenna for transmission and reception is generally more economical, but in such cases a larger frequency separation must be adopted to avoid blocking the receiver (e.g. 3% to 5% of the mean frequency). But it is suggested that technical difficulties might arise from the adoption of too large a frequency separation because of the bandwidth limitation of some antennas.

In the multiple access system, the antenna(s) at the base unit (where all the subscribers in the service area are concentrated) should be chosen so that their radiation characteristics are as closely matched as possible to the geographical area to be covered.

The repeater stations in the DRCS have two antennas one for each transmitter-receiver. The most common configuration would be a Yagi antenna directed towards the exchange-end and an omnidirectional antenna to serve the local subscribers and for linking with the further out receivers (if any).

4.5 *Signalling*

The equipment must be fitted with appropriate signalling apparatus, comprising all calling and controlling devices, for the modes of operation required.

Recommendation 257 describes a selective calling system which might be envisaged for multiple access analogue systems. Digital TDMA systems would normally use a combination of common channel signalling and channel associated signalling.

In general, radiotelephone systems for rural subscribers should provide for the transmission of charge and public telephone signalling.

4.6 *Power supply*

Special Autonomous Group 4 (GAS 4) of the CCITT has published a document entitled "Primary sources of energy" (1970 edition) which discusses the related problems.

In general, dynamic sources of energy (generator sets) should not be used owing to the amount of maintenance required.

Solar energy is particularly attractive, although its use may be ruled out by the climatic conditions prevailing in certain areas.

To economize in power consumption, only the receivers should operate continuously, the transmitters being switched on automatically at the start of each call. For a TDMA system further power savings are possible by turning the transmitter on for only the duration of the active time slots.

It might be worthwhile to consider operating the receiver equipment on the basis of active/idle working cycles, using timing that is compatible with the signalling philosophy adopted.

5. Installation

The radio equipment may be placed either at the top of the support structure carrying the antennas, which reduces cable losses but makes maintenance more difficult, or at the foot of the support structure. In certain cases, where temperature fluctuations are very great (desert areas), it may be advisable to install the equipment in underground shelters.

The above information is applicable to the installation of subscriber radio equipment in multiple access systems. However, infrastructure requirements for the radio equipment of the base unit may be greater, since equipment is bulkier, power consumption higher, etc.

REFERENCES

- BEAUPRE, D. M. [May, 1980] Subscriber radio — a new solution for rural telephony. *Comm. Int.*, Vol. 7, 5, 52-54.
- SARGEANT, V. K. and STEEL, J. [March, 1981] Planning telephone networks for rural and remote areas using digital radio concentrators. Proc. IE Australia General Engineering Conference, Canberra, Australia.

ANNEX I

CELL ARRANGEMENT AND FREQUENCY PLAN FOR A DIGITAL RADIO CONCENTRATOR SYSTEM (DRCS)

1. Introduction

For the DRCS to be capable of serving extended geographical areas with one or more systems an orderly plan of frequency reuse needs to be established. This annex describes such a plan that uses 7 frequency pairs and achieves an acceptable balance between spectrum efficiency, system performance and equipment complexity.

2. Sub-division of service areas

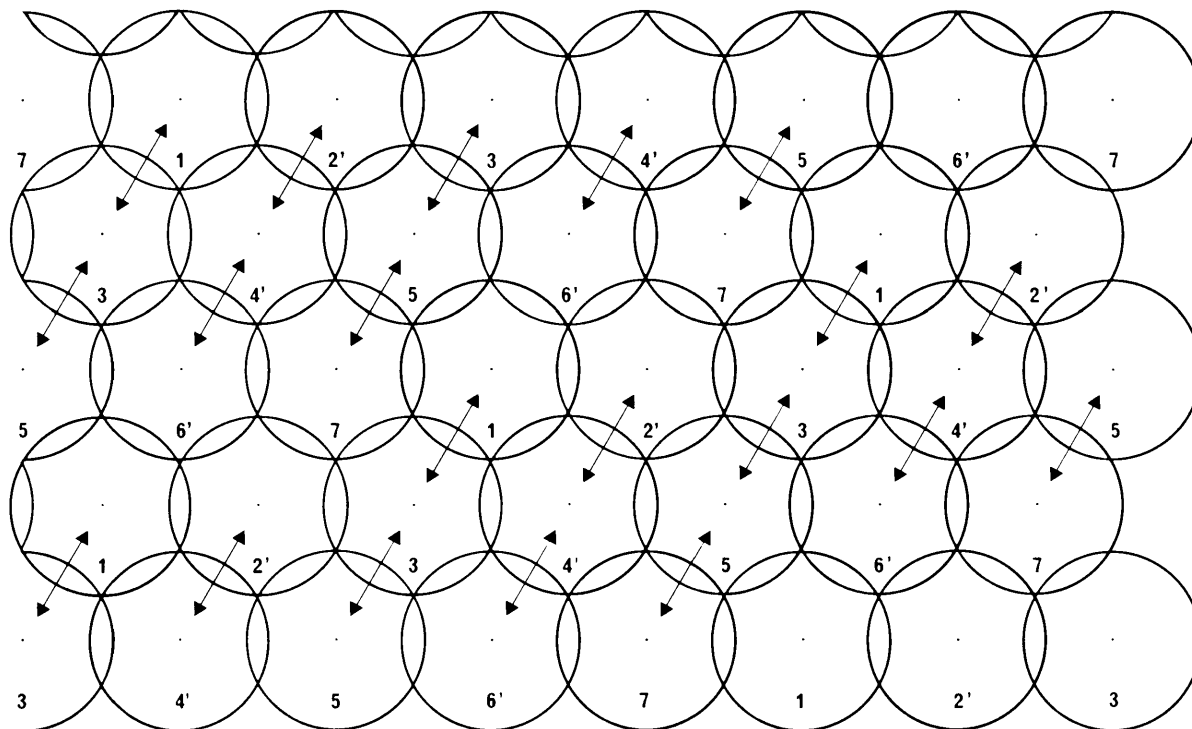
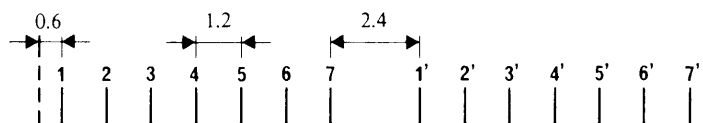
The service area is sub-divided into sub areas or cells similar to those used for high capacity mobile radio systems. Each cell contains a single base or repeater station which operates on a specific frequency channel and is linked to an adjacent cell so that a complete service area is formed. A repeater station consists of two transceivers and is located at the centre of the cell. The two transceivers are termed base and repeater transceivers according to the function they perform. The base transceiver uses an omnidirectional antenna to serve subscribers in its cell and the repeater transceiver uses a Yagi antenna to establish a link with a base or repeater station in an adjacent cell.

3. Control of co-channel and adjacent channel interference

Co-channel interference is controlled by increasing the distance between cells that use the same frequencies. This co-channel cell spacing can be increased if the number of RF channels used is increased. To conserve the spectrum it is essential to minimize the number of channels and the adjacent channel separations consistent with acceptable levels of interference and economic system realization.

3.1 Cell arrangement

Figure 4 illustrates a particular cell pattern that uses 7 pairs of frequencies, where for example, in cell 5, frequency channel 5 is used to transmit to the subscribers in that cell and the subscribers in cell 5 transmit on frequency 5'. To reduce the required discrimination that needs to be provided, some repeating directions need to be forbidden as shown in Fig. 4 and all even frequencies that are transmitted by the base transceivers are reversed in sense with respect to the odd frequencies. Adherence to this plan results in the minimum separation between a frequency that is transmitted and another that is received at a repeater station being at least 3 channels apart. Figure 5 shows the proposed RF channel arrangement for use with the cell arrangement shown in Fig. 4.

FIGURE 4 — 7 cell system showing forbidden repeating directions ($\leftrightarrow$)FIGURE 5 — Frequency plan for a DRCS
(All frequencies are in MHz)

3.2 Frequency plan

The frequency plan shown in Fig. 5 will accommodate transmission rates of between 600 and 800 kbaud according to Report 378. This in turn, with a 4-level modulation method and 64 kbit/s PCM encoding of speech or 2-level modulation with 32 kbit/s encoding of speech will provide between 15 and 20 speech time slots after allowance is made for the additional bits required to transmit TDMA signals.

4. Conclusion

The proposed cell and RF channel arrangement described in this Annex is considered as an efficient means of providing the DRCS with a means of being able to serve large geographical areas economically. The principles discussed can also be extended to determine an orderly plan of frequency reuse for analogue radio concentrator systems.

REPORT 615-1

TRANSPORTABLE FIXED RADIOCOMMUNICATIONS EQUIPMENT FOR RELIEF OPERATIONS

(Question 20/9)

(1974-1982)

1. Introduction

Question 20/9 foresees the need for transportable radio links to restore or supplement local communications in the event of a disaster. It requests the study of the preferred characteristics and frequency bands for such transportable systems when:

- the equipment is used to establish terrestrial access to a transportable earth station and
- only terrestrial relief telecommunication facilities are involved.

The following points are important:

- the system should be capable of acting as a stand-by for any radio-link station, whatever the working frequency or the equipment used, or for a cable system of similar capacity;
- the system should be capable of functioning in any environment;
- interconnection should be possible at baseband or intermediate frequencies;
- electromagnetic compatibility must be ensured in all cases, not only with the other systems which may be installed at a particular station where an emergency has occurred but with other (earth and terrestrial) stations in the vicinity.

2. Emergency situations and types of transportable equipment

Administrations may wish to have emergency equipment ready for use, if and when an emergency arises, and to reserve the appropriate frequencies.

It seems appropriate to consider the emergency situations mentioned below, and the types of transportable radio equipment appropriate for each of these situations.

2.1 *A devastated area*

A town, a village, or an area containing a number of towns and villages, which is devastated.

Equipment required:

- Type A: A simple communication link which can be established rapidly for telephone communication with a governmental or international relief headquarters. This would be needed in Phase I of the relief operations.
- Type B: One or more local networks, each with a communications centre, and facilities for telephone communication with up to about ten or twenty out-stations situated at distances usually up to a few kilometres.
- Type C: Transportable equipment for between about 6 and 24 telephone channels.

2.2 *A break in communication circuits*

A communication link, on radio or cable or open-wire line, has been broken by a disaster. The need is to re-establish communications on the route concerned, which could be one of any circuit capacity between one and several thousand telephone channels (or the equivalent).

Equipment required:

- Type A: (As above), used as gap-bridging equipment in Phase I of the relief operations.
- Type C: A gap-bridging link with a capacity of up to 24 telephone circuits, over line-of-sight and near line-of-sight paths. This would be sufficient to restore priority communications even on a route which normally carries a much larger number of telephone circuits.
- Type D: A gap-bridging link over an obstructed or non-line-of-sight path.
- Type E: A high capacity link (greater than 24 telephone channels) for gap-bridging purposes.

3. Preferred frequencies

The frequency bands suggested here are for general guidance.

Administrations will wish to ensure that the frequency assignments used for emergency equipment conform with the Radio Regulations and with national and regional use of the spectrum.

3.1 *Equipment Type A*

Emergency links, with one or two channels to be provided at very short notice, may be provided in the HF bands particularly at frequencies between about 2 and 10 MHz. Such equipments can usually be used at ranges of up to about 250 km depending on local circumstances, annual and seasonal variations, etc. The transmission may be poor due to fading, noise, and interference.

3.2 *Equipment Type B*

Local networks can be provided by using a number of single-channel links or by an arrangement similar to a land mobile system, using as low a frequency as possible in the VHF or UHF bands so that acceptable performance can be achieved even over marginally line-of-sight paths. Frequencies between about 50 and 88 MHz and between about 150 and 174 MHz are suitable but these bands are congested in many areas. It is possible that frequencies in appropriate bands between about 335 and 470 MHz could be reserved.

Special care should be taken to choose individual frequencies in such a way as to avoid difficulties due to intermodulation when several frequencies are used for each direction of transmission. A two-frequency scheme, in which all the "outward" frequencies are in one half of the band and all the "inward" frequencies are in the other half of the band, is preferred.

3.3 *Equipment Type C*

This equipment would be appropriate for restoring up to about 30 telephone channels in a main route broken by a disaster and could operate on frequencies below 174 MHz, but the chances of reserving frequency assignments with sufficiently wide bandwidths are small. Frequencies could be reserved in appropriate bands between about 335 and 470 MHz, 1.4 to 1.6 GHz, 7 to 8 GHz, and 10.5 to 10.68 GHz for line-of-sight links. Frequencies above about 1 GHz are preferred as the effects of multipath propagation are more serious below 1 GHz.

3.4 *Equipment Type D*

If it is foreseen that the gap could be such that the radio path is obstructed (by mountains, for example) or is not line-of-sight, then frequencies appropriate for trans-horizon operation could be reserved. The frequencies are likely to be in appropriate bands in the ranges 800 to 1000 MHz, 1.7 to 2.7 GHz, and 4.2 to 5 GHz.

3.5 *Equipment Type E*

Transportable line-of-sight microwave links can readily provide sufficient baseband width to carry up to at least 960 telephone channels and multi-hop FM equipment for up to 2700 telephone channels has been developed at 11 GHz. It would be preferable to avoid bands likely to be in use or planned for trunk communications (e.g. 1.7 to 2.3, 3.8 to 4.2, 5.9 to 7.1 GHz). Suitable bands for emergency purposes could be in the approximate ranges 4.2 to 5.0, 7.1 to 8.5, 10.5 to 10.68 GHz, 11.7 to 13.2 GHz, etc. When these bands are not available for exclusive use, care will be needed to avoid interference problems; as an example, the emergency channels could be interleaved with existing channels. The choice of frequencies within these bands is likely to vary from one administration to another. At all frequencies the use of a four-frequency plan for multi-hop systems is to be preferred in order to reduce interference arising from the low back-to-front ratio of the relatively small antennas. There may be advantages in setting up links at the lower frequencies, due to the wider beam angles of the antennas, and the greater efficiency of power conversion from d.c. to microwave.

3.6 *Choice of frequencies for terrestrial access to a transportable earth station*

In the case of choice of frequency band for emergency terrestrial communications to an earth station operating in a satellite service, the following additional restrictions should be considered:

- space-earth frequency bands should be avoided,
- careful consideration should be given to difficulties which could arise if earth-space frequency bands are used,
- trans-horizon systems should be avoided.

4. Engineering principles

4.1 *Low-capacity links (Equipment Type A)**

HF transportable equipments for 1 or 2 channels should employ only solid-state components and should be designed to switch off the transmitters when not in use, in order to conserve battery power.

As an example, a solid-state 100 W single-sideband terminal in a band between (say) 2 and 8 MHz operated with a whip antenna, could have a range of up to 250 km. Simplex operation (transmitter and receiver employing the same frequency) with a frequency synthesizer to ensure a wide and rapid choice of frequency when interference occurs and to facilitate setting-up in an emergency, can give up to 24 hours operation from a relatively small battery (assuming that use of the transmitter is not excessive). The battery can be charged from a vehicle generator and all units can be hand-carried over rough country.

4.2 *Local radio networks (Equipment Type B)*

Radio networks B are envisaged in § 2.1 and 3.2 as local centres with single-channel radiocommunication with 10 to 20 out-stations, operating on VHF or UHF up to about 470 MHz. Single-channel and multi-channel equipments similar to types used in the land mobile service could be used.

4.3 *Links up to 30 channels (Equipment Type C)*

D.c. operated solid-state equipment is preferred. It can be associated with light-weight, high gain Yagi (or similar) antennas, giving a range of up to 100 km line-of-sight, but capable of accepting some obstruction from trees on shorter paths. Simply erected guyed poles which can be rotated from ground level are to be preferred. If separate antennas are used for transmitting and receiving with cross polarization, it is convenient for the transmitters to be connected to antennas which are polarized at 45° (from top right to bottom left looking along the path from behind the antenna); if transmitter and receiver antennas are mounted on the same sub-assembly, with male and female connectors, there can then be no confusion over the plane of polarization to be selected, since the received signal will always be cross-polarized with respect to the transmitted one.

Single frequency, or selectable pre-set frequencies are to be preferred to eliminate as many variables as possible during the initial setting-up of the equipment. Foam-filled or solid dielectric flexible cable is to be preferred as this is less liable to mechanical damage and the effects of moisture.

4.4 *Trans-horizon (Equipment Type D)*

Equipment which is suitable for transportation by road or railway or by helicopter is available; such equipment, together with power supply equipment, can be easily and quickly installed and put into service. The equipment capacity is from about 12 to 120 telephone channels, depending on the requirements, the topography and other factors. The use of receivers with low noise factors and with special demodulators, and of diversity reception, enables the size of the antennas, the transmitter power, and the size of the power supply equipment, to be smaller than those often used for conventional trans-horizon installations.

4.5 *High capacity links (Type E)*

For capacities of 300 telephone channels and above, it is recommended that the radio-frequency equipment is mounted in head units directly behind the antennas. For transportable equipment, preference should be given to equipment in which reflectors of diameter less than about 2 m are available. Because IF interconnection at repeaters is a desirable feature, an IF interconnection should be possible between the radio-frequency heads. However, since the equipment which is to be bypassed in an emergency or for temporary use will most likely be at ground level, the control cable should bring the IF to the control unit at ground level. The antennas of equipments used for relief operations are likely to be smaller than those of fixed microwave links, and it is therefore important that the output power of the transmitters should be as high as possible, and the noise factor of receivers should be as low as possible. Battery operated equipment is preferable; 12 V and/or 24 V supplies are appropriate if the batteries are to be rechargeable from the dynamos or alternators of any vehicles which are available.

* These remarks on equipments operating on frequencies below about 30 MHz are a concern of Study Group 3 as well as Study Group 9.

An alternative arrangement would be to house the equipment in a number of containers. These would not only facilitate the transport of the equipment but each container could provide facilities for rapidly installing a number of transmitters and receivers. The maximum number of transceivers to be housed in any one container would depend on the dimensions and maximum weight adopted, allowing for transport by helicopter, aeroplane or any other means of transport.

From a logical standpoint, the design of an emergency system covers a very wide range of problems requiring the collaboration of specialists in a number of technical fields. Each country or administration should find the solution adapted to its special needs.

5. Interfaces with existing communications links

5.1 Equipments Type A and Type B

These equipments will usually terminate on a telephone (or the equivalent) and few (if any) problems of interfaces will arise.

5.2 Equipments Types C, D and E

These equipments might have to be interconnected with the existing network at baseband at the basic group or super-group frequency, at 12-108 kHz and/or at various other frequencies such as the intermediate frequencies of radio systems and the frequencies used in various cable and open-wire line systems. Analogue radio-relay equipment can also be used for the emergency connection of PCM systems providing suitable interface equipment is available. No attempt is made in this Report to discuss in detail this most important aspect of transportable equipment for relief operations, but clearly if an administration is holding reserve radio equipment for use in possible disasters, it will in many cases be desirable to provide multiplexing and interface equipment in addition.

6. Transmission quality

Equipment of type A will have a noise performance which is critically dependent upon the antennas and path length in a particular case.

Equipments of types B and C are more likely to provide similar transmission quality, when in use for relief work, as in normal use.

Equipment of type D would, as with type A, be very dependent upon the siting of the terminals and the size of antennas.

Transportable microwave equipment of type E, because of the need to use smaller antennas and lower transmitter powers than for fixed links, would be likely to have a transmission quality below that normally required for trunk connections. Nonetheless this performance should be such that the network can still carry out all normal functions. Equipments currently available typically have noise contributions as follows:

- < 1000 pW for up to 50 km for 960 channels (4 to 12 GHz);
- < 5000 pW for up to 50 km for more than 1800 channels (4 to 6 GHz);
- < 5000 pW for up to 25 km for 2700 channels (11 GHz);
- < 1 in 10^7 error ratio for PCM systems (120 to 480 channels).

Note. — It should be noted that the frequency bands or parts of these bands indicated in the present Report can also be used for other services in accordance with the Radio Regulations.

REPORT 940

POINT-TO-MULTIPOINT SYSTEMS

(Question 27/9 and Study Programme 27A/9)

(1982)

1. Introduction

This Report is the response to Study Programme 27A/9 which is concerned with point-to-multipoint systems for telephony, data or video applications. Terrestrial point-to-multipoint (P-MP) microwave radiocommunications are beginning to emerge as economical solutions for services that must be provided to multiple termination sites. In the past, such systems normally utilized local distribution wire plant, coaxial cable or point-to-point radiocommunications systems.

In some instances, however, the technical and economic constraints of that type of media have tended to limit further development, especially for large bandwidth transmission systems.

Examples of such systems have been described in various CCIR Reports. Report 607 identifies a P-MP application whereby simultaneous transmission of several television and associated sound signals are distributed to more than one receive location. Report 380 describes a P-MP rural subscriber telephone system that incorporates omnidirectional transmission from base and repeater radio transmitters to subscriber stations. Report 379 (Annex III) describes a multi-directional time division multiplex system operating in Band 9 for telephone trunk connections. Annexes I, II and III in this Report provide additional examples of P-MP systems.

The following paragraphs discuss general features of P-MP systems and factors to be considered in their design.

2. System configuration

All P-MP systems share a common feature in having a central station generally using an omnidirectional antenna and a number of terminal or subscriber stations. The subscriber stations typically employ directional antennas. Transmission may be one-way as in the case of video signal distribution but most applications employ two-way transmission. When coverage of a large geographic area is required, a cellular network is employed, similar to high density mobile radio systems. Various frequency re-use schemes have been used in the reported systems. This becomes an important factor in system design in order to assure efficient use of the spectrum.

3. Frequency band considerations

A number of considerations enter the choice of frequency band, depending on service requirements and other factors. Experience has indicated that the following sub-division is useful:

3.1 *Frequency bands below 1 GHz*

Because of low cost and compact size of the radio equipment, these bands have proved suitable for various mobile services. These same features are desirable for P-MP systems. However, the use of these bands is limited to special applications, such as low capacity systems in rural areas, because of limited available bandwidth.

3.2 *Frequency bands between 1 and 10 GHz*

These bands are widely used for medium to high capacity point-to-point systems. Considering that an omnidirectional antenna is used at the central station, sharing with other systems in congested RF environments is difficult. Some applications may be best accommodated in rural areas or in exclusively allocated bands.

3.3 *Frequency bands above 10 GHz*

For widespread use in congested RF environments, the bands above 10 GHz offer certain advantages, including small component size and availability of spectrum. There are indications that the use of bands near 20 GHz are desirable for systems designed to carry high capacity data. Frequencies below 20 GHz offer the advantage of lower rain attenuation and those above 20 GHz of uncongested spectrum.

4. Modulation/access techniques

A variety of modulation, accessing and multiplexing methods have been used for P-MP systems.

Modulation methods used for P-MP applications have included both analogue and digital. Digital modulation formats used include ASK (amplitude-shift keying), PSK (phase-shift keying) and FSK (frequency-shift keying). Although ASK requires a higher signal-to-noise ratio for a given BER, it has found application above 20 GHz due to requirements imposed by oscillator stability and cost. PSK or FSK modulation is generally suitable at lower frequencies.

For multiple access systems, a comparison of three access techniques has been made [CCIR, 1978-82]. TDMA (time division multiple access) was found superior in certain applications, to SSMA (spread spectrum multiple access) and SCPC-MA (single channel per carrier multiple access) when considering factors such as spectrum efficiency, flexibility and economy. SSMA was generally found to be less economical and to require a greater bandwidth whereas SCPC-MA has somewhat less flexibility for varying subscriber bit rates.

5. Summary

This Report serves to introduce the concepts involved in point-to-multipoint systems. A wide variety of methods and applications have been reported. Continuing studies of these techniques are needed especially with regard to optimum frequency reuse patterns and sharing with other types of systems.

REFERENCES

CCIR Documents

[1978-82]: 9/239 (Japan).

ANNEX I

A DIGITAL POINT-TO-MULTIPOINT SYSTEM

1. Introduction

This Annex describes a point-to-multipoint (P-MP) system designed to transmit business information, such as computer data, facsimile and video. For the example described here, a frequency near 26 GHz was chosen [Shindow *et al.*, 1981].

2. System description

The system offers end-to-end digital communication services. Each subscriber has access to the base station on a demand assigned or pre-assigned basis. Considering the large P-MP system capacity requirement due to rapid growth in business communications, this P-MP system was designed with the following features:

- each subscriber has access to the base station with transmission rates ranging from 64 kbit/s to 2 Mbit/s;
- services can be provided to a new subscriber rapidly and economically;
- the utilization of modern microwave technology (microwave integrated circuits) which miniaturise the transmitter and receiver for ease of installation at the subscriber's premises.

3. Access scheme

The features described above led to a decision that TDMA was the most appropriate access method for this P-MP system particularly when subscribers have various bit rates [CCIR, 1978-82]. Subscriber receivers operate in the continuous mode, but transmitters operate in the burst mode. Thus the burst carrier received at the base station is not coherent.

4. Modulation method

Typical modulation methods are ASK, FSK and PSK. Taking into account the strong requirements of low cost and small size for subscriber radio equipment, it may be necessary to produce all the RF circuits, such as mixer, modulator, circulator, oscillator and switch using microwave integrated circuit (MIC) technology. The use of a dielectric resonator stabilized microwave oscillator is considered to be particularly important. The highest stability in available MIC oscillators is $10^{-4}/(5^{\circ}\text{C} \sim 60^{\circ}\text{C})$ in the 26 GHz band. A promising modulation scheme found for this application is ASK.

5. Frequency reuse pattern

This P-MP system uses more than one base station to obtain adequate geographic coverage in metropolitan areas. This requirement leads to a cellular configuration of the network [CCIR, 1978-82]. A smaller cell will increase the number of base stations but will ensure a greater reuse of frequency. It is sometimes desirable for economic reasons to design the system with, initially, a larger cell size and then reduce its size later. Therefore any frequency plan should be adaptable to accommodate subsequent cell size reduction.

The cellular structure used in this system is based on a rhombus configuration. Other reuse patterns can be made on a triangular or hexagonal basis. Further studies and experiments are necessary to define the optimum assignment pattern taking into account achievable radiation patterns and reflection problems.

6. Conclusion

The basic features of a P-MP system are described. However studies are only at an early stage, and further work is necessary. Other important problems such as propagation conditions, performance objectives, frame and burst structures, interface between data terminal equipment and TDMA equipment, and also between base station TDMA equipment and exchange termination in public networks need to be studied.

REFERENCES

SHINDOW, S., KURITA, O. and AKAIKE, M. [June, 1981] Radio subscriber loop system for high-speed digital communications. IEEE International Conference on Communications (ICC '81), Denver, Co., USA, Conf. Rec., 66.1.1-66.1.5.

CCIR Documents

[1978-82]: 9/239 (Japan).

ANNEX II

MULTIPOINT DISTRIBUTION SERVICE (MDS)

1. System description

The MDS provides for one-way broadcast transmission, at approximately 2 GHz, of information such as M/NTSC video signals to geographically distributed communities of interest [CCIR, 1978-82]. These signals may be used for either entertainment, business, social or community purposes. A typical MDS system consists of an omnidirectional microwave transmitter and antenna at the transmitting site, a directional receive antenna, down converter and a broadcast television receiver at each receive location. The transmit site is generally limited in output power, typically 200 W e.i.r.p., and normally drives an antenna with either an omnidirectional or a cardioid radiation pattern with gains of 10 to 16 dB. In some instances pairs of back-to-back cardioid antennas are driven by a single transmitter. The received signal is changed by the down converter from the transmission frequency to an unused channel frequency compatible with the broadcast television receiver.

The system design philosophy for MDS was selected to allow randomly sited transmitters to optimally reuse the same or adjacent channel as often as possible and provide a reasonable size of protected area surrounding each transmit site. Elements of this philosophy required trading off high transmit power against the availability of high gain receive antennas and limiting service to only those receive sites that have unobstructed paths between the transmit and receive sites.

2. Interference considerations

Co-channel interference is controlled by establishing a protected signal area around a transmit site and forbidding any later transmitter installations from violating a 45 dB carrier-to-interference protection ratio for any receiver located in that area as per Report 306. Since this takes advantage of the receive antennas' angular and orthogonal discrimination characteristics, the specific receive antenna used as reference is instrumental in determining the amount of frequency reuse in an area. The characteristics of a typical 0.6 m (2 ft) parabolic reflector was selected for the purpose of making such calculations. New transmit sites are authorized only if it can be demonstrated that the new site will not cause interference to any receiver in the protected area and that the antenna height at the new transmit site will be limited to serve no more than one population centre. The boundary of the protected signal area, in general, is limited to a maximum radius of about 25 km around the transmitter antenna site. A distance of 25 km was chosen as the boundary definition, as that was the maximum distance that a transmit site with an e.i.r.p. of 200 W could reliably provide a signal to a receive site in the worst propagation areas of the North American continent [Vigants, 1975] having a 10 dB noise figure down converter. A reliable signal for this purpose is defined to be a signal sufficient to provide a 23 dB or better signal-to-noise ratio for 99.9% of the time [Fine, 1960].

Adjacent-channel interference is controlled by imposing conditions on both the MDS transmit and receive sites. Measurements indicate that acceptable adjacent-channel interference performance can be expected for more than 90% of the available receiver population if the desired signal at the TV receiver input is always 15 dB higher in level than the undesired signal [FCC, 1974]. In order to help achieve this condition in a practical manner both MDS channels serving the same area are encouraged to physically co-locate transmit antennas as close as possible (0.5 km or less separation) and to transmit orthogonal but equal power signals [FCC]. Further study is required as to the effects of propagation on polarization stability in the 2 GHz band.

REFERENCES

- FCC [June, 1974] A study of the characteristics of typical television receivers relative to the UHF taboos. Federal Communications Commission, Project No. 2229-63, Washington DC 20554, USA.
- FCC Adjacent channel interference test for the multi-point distribution service. FCC/CC Report No. 75-01, Federal Communications Commission, Washington DC 20554, USA.
- FINE, H. [1960] A further analysis of TASO Panel 6 data on signal-to-interference ratios and their applications to description of television service. Federal Communications Commission, Washington DC 20554, USA, OCE Tech. Research Division TRR Report No. 5.1.2.
- VIGANTS, A. [January, 1975] Space-diversity engineering. *BSTJ*, Vol. 54, 1, 103-142.
- CCIR Documents*
- [1978-82]: 9/224 (Conclusions of the Interim Meeting of Study Group 9).

ANNEX III

PACKET RADIO SYSTEM

1. Introduction

This Annex serves to introduce the new technology of packet radio. This technology is currently undergoing experimentation in the United States of America in the 2 GHz band [CCIR, 1978-82].

2. System description

A packet radio network provides the interconnection means in a computer communications network. Communications may be between host computers and end user terminals, and between end terminals.

The basic concept in packet radio is that data is transmitted in packets. Subscriber access is via time division multiple access. A data packet is generated by a user and has routing and destination addresses in the packet header together with the necessary control information. Such a data packet is then transmitted to a nearby repeater which is identified within the packet. Upon correct receipt of the packet, the nearby repeater processes the header to determine if it should relay the packet, deliver it to an attached device, or discard it. Several nearby repeaters may actually receive the packet, but only one repeater will typically be identified to relay it while other repeaters will discard the packet. The packet will then be relayed from repeater to repeater until it arrives at the final destination. Omnidirectional antennas are employed at all stations.

In one configuration, network management is conducted by a unit called a station. Such a station has a number of radios in its subset and it determines the overall link connectivity of the network. In environments composed of fixed and possibly mobile units, each radio collects possible link connections, stores such in memory, and sends such data to the station. Using this data, the station establishes a final connectivity network [Kahn *et al.*, 1978]. Network architecture can be varied to include configurations without stations or a broadcast configuration.

3. Modulation

The choice of the modulation method for use by the packet radio is governed largely by performance requirements. It is necessary to overcome the data rate limitations imposed by multipath propagation. The selection of modulation is also governed by a requirement for the packet radio to reject interference as best as it can and, secondly, to minimize the interference to other systems sharing the same frequency and frequency bands. One modulation method that provides these advantages is direct sequence (DS) spread spectrum modulation with minimum-shift keying (MSK) of the carrier frequency. (Direct sequence spread spectrum is described in Report 651.)

4. Sharing considerations

The packet radio experiments are being conducted in radio frequency bands that are used by systems employing analogue modulation techniques. The packet radio, when using a matched filter or correlation techniques, will have a processing gain that improves the signal-to-noise or signal-to-interference when the interference is uncorrelated with the desired signal as is generally the case. Thus, the packet radio receiver can function satisfactorily with a lower signal-to-interference ratio than an analogue receiver.

The packet radio emissions are of low power spectral density and low duty cycle as compared to analogue and some digital emissions. In some cases, the lower spectral density will enable the packet radio transmitter to more readily share with other receivers. This is an improvement over analogue-to-analogue and some digital-to-digital sharing because of the higher spectral density of these systems.

5. Summary

The packet radio technology is undergoing continuing research and experimentation. It may offer certain advantages over systems using conventional modulation techniques in sharing frequency bands. Some examples of future applications can be found in [Martin, 1977; Abramson, 1970].

REFERENCES

- ABRAMSON, N. [1970] The Alpha system – another alternative for computer communications. AFIPS Conf. Proc., Vol. 37, FJCC.
- KAHN, R. E., GRONEMEYER, S. A., BURCHFIEL, J. and KUNZELMAN, R. C. [November, 1978] Advances in packet radio technology. *Proc. IEEE*, Vol. 66, 11, 1468-1496.
- MARTIN, J. [1977] *Future Developments in Telecommunications*. Prentice Hall Inc., New York, NY, USA.
- CCIR Documents*
[1978-82]: 9/264 (United States of America).
-

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

SECTION 9F: FREQUENCY SHARING WITH OTHER SERVICES

Reports

REPORT 789-1

**PROTECTION OF TERRESTRIAL LINE-OF-SIGHT RADIO-RELAY
SYSTEMS AGAINST INTERFERENCE FROM THE BROADCASTING-SATELLITE
SERVICE IN THE BAND 11.7 TO 12.75 GHz**

(Question 17/9 and Study Programme 17B/9)

(1978-1982)

1. Introduction

According to the Final Acts of the WARC-79, the band 11.7 to 12.75 GHz is allocated to a variety of services in all Regions. The frequency band 11.7 to 12.5 GHz in Region 1, the band 12.1 to 12.70 GHz in Region 2 and the bands 11.7 to 12.2 GHz and 12.5 to 12.75 GHz in Region 3 are allocated to the broadcasting-satellite service. This Report considers only interference to the fixed service from the broadcasting-satellite service.

The high power flux-densities expected from the broadcasting-satellite service necessary for individual reception suggests that sharing will be difficult although the use of spot beam antennas will ease the situation.

Interference both to and from the broadcasting-satellite service is considered in Report 631 and the Report of Interim Working Party 9/3 [CCIR, 1978-82]. In this present Report some parameters of radio-relay systems are given by way of example. Provisional technical parameters for the fixed services in the 12 GHz band are provided and maximum permissible interfering power flux-densities for these services are presented.

Interference from satellite-broadcasting spurious emissions to fixed-service systems in the adjacent frequency bands is also discussed.

2. Protection of the fixed service in the band 11.7 to 12.75 GHz

Several diverse systems operate or are expected to operate in this band. They include the following:

- radio-relay links carrying television using amplitude modulation;
- radio-relay links carrying television using frequency modulation;
- radio-relay links carrying telephony using frequency modulation.

Those provisional technical parameters relevant to sharing problems for these three systems, together with the maximum permissible interfering power flux-density for different angles of arrival, are derived from [CCIR, 1974-78a] and are given in Table I.

The figures given are applicable only to the 12 GHz band and may not be assumed to apply in general to other bands. Other radio-relay systems, for example, those employing digital techniques, could use this band but technical parameters and interference limits have not yet been established.

When using the data given in Table I to assess whether sharing is possible in particular cases, it should be noted that other factors may have to be taken into account. The allowable interference levels assume only a single co-channel interfering source of the same polarization. In some practical situations additional sources of interference may have to be considered in assessing the aggregate effects of interference. The use of larger diameter antennas, different polarizations or frequency interleaving for example, could facilitate sharing. It is likely that sharing between the fixed and broadcasting-satellite services will rely on the antenna discrimination of the radio-relay receiving antenna. It should be noted that particularly in an urban environment, signals from a broadcasting satellite may be reflected, say from a building, into the main beam of a radio-relay receiving antenna resulting in a higher interfering level than would otherwise be the case.

TABLE 1 — Parameters of radio-relay systems in the band 11.7 to 12.75 GHz

Characteristics	TV outside broadcast			TV radio-relay	FDM telephony radio-relay
Type of modulation	FM			AM-VSB	FM
Minimum channel spacing (MHz)	28 ⁽¹⁾			⁽²⁾	28
e.i.r.p. (dBW)	41			23.5-46 ⁽³⁾	39
Transmitting antenna:					
Gain (dBi)	41			40.5	42
Side-lobe characteristic	—			$30 - 25 \log \left(\frac{\varphi}{\varphi_0} \right) \text{ (dB)}^{(5)}$ for $\varphi \geq \varphi_0/2$	$35 - 25 \log \varphi \text{ (dB)}$ for $2^\circ < \varphi \leq 25^\circ$
Polarization	linear			linear	linear
Maximum allowable interfering power flux-density (dB(W/m ²)) ⁽⁴⁾	−125	−100	−90	−134	−128
Angle of arrival (degrees above the horizontal)	<15°	15-25°	>25°	0° ⁽⁶⁾	0-90°
Bandwidth	5 MHz			5 MHz	4 kHz
Percentage of time	99.9			99.9	99.9

⁽¹⁾ This figure is not final. It is foreseen that this terrestrial service would adopt the same channel plan as selected for satellite broadcasting.

⁽²⁾ Most 12 GHz AM television radio-relay systems are multi-channel and use channel separations in multiples of 7 to 8 MHz.

⁽³⁾ The actual value of e.i.r.p. depends on the operational constraints placed on the system.

⁽⁴⁾ In deriving these interference limits the following assumptions have been made:

- TV outside broadcast:
Single-hop links with an allowable single-interference entry 6 dB below receiver noise level.
- TV radio-relay:
Single or two-hop links with a single interference entry 10 dB below receiver noise.
- FDM telephony radio-relay:
A 50-hop link with a total interfering power of 1000 pW in one telephone channel with restrictions on the pointing direction of all link sections.

⁽⁵⁾ Where φ_0 is the half power antenna beamwidth (see Report 631 and Annex 8 of Appendix 30 to the Radio Regulations).

⁽⁶⁾ For other angles of arrival the maximum permissible pfd values should be calculated by using the equation:

$$-134 + 10.5 + 25 \log (\varphi / \varphi_0) \text{ dB for receiver antenna gains of 40.5 dBi.}$$

3. Protection of the fixed service in adjacent bands

Services in the adjacent bands will require protection from spurious emissions from the broadcasting-satellite service. It is shown in [CCIR, 1974-78b], that the maximum allowable interfering power flux-density for the fixed service in the band 11.45 to 11.7 GHz is $-171.4 \text{ dB(W/m}^2\text{)}$ in any 4 kHz band. This figure may be assumed to apply also to the upper adjacent band 12.5 to 12.75 GHz.

REFERENCES

CCIR Documents

[1974-78]: **a.** 9/76 (Germany (Federal Republic of)); **b.** 9/80 (Italy).

[1978-82]: 9/398 (Rev. 1) (IWP 9/3 Report) (The CCIR Secretariat can supply a copy of this Report on request).

REPORT 941 *

**PROTECTION OF TERRESTRIAL LINE-OF-SIGHT RADIO-RELAY SYSTEMS
AGAINST INTERFERENCE FROM THE BROADCASTING-SATELLITE SERVICE (SOUND)
IN THE BAND 1427 TO 1530 MHz**

(Study Programme 17C/9)

(1982)

1. Introduction

Resolution No. 505 of the WARC-79 invites the CCIR to continue and expedite studies relating to the technical characteristics of a satellite sound-broadcasting system for individual reception by portable and automobile receivers, the feasibility of sharing with terrestrial services and the appropriate sharing criteria. Several administrations and organizations have already, from theoretical considerations or by simulation, demonstrated the feasibility of such a satellite sound-broadcasting service operating in the frequency range 500 to 2000 MHz.

This Report examines the problem of sharing with terrestrial fixed services if the band 1427 to 1530 MHz were to be made available for satellite sound broadcasting.

2. Characteristics of a Satellite Sound-Broadcasting System

Report 955 outlines the operational objectives of satellite sound broadcasting and gives link budgets for systems serving areas of a diverse nature with differing quality objectives. The parameters given in the Report relate to a frequency of 1000 MHz and here these have been suitably modified to take account of increased path losses at 1500 MHz. Four standards of service, A, B, C and D have been defined in Report 955 and only satellites conforming to standards A and C with half power beamwidths of 2.5° and 1° respectively have been considered in this study. A brief description of these two standards is given at the foot of Table I. Comprehensive details of all the standards can be found in Report 955. The reference antenna pattern of Report 810 has been adopted in preference to that of Report 391 since this is less restrictive to the broadcasting service in the determination of side-lobe patterns. The pertinent equations, based on Report 810, are set out below:

$$G(\varphi) = G_m - 12 (\varphi/\varphi_0)^2 \quad \text{dB for } 0 \leq \varphi < 1.58 \varphi_0 \quad (1)$$

$$G(\varphi) = G_m - 30 \quad \text{dB for } 1.58 \varphi_0 \leq \varphi < 3.16 \varphi_0 \quad (2)$$

$$G(\varphi) = G_m - 17.5 - 25 \log (\varphi/\varphi_0) \quad \text{dB for } 3.16 \varphi_0 \leq \varphi < \varphi_1 \quad (3)$$

where

φ_1 : value of φ in equation (3) which makes $G(\varphi) = 0$ dB

$$G(\varphi) = 0 \text{ dB for } \varphi > \varphi_1 \quad (4)$$

where in Equations (1) to (4):

$G(\varphi)$: gain of the satellite transmitting antenna at an angle of φ degrees offset from the main beam;

G_m : maximum isotropic gain of the satellite transmitting antenna;

φ_0 : half-power beamwidth of the satellite transmitting antenna (degrees).

It is a normal practice when assessing the likelihood of interference to radio-relay systems to express the interfering signal level in terms of its power flux-density in any 4 kHz band. As no energy dispersal techniques are proposed for the satellite transmitter the worst-case condition of the total interfering power lying within a 4 kHz band must be assumed. This condition corresponds to long "quiet" passages in the transmitted signal.

* This Report should be brought to the attention of Study Group 10.

TABLE I — *Link budgets for sound-broadcasting satellite systems*

	Standard of service			
	A	B	C	D
Type of modulation	FM			
Type of polarization	Circular			
Carrier deviation (kHz)	± 75			
Noise bandwidth (kHz)	250			
Carrier-to-noise ratio (dB)	10			
Coupling loss (dB)	1			
Receive antenna gain (dBi)	3			
Receive system noise temperature (K)	2000			
Carrier frequency (MHz)	1500			
Link margin (dB)	6	15	25	33
Line of sight pfd at edge of beam (-3 dB) (dB(W/m ²))	-102.9	-93.9	-83.9	-75.9
Maximum spreading loss (dB/m ²)	163			
E.i.r.p. on axis (dBW)	63.1	72.1	82.1	90.1
Isotropic gain of satellite antenna (dB)	37.1	43.6	43.6	43.6
Satellite antenna half power beam width (degrees)	2.5	1.0	1.0	1.0
Approximate diameter of satellite transmitting antenna (m)	8	13	13	13
Approximate power to be fed into the satellite transmitting antenna (dBW)	26	28.5	38.5	46.5
(kW)	0.4	0.7	7.0	45

Standard A:

90% of receiving points in a rural area with the angle of elevation of the satellite exceeding 70°, corresponding to a service in low latitude countries.

Standard C:

Reception in medium latitude locations where 90% of areas are served in such a way that 90% of receiving points within the area receive an adequate performance.

3. Power flux-density limits

Recommendation 358 sets out limits to the pfd at the surface of the Earth produced by satellites in the fixed-satellite service. Since the lower frequency limit in this Recommendation is 1.7 GHz and in the absence of a similar recommendation for the satellite broadcasting service (sound) it seems reasonable to adopt the limits of Recommendation 358-2 (Kyoto, 1978) for the present study. However it is recognized that Recommendation 358-2 has been modified (Recommendation 358-3) to raise the lower frequency limit to 2.5 GHz. Since the original figures are more accurate for the purposes of this Report, these have been used (Table II).

TABLE II — *Power flux-density limits in the band 1700 to 2535 MHz in any 4 kHz band*

-154	dB(W/m ²) for $\delta \leq 5^\circ$
$-154 + (\delta - 5)/2$	dB(W/m ²) for $5^\circ < \delta \leq 25^\circ$
-144	dB(W/m ²) for $25^\circ < \delta \leq 90^\circ$

where δ is the angle of arrival of the radio wave (degrees above the horizontal).

4. Interference to fixed services

If the lowest value of transmitter power appearing in Table I is assumed, i.e. 400 W, and the most favourable case of satellite antenna gain, i.e. 0 dB, then the least value of pfd expected at the Earth's surface is -137 dB(W/m²). It may however be possible to assume a further 3 dB circular to linear polarization factor.

Since a pfd of -137 dB(W/m²) exceeds all the limits detailed in Table II it is reasonable to conclude that sharing on the above assumptions may not be feasible in geographical areas visible to the geostationary satellite as the band 1427 to 1530 MHz is used extensively in some European countries for terrestrial fixed services. The use of the geostationary orbit between about 75° West and 75° East, for sound broadcasting by satellite would therefore be precluded in this band.

5. Energy dispersal

Although energy dispersal for satellite sound-broadcasting has not been considered in recent studies on satellite sound-broadcasting, such techniques might ease the sharing problem. Therefore, as an example, a satellite is considered below which has some measure of energy dispersal applied, such that, under the worst condition, the energy is distributed triangularly within a band 180 kHz wide (see Fig. 1).

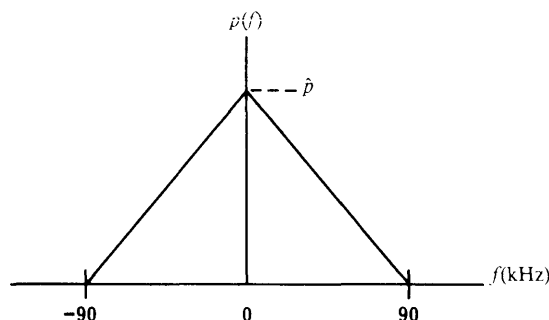


FIGURE 1 — Worst-case power distribution.

Under the conditions depicted in Fig. 1, the total transmitted power P_T is given by:

$$P_T = 1/2(\hat{p} \cdot 180) = \hat{p} \cdot 90$$

therefore:

$$\hat{p} = \frac{P_T}{90}$$

where $p(f)$ is the power spectral density of the emission in W/kHz as a function of frequency f (kHz) relative to the unmodulated carrier frequency and $\hat{p}$ is the maximum value of $p(f)$.

Therefore:

$$p(4 \text{ kHz}) = \frac{P_T}{90} \cdot 4$$

The energy dispersal coefficient = $10 \log \left(\frac{\frac{P_T}{P_T \cdot 4}}{\frac{P_T}{90}} \right) = 13,6 \text{ dB}$

The factor 13.6 dB is employed as an energy dispersal coefficient when re-examining the likelihood of interference to terrestrial radio-relay links. Using this coefficient the least value of pfd becomes -150.6 dB(W/m²) and this may allow sharing where elevation angles exceed about 12°.

6. Interference to Terrestrial radio-relay systems — energy dispersal

Annex I shows details of the power flux-densities (in 4 kHz) expected at four locations in Western Europe from various visible geostationary satellites. The satellites are assumed to serve:

- (a) areas of northern latitude viz., Eastern Canada, France and central U.S.S.R.;
- (b) near equatorial areas viz., Eastern Brazil, Senegal, Egypt and India;
- (c) areas of southern latitude viz., Argentina and southern countries of the African continent.

In each case the longitude of the satellite is assumed to be the same as that of the service area since maintaining a high elevation angle at the service area is considered more important than overcoming eclipsing problems.

For services to areas in (a) and (c) above 1° satellite beamwidths have been assumed with an e.i.r.p. of 63.1 dBW and to area (b) a satellite beamwidth of 2.5° has been considered with an e.i.r.p. of 63.1 dBW. An energy dispersal coefficient of 13.6 dB is assumed throughout.

Satellites having 1° beams serving the areas of northern latitude specified in (a) exceed the pfd limits at the visible Western European locations.

2.5° beam services to the equatorial areas in (b) exceed the pfd limits in all cases where the satellite is visible. If a 3 dB circular to linear polarization factor is assumed sharing may be feasible in some situations.

Services to the areas of southern latitude in (c) employing 1° beams exceed the pfd limits in all cases.

7. Conclusions

The pfd limits assumed in Table II of § 3 have been chosen as a convenient starting point for this study. Based upon these assumptions the following conclusions may be drawn.

Sound-broadcasting services from the geostationary orbit may not share the band 1427 to 1530 MHz with terrestrial radio-relay systems which are visible to the satellite unless some form of energy dispersal is employed.

If energy dispersal of the order of 14 dB is employed satellite sound-broadcasting services with 2.5° beams operating to certain equatorial areas could frequency share with some existing 1500 MHz terrestrial radio-relay systems in Western Europe which are visible to the satellite if a 3 dB polarization discrimination factor is assumed.

Satellite sound-broadcasting services to areas of northern latitude are not likely to be able to share with existing visible 1500 MHz fixed services in Western Europe.

Some scope may exist for sharing between Western European fixed services and areas of southern latitude if e.i.r.p.s could be employed which conformed with the standard A link budget in Table I. However, this could lead to difficulties with fixed services in other geographical areas.

In order to protect single channel and low capacity 1500 MHz radio-relay links more stringent limitations may have to be adopted. This point is worthy of further investigation.

ANNEX I

DETAILS OF POWER FLUX-DENSITY CALCULATIONS REFERRED TO IN § 6 OF THIS REPORT

TABLE III

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Eastern Canada 55°N, 67°W 1° beam 82.1 dBW	Iceland	65°N 20°W	8.17	2.80	40906	163.2	14.00	-124.7	-152.4	-27.7
	United Kingdom	55°N 2°W	5.39	4.63	41207	163.3	9.83	-129.0	-153.8	-24.8
	Spain	40°N 5°W	12.61	6.40	40433	163.1	6.32	-132.3	-150.2	-17.9
	Norway	62°N 10°E	NV							
France 47°N, 2°E 1° beam 82.1 dBW	Iceland	65°N 20°W	14.68	1.91	40217	163.1	14.00	-124.6	-149.2	-24.6
	United Kingdom	55°N 2°W	27.19	0.79	38989	162.8	36.58	-101.7	-144.0	-42.3
	Spain	40°N 5°W	43.18	1.18	37665	162.5	27.22	-110.8	-144.0	-33.2
	Norway	62°N 10°E	19.53	1.29	39724	163.0	24.06	-114.4	-146.7	-32.3
Central U.S.S.R. 55°N, 75°W 1° beam 82.1 dBW	Iceland	65°N 20°W	NV							
	United Kingdom	55°N 2°W	NV							
	Spain	40°N 5°W	NV							
	Norway	62°N 10°E	2.78	3.75	41494	163.4	12.12	-126.7	-154.0	-17.1

TABLE IV

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Southern Africa 30°S, 23°E 1° beam 82.1 dBW	Iceland	65°N 20°W	9.45	13.37	40769	163.2	0.00	-138.7	-151.8	-13.1
	United Kingdom	55°N 2°W	23.36	12.79	39350	162.9	0.00	-138.4	-144.8	-6.4
	Spain	40°N 5°W	35.51	11.63	38262	162.6	0.00	-138.1	-144.0	-5.9
	Norway	62°N 10°E	19.02	13.13	39775	163.0	0.00	-138.5	-147.0	-8.5
Argentina 38°S, 67°W 1° beam 82.1 dBW	Iceland	65°N 20°W	8.17	14.41	40906	163.2	0.00	-138.7	-152.4	-13.7
	United Kingdom	55°N 2°W	5.39	14.09	41207	163.3	0.00	-138.8	-153.8	-15.0
	Spain	40°N 5°W	12.61	13.34	40433	163.1	0.00	-138.6	-150.2	-11.5
	Norway	62°N 10°E	NV							

TABLE V

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Eastern Brazil 5°S, 45°W 2.5° beam 63.1 dBW	Iceland	65°N 20°W	14.11	9.28	40276	163.1	4.23	-145.4	-149.4	-4.0
	United Kingdom	55°N 2°W	16.49	9.12	40032	163.0	4.42	-145.1	-148.3	-3.2
	Spain	40°N 5°W	28.30	8.35	38888	162.8	5.38	-143.9	-144.0	-3.7
	Norway	62°N 10°E	7.01	9.43	41031	163.3	4.06	-145.7	-153.0	-7.3
Senegal 15°N, 15°W 2.5° beam 63.1 dBW	Iceland	65°N 20°W	16.59	5.70	40021	163.0	6.00	-143.5	-148.2	-4.7
	United Kingdom	55°N 2°W	26.20	5.21	39081	162.8	6.00	-143.3	-144.0	-0.7
	Spain	40°N 5°W	42.60	3.85	37708	162.5	7.55	-141.5	-144.0	-2.5
	Norway	62°N 10°E	16.88	5.77	39991	163.0	6.00	-143.5	-148.1	-4.6
Egypt 25°N, 15°W 2.5° beam 63.1 dBW	Iceland	65°N 20°W	7.16	4.84	41015	163.3	6.00	-143.8	-152.9	-9.1
	United Kingdom	55°N 2°W	21.01	4.39	39578	162.9	6.00	-143.4	-146.0	-2.6
	Spain	40°N 5°W	31.48	4.57	38605	162.7	6.00	-143.2	-144.0	-0.8
	Norway	62°N 10°E	17.93	4.16	39885	163.0	6.00	-143.5	-147.5	-4.0
India 20°N, 80°E 2.5° beam 63.1 dBW	Iceland	65°N 20°W	NV							
	United Kingdom	55°N 2°W	NV							
	Spain	40°N 5°W	NV							
	Norway	62°N 10°E	0.57	5.80	41739	163.4	6.00	-143.9	-154.0	-10.1

Notes to Tables III, IV and V:

Columns (1) Location of broadcasting service area and details of satellite emissions.

(2) Location at which power flux-density is estimated.

(3) Elevation from location in column (2) to satellite (degrees).

(4) Offset angle from satellite antenna main beam (degrees).

(5) Path length from satellite (km).

(6) Spreading loss (dB/m²).

(7) Satellite antenna gain at off-set angle (dB).

(8) Estimated interfering power flux-density (dB(W/m²)).

(9) Power flux-density limit as defined in § 3 of this Report (dB(W/m²)).

(10) Power flux-density margin; negative values indicate that the limit is exceeded.

NV: not visible.

REPORT 942 *

**FREQUENCY SHARING BETWEEN THE FIXED SERVICE AND PASSIVE
SENSORS IN THE BAND 18.6 TO 18.8 GHz**

(Study Programme 17D/9)

(1982)

Report 850 prepared by Study Group 2 considers the problem of frequency sharing between passive sensors and the fixed, mobile (except aeronautical) and fixed-satellite services in the band 18.6 to 18.8 GHz.

So far as the fixed service is concerned, account should be taken of the following additional considerations:

- (a) The development of fixed-service systems for the 18 GHz band is at an early stage and a highly desirable feature would be the use of small antennas.
 - (b) The conclusions of Report 850 are drawn from curves with only discrete values of transmitting antenna gain, i.e. 0, 10, 20, 30 and 40 dBi. Because of the crossings of certain curves, it is very difficult to determine intermediate values. Therefore, it may be possible that minimum antenna gains of say 38 dBi would be acceptable.
 - (c) Report 850 is the result of a study carried out pursuant to § 3 of the operative part of the WARC-79 Recommendation No. 706. Before specific values for the minimum restrictions applicable to the fixed service are determined, § 4 of the operative part of this Recommendation should be studied.
 - (d) Any limits imposed for the e.i.r.p. and the transmission power could be mandatory in Region 2 where passive sensors have primary status. Although administrations in Region 1 and in Region 3 recognize Radio Regulations No. 871 and endeavour to limit harmful interference to passive sensors, this can in no way impede the installation of fixed-service stations if e.i.r.p. higher than the values mentioned in Report 850 were to be used.
- .

* This Report is brought to the attention of Study Group 2.

QUESTIONS AND STUDY PROGRAMMES, RESOLUTIONS, OPINIONS AND DECISIONS

QUESTION 1/9

**ANALOGUE RADIO-RELAY SYSTEMS FOR TELEPHONY
USING FREQUENCY-DIVISION MULTIPLEX**

(1953-1959)

The CCIR,

CONSIDERING

- (a) that a variety of types of multi-channel radio-relay systems, operating at frequencies above about 30 MHz, use frequency-division multiplex;
- (b) that it is sometimes desirable to be able to interconnect systems of different types particularly on international circuits,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the radio, baseband or intermediate-frequency characteristics of frequency-division multiplex radio-relay systems, operating at frequencies above about 30 MHz, which it is essential to specify to enable two such systems to be interconnected;
2. what specifications should be drawn up for such characteristics and should be recommended as standards for radio-relay systems, carrying frequency-division multiplex for use on international circuits and operating at frequencies above about 30 MHz?

Note. — See Recommendations 268, 275, 283, 306, 380, 381, 382, 383, 385, 386, 387, 401, 403, 404, 497 and Report 933.

STUDY PROGRAMME 1A-1/9

**ANALOGUE RADIO-RELAY SYSTEMS OF CAPACITY GREATER THAN
1800 TELEPHONE CHANNELS, OR THE EQUIVALENT**

(1959-1978)

The CCIR,

CONSIDERING

- (a) that there may be economic and operational advantages in the use of radio-relay systems using frequency or amplitude modulation and having a capacity substantially greater than 1800 telephone channels in a single radio channel;
- (b) that amplitude-modulated and frequency-modulated systems should be capable of operating compatibly in the same frequency bands;
- (c) that very large capacity radio-relay systems may also be required in the future for the transmission of higher-definition television;
- (d) that additional information is needed to establish the practical limits of capacity, performance, and environmental integration of such very large capacity systems,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the determination of optimum values for the system characteristics (including the baseband, intermediate-frequency and radio-frequency characteristics), to enable the maximum capacity of each radio channel to be achieved;
2. the value of path cross-polarization discrimination achieved by improving the antenna and feeder system, taking into account any other factors concerned*.

Note. — See Recommendation 384 and Reports 287 and 781.

* The effects of propagation are being studied under Question 25/9.

QUESTION 2-1/9 *

**HYPOTHETICAL REFERENCE CIRCUITS AND CIRCUIT NOISE
FOR RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY**

(1953-1959-1970)

The CCIR,

CONSIDERING

that the noise permissible in a radio-relay system may be expected to depend to some extent on the length of the system, and that it may, therefore, be desirable for design purposes to specify hypothetical reference circuits for radio-relay systems analogous to those specified by the CCITT for cable systems,

UNANIMOUSLY DECIDES that the following question should be studied, in cooperation with the CMBD and the CMTT, each within its own terms of reference:

1. what hypothetical reference circuits are required for the design of radio-relay systems;
2. what are the elements appropriate to such circuits;
3. what is the division of the permissible noise power amongst the various elements?

Note. — See Recommendations 390, 391, 392, 393, 395, 396, 397, 555 and Reports 375 and 931.

STUDY PROGRAMME 2A-1/9

**NOISE TOLERABLE DURING VERY SHORT PERIODS OF TIME
FOR ANALOGUE RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY**

(1956-1959-1966-1970)

The CCIR,

CONSIDERING

- (a) that, for radio-relay links, it is necessary to clarify how high noise levels, occurring for short periods of time, should be taken into consideration;
- (b) that consideration must be given not only to the percentage of time during which high noise levels occur, but also to the duration of each burst of noise;
- (c) that account should be taken of the fact that in radio-relay systems, high noise levels often occur at night and further, that the introduction of low night rates in certain countries and the transmission of data may produce heavy loading of the system at night;
- (d) that examples of the distribution of noise with time in radio-relay systems are given in Recommendation 393, which also contains examples of the values of noise power likely to be experienced for short periods of time,

UNANIMOUSLY DECIDES that the following studies should be carried out in cooperation with the CMBD and the CMTT, each within its own terms of reference:

1. the way in which the maximum value of noise should be specified when considering transmission on radio-relay systems;
2. the time constant which the noise measuring apparatus should have;
3. whether a limit should be set to the number of high noise bursts, of a duration exceeding a given value, occurring in a given time;
4. whether account should be taken of the fact that heavy system loading may occur at night as well as in the day;
5. the way in which the maximum tolerable noise power for a part of a radio-relay link can be deduced from the maximum value of noise power tolerable for the complete link.

* This Question also concerns trans-horizon radio-relay systems.

STUDY PROGRAMME 2B-1/9

**NOISE IN ANALOGUE RADIO-RELAY CIRCUITS FORMING PART
OF VERY LONG TELEPHONE CONNECTIONS**

(1965-1966-1970)

The CCIR,

CONSIDERING

- (a) that CCITT Recommendations G.143 and G.153 state that very long circuits should have, as an objective, a noise performance better than 3 pW/km;
- (b) that a hypothetical reference circuit longer than 2500 km has not been found necessary for radio-relay systems;
- (c) that radio-relay systems will be interconnected with long submarine cables or satellite systems with overall noise performance frequently better than that recommended by Recommendations 393 and 395;
- (d) that very long circuits may be carried either over selected channels of radio-relay systems designed in accordance with Recommendation 393 or carried over radio-relay systems intended specifically for this purpose (see Question 7/CMBD);
- (e) that the demand for long low-noise circuits may become so great that the selection of channels from radio-relay systems, designed in accordance with Recommendation 393, may not always provide sufficient capacity;
- (f) that, therefore, there may be an increasing requirement for circuits longer than 2500 km, having a noise performance better than the general noise objectives of Recommendation 393;
- (g) that to provide for such circuits, it might become desirable to establish additional and better design objectives for radio-relay systems than those now stated in Recommendation 393;
- (h) that the provision of long circuits with special noise requirements should not adversely affect the economy or efficiency of radio-relay systems;
- (j) that due regard should be paid to the efficient use of the radio-frequency spectrum,

UNANIMOUSLY DECIDES that the following studies should be carried out in cooperation with the CMBD:

1. the extent to which channels, suitable for inclusion in very long circuits, may be provided by the selection of low-noise channels on radio-relay systems, designed in accordance with Recommendation 393;
2. the way in which radio-relay systems, designed in accordance with Recommendation 393, can be adapted to provide a better noise performance suitable for very long circuits and the extent to which this is practicable;
3. the desirability of designing radio-relay systems especially for the purpose of providing circuits meeting low noise objectives similar to those which apply to circuits carried on long submarine cable and communication-satellite systems, and the factors involved;
4. the improvements in the noise objectives for radio-relay systems, which might reasonably be considered without restricting the economic development of radio-relay systems, in the light of advancing technology and taking into account the studies by the CMBD;
5. in a general way, the characteristics of radio-relay systems providing better noise performance than that now stated in Recommendation 393.

Note. — See Report 288.

STUDY PROGRAMME 2C/9

**NOISE IN ANALOGUE RADIO-RELAY SYSTEMS FOR TELEVISION
AND TELEPHONY DURING PERIODS WITHOUT FADING**

(1974)

The CCIR,

CONSIDERING

- (a) that it is desirable to evaluate for planning purposes the noise that exists during periods without fading;
- (b) that the overall performance of a real link depends on both the equipment and the conditions under which it is operating;
- (c) that any one type of equipment may be operated under a variety of different conditions;
- (d) that information is therefore required on the equipment-dependent noise since it makes a significant contribution to the overall noise for long periods in which there is no fading;
- (e) that to meet the noise limits for systems in practical operation it is essential to allow a margin over the values measured on a simulated link;
- (f) that the International Electrotechnical Commission (IEC) has standardized methods of measurement on simulated links,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. definitions of different sources of noise in radio-relay systems during periods without fading and how these sources affect the total noise;
 2. criteria which are necessary to judge the results of measurements made on simulated links in view of their future application to real links;
 3. requirements which should be met by equipment in order to meet the requirements of Recommendation 395, whilst allowing a reasonable margin for other sources of noise which are not present on simulated links.
- Note.* — See Reports 612 and 931.

QUESTION 3-2/9

**ANALOGUE RADIO-RELAY SYSTEMS FOR THE TRANSMISSION
OF TELEVISION SIGNALS OR FOR THE SIMULTANEOUS TRANSMISSION
OF TELEVISION AND SOUND PROGRAMME SIGNALS**

(1956-1959-1970-1978)

The CCIR,

CONSIDERING

- (a) that the study of preferred characteristics for radio-relay systems for multi-channel telephony is being pursued;
- (b) that the performance requirements for video and sound programme circuits over long distances are given in Recommendations 567 and 503 to 505 respectively;
- (c) that these Recommendations do not, however, include a consideration of the characteristics of radio-relay systems designed for the simultaneous transmission of analogue sound programme and television signals;
- (d) that it is preferable for the major intermediate-frequency and radio-frequency characteristics of radio-relay systems for analogue sound programme and television signals to conform, as far as possible, with those for multi-channel telephony,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics of international radio-relay systems for the transmission of signals for analogue sound programme and television when they differ from those for telephony?

Note. — See Recommendations 270, 276, 402, 405, 463, 555 and Report 375.

STUDY PROGRAMME 3A-2/9

**PREFERRED CHARACTERISTICS FOR THE TRANSMISSION OF ANALOGUE TELEVISION
OR SOUND PROGRAMME SIGNALS OR THE SIMULTANEOUS
TRANSMISSION OF THESE SIGNALS**

(1959-1970-1978)

The CCIR,

CONSIDERING

- (a) that the CMTT studies the characteristics of systems in which the sound signals and video signal are multiplexed in a way that is not designed to be dependent on a particular transmission medium, for example, systems in which the sound signals and the video signal are multiplexed within the television signal video baseband;
- (b) that radio-relay systems are used for the simultaneous transmission of television and analogue sound programme signals;
- (c) that Recommendation 402 gives values for the preferred characteristics of a frequency-modulated sub-carrier for the transmission of a single analogue sound programme channel on a radio-frequency carrier modulated with a television signal;
- (d) that, in certain circumstances, several sound programme channels may be required over the same route as a television transmission;
- (e) that radio-relay systems with a capacity of up to 960 telephone channels may be used to transmit a television signal or several sound programme channels on each radio-frequency carrier;
- (f) that radio-relay systems with a capacity of 1260 or 1800 telephone channels may be used to transmit simultaneously a television signal and several sound programme channels on each radio-frequency carrier,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the preferred characteristics and most critical parameters for the simultaneous transmission of analogue sound programme and television signals in a way designed to be specific to radio-relay systems;
2. determination of the preferred characteristics for the provision of several sound programme channels when the radio-frequency carrier transmitting the sound programme channels is used alternatively for television (radio-relay systems with a capacity of up to 960 telephone channels).

Note. — See Report 289.

QUESTION 4/9

**SERVICE CHANNELS FOR RADIO-RELAY SYSTEMS
FOR TELEVISION AND TELEPHONY**

(1956-1959)

The CCIR,

CONSIDERING

- (a) that service channels are necessary for the maintenance of radio-relay systems;
- (b) that it would be desirable to define the steps to be taken for the establishment of such service channels and for facilitating their international connection,

UNANIMOUSLY DECIDES that the following question should be studied:

1. in what form and by what means should the service channels required for the maintenance of radio-relay systems be established;
2. what are the characteristics, if any, to be specified, with a view to permitting international connection of such service channels;
3. what are the preferred values of such characteristics?

Note. — See Recommendation 400 and Report 444.

STUDY PROGRAMME 4A-1/9

**PREFERRED CHARACTERISTICS FOR AUXILIARY RADIO-RELAY SYSTEMS
FOR THE PROVISION OF SERVICE CHANNELS FOR RADIO-RELAY SYSTEMS
FOR TELEVISION AND TELEPHONY**

(1959-1970)

The CCIR,

CONSIDERING

- (a) that an auxiliary radio-relay system may be required for the provision of service channels for the maintenance, supervision and control of radio-relay links;
- (b) that this auxiliary system may be arranged by combining it with the main system, as is shown in Recommendation 389;
- (c) that, on the other hand, it may be preferable to use an auxiliary radio-relay system quite independent of the main radio-relay system;
- (d) that the frequency band concerned and the exact frequency allocation plan must be chosen carefully, to avoid interference with the main system;
- (e) that the utmost reliability is essential for this auxiliary radio-relay system, because of the operational importance of the supervisory circuits;
- (f) that Recommendation 400 states the number and the function of the service channels that are required;
- (g) that economy in the use of the radio-frequency spectrum is important,

UNANIMOUSLY DECIDES that the following studies should be carried out:

determination of the characteristics (baseband, type of modulation and radio-frequency arrangement) for an auxiliary radio-relay system of high reliability.

Note. — See Recommendation 389 and Reports 284 and 374.

QUESTION 5-3/9

**AVAILABILITY OF RADIO-RELAY SYSTEMS
FOR TELEPHONY AND TELEVISION**

(1968-1970-1974-1978)

The CCIR,

CONSIDERING

- (a) that all interruptions to traffic, including those caused by excessive noise, are factors affecting availability;
- (b) that the degree of availability required of a system, has a major bearing on system design and on the cost of its provision and operation;
- (c) that protection arrangements are frequently used to improve system availability;
- (d) that information on the availability of radio-relay systems between the points shown as R' and R of Fig. 1, Recommendation 380 will assist the CCITT and Study Group CMBD to define reliability and availability objectives for the overall telephone and television connection,

UNANIMOUSLY DECIDES that the following question should be studied:

1. how should the concept of system availability be applied to radio-relay systems;
2. what standards of availability are the objectives when providing radio-relay systems;
3. what standards of availability are now achieved by radio-relay systems of current design;
4. what standards of availability should be the objective for future radio-relay systems having a length equal to that of a hypothetical reference circuit, when measured between the points shown as R' and R of Fig. 1 of Recommendation 380;
5. what is the contribution of protection switching to system availability?

Note. — See Recommendation 557 and Report 445.

STUDY PROGRAMME 5A-3/9 *

**PREFERRED CHARACTERISTICS FOR MULTI-LINE SWITCHING
ARRANGEMENTS OF ANALOGUE RADIO-RELAY SYSTEMS**

(1965-1966-1970-1974-1978)

The CCIR,

CONSIDERING

- (a) that protection arrangements may be required for radio-relay systems to meet availability objectives;
- (b) that such protection arrangements might permit interconnections across international borders and this requires agreement on some major characteristics;
- (c) that so far only the results from partial studies of relevant characteristics of multi-line switching arrangements are available;
- (d) that the criteria to be used for the switching of television and sound programme circuits as well as the impairments introduced by the switching action are studied by the CMTT;
- (e) that single-line switching and combiner studies are being undertaken under Question 13/9,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the preferred characteristics of multi-line switching arrangements for international interconnection of radio-relay systems, particularly the signalling methods between receiving and transmitting ends;
2. the characteristics of radio-relay systems relevant to the operation of multi-line switching arrangements, particularly the noise detection band allocation;
3. the preferred values for such characteristics.

Note. — See Recommendations 305, 444 and Reports 137 and 443.

STUDY PROGRAMME 5B-1/9

**INTERRUPTIONS TO TRAFFIC ON LINE-OF-SIGHT ANALOGUE
RADIO-RELAY SYSTEMS FOR TELEPHONY**

(1970-1974)

The CCIR,

CONSIDERING

- (a) that continuity of traffic on radio-relay systems may be interrupted either by equipment failure or by excessive fading;
- (b) that, in planning a radio-relay route, decisions must be taken on repeater spacing, fading margins, provisions of diversity and protection switching, etc., which have a major effect on the system availability;
- (c) that diversity and protection switching converts many longer interruptions into either very brief interruptions or none at all;
- (d) that existing Recommendations permit a high noise level for very small percentages of the month;
- (e) that the CCITT is being asked for advice on the level of noise which can be regarded as equivalent to a total interruption;
- (f) that the CCITT in its Recommendation G.221, § 3, has pointed out the malfunctioning which can arise due to noise in fault conditions which can be transferred to subsequent systems, and has drawn attention to the responsibilities of the CCIR in this respect as regards radio-relay systems;

* This Study Programme applies to line-of-sight and near-line-of-sight radio-relay systems.

- (g) that radio-relay equipment may contain devices which mute receivers under conditions of extreme fading;
- (h) that noise occupying excessive bandwidth transmitted from a radio-relay transmitter can result in disturbance of adjacent radio channel(s);
- (j) that the duration of interruptions during protection switching is being studied under Study Programme 5A/9,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the rate of incidence and the duration of interruptions to be expected in modern radio-relay systems between the points *R'* and *R* of one or more homogeneous sections (see Report 443);
2. for systems with and without stand-by protection the proportion (in frequency and in duration) of interruptions due to:
 - propagation,
 - equipment failure,
 - maintenance (including human error);
3. the preferred characteristics of devices that would prevent malfunctioning of other systems connected in cascade at baseband and prevent excessive noise from disturbing other radio channels or other equipment on the same system.

STUDY PROGRAMME 5C-2/9

RELIABILITY AND AVAILABILITY TERMINOLOGY OF RADIO-RELAY SYSTEMS FOR TELEPHONY AND TELEVISION

(1970-1974-1978)

The CCIR,

CONSIDERING

- (a) that, to facilitate work in the field of reliability and availability, general acceptance of the relevant terms and definitions is desirable;
- (b) that the terminology relating to reliability and availability should, as far as possible, be based on internationally accepted expressions;
- (c) that the International Electrotechnical Commission (IEC) has carried out a considerable amount of work, which is contained in IEC Publication 271;
- (d) that an International Joint Co-ordination Group IEC/CCIR-CCITT has been established to deal with the terminology pertaining to telecommunications,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. which of the terms and definitions now available in the documents of the several international bodies interested in terminology will be useful in studies of radio-relay system reliability and availability;
2. the additional terms and definitions that are required in connection with studies of radio-relay system reliability and availability.

QUESTION 7-3/9

TRANS-HORIZON RADIO-RELAY SYSTEMS

(1963-1970-1974-1978)

The CCIR,

CONSIDERING

- (a) that trans-horizon radio-relay systems have received acceptance and are increasingly being used operationally in many parts of the world;
- (b) that it is desirable to determine the preferred characteristics of such systems needed to facilitate their international connection;

- (c) that the frequency bands used by trans-horizon radio-relay systems are often shared with line-of-sight radio-relay systems, other fixed and mobile, or broadcasting services;
- (d) that there are technical and operational difficulties in sharing frequency bands between tropospheric-scatter systems and space systems (see Recommendation Spa2 – 2),

UNANIMOUSLY DECIDES that the following question should be studied:

1. how do the characteristics of tropospheric-scatter propagation affect the design of radio-relay systems for telephony and television;
2. to what extent are systems, employing this mode of propagation and operating on the same or on neighbouring frequencies, liable to interfere with each other, with systems employing different modes of propagation as well as with other services;
3. on what basis should radio-frequency channel arrangements for trans-horizon systems be established;
4. what are the technical criteria affecting the choice of radio-frequency bands for trans-horizon systems (whether by tropospheric scatter mode or by diffraction propagation, using comparable equipment, with high power transmitters and/or very sensitive receivers);
5. what are the methods to be used for measuring the noise and the stability of the net loss in trans-horizon systems designed on the basis of meeting the objectives in Recommendation 397?

Note. — See Recommendations 302, 388, 396, 397, 593 and Reports 285, 286 and 939.

STUDY PROGRAMME 7B/9

PATH ANTENNA-GAIN IN TRANS-HORIZON RADIO-RELAY SYSTEMS

(1966)

The CCIR,

CONSIDERING

- (a) that determination of path antenna-gain is most important in the design of trans-horizon radio-relay systems;
- (b) that measurements in this area, though extensive, have not always been appropriately standardized and indicate significant controversy;
- (c) that the relationship between theoretical models and experimental data seems to indicate agreement with some measurements, but disagreement with others;
- (d) that particularly in long systems, errors in evaluating the characteristics or the overestimation of path antenna-gain can lead to unnecessary expense or to poor performance;
- (e) that the separation of path antenna-gain from transmission loss may be difficult,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the determination of the parameters that the system designer must take into consideration in estimating the path antenna-gain;
2. the way in which these parameters (frequency, distance, elevation, antenna beamwidth, etc.) relate to the path antenna-gain;
3. the extent to which the path antenna-gain is dependent on time, geographical, seasonal or other factors;
4. the relationships of the path antenna-gain to other system design factors, such as use of diversity (see Question 13/9), antenna symmetry, shaping and polarization.

Note. — See Report 285.

STUDY PROGRAMME 7C/9

**OPTIMUM FREQUENCY DEVIATION IN FREQUENCY-MODULATION
TRANS-HORIZON RADIO-RELAY SYSTEMS USING FREQUENCY-DIVISION MULTIPLEX**

(1970)

The CCIR,

CONSIDERING

- (a) that the total noise power (consisting of thermal, equipment and path intermodulation and echo distortion noise, etc.) in a single trans-horizon radio link, depends on certain characteristics, in particular the multipath delay, which are peculiar to that link;
- (b) that as the deviation is increased some noise components are increased while some are decreased;
- (c) that because of § (b) it is common practice to optimize the deviation for the lowest total noise power after the equipment is installed,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the method of determining which parameters (bandwidth at intermediate frequencies, etc.) the system designer must take into consideration in arriving at the optimum deviation for a given link;
2. the way in which the various noise contributions relate to the optimum deviation;
3. the extent to which the optimum deviation is affected by seasonal and other factors.

Note. — See Report 285.

STUDY PROGRAMME 7E/9

**PREFERRED CHARACTERISTICS, PERMISSIBLE NOISE AND SIGNAL DISTORTION
FOR THE TRANSMISSION OF TELEVISION SIGNALS
OVER TRANS-HORIZON RADIO-RELAY SYSTEMS**

(1978)

The CCIR,

CONSIDERING

- (a) that in many cases, the use of trans-horizon radio-relay systems is the only practicable way to transmit television signals to certain areas;
- (b) that a hypothetical reference circuit for television transmission as in Recommendation 567 may also be suitable for trans-horizon radio-relay systems;
- (c) that, wherever practicable, trans-horizon radio-relay systems should conform to Recommendation 567 or Recommendation 555 when transmitting television signals;
- (d) that, nevertheless, the complete achievement of these objectives could result in prohibitive system cost or harmful interference,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the preferred characteristics of trans-horizon radio-relay systems for the transmission of television signals;
2. the special design considerations that need to be taken into account for the successful transmission of television signals;
3. whether the performance criteria in Recommendation 567 and Recommendation 555 are generally achievable in trans-horizon systems, or whether additional Recommendations relating to the transmission of television signals are required.

STUDY PROGRAMME 7F/9

**PREFERRED FREQUENCY BANDS FOR TROPOSPHERIC SCATTER
RADIO-RELAY SYSTEMS**

(1982)

The CCIR,

CONSIDERING

- (a) the technical and operational difficulties in the bands shared by tropospheric scatter systems, space systems and other terrestrial systems, as reported by the Special Preparatory Meeting for the WARC-79, Geneva, 1978;
- (b) that the World Administrative Radio Conference, Geneva, 1979, has made additional allocations of frequency bands for the space services in view of their increasing development;
- (c) that Recommendation No. 100 of the WARC-79 notes that the proliferation of tropospheric scatter systems in all frequency bands, and particularly in those shared with the space systems, is bound to aggravate an already difficult situation,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. identification of the frequency bands offering characteristics best suited from the propagation standpoint to tropospheric scatter systems;
2. the possibilities and criteria for sharing between systems using tropospheric scatter and other systems, particularly space systems.

 QUESTION 9-2/9
**RADIO-RELAY SYSTEMS OPERATING IN BANDS 8 AND 9
FOR THE PROVISION OF TELEPHONE TRUNK CONNECTIONS
IN RURAL AREAS**

(1970-1982)

The CCIR,

CONSIDERING

- (a) that it is most important to extend telecommunication media in rural areas and especially in the developing countries, particularly with a view to connecting small rural exchanges to the national network and, through it, where possible, to the international network;
- (b) that in many cases, in view of the extent of these countries, nature of the terrain, climatic conditions, low density of rural population, etc., it is advisable for technical and economic reasons to use radio-relay systems;
- (c) that it is necessary to define the technical characteristics of the equipment used for this purpose;
- (d) that the performance standards of such systems should be determined,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what characteristics should be adopted for simple, economical radio equipment intended to provide telephone trunk connection, with up to 6, 12, 24, 30, 48 or 60 channels in bands 8 and 9;
2. what performance standards should be adopted for the systems?

Explanatory note. — CCIR Recommendations already deal with the major characteristics of systems operating in the 2 and 7 GHz bands with capacities of 60 and 120 channels. There is also, nevertheless, a need in the developing countries for systems of smaller capacities (up to 6, 12, 24, 30, 48 and 60 channels) operating in bands 8 and 9. Special Autonomous Study Group 3 (GAS 3) which is engaged in drawing up technical sheets giving the principal characteristics of the various types of system has an urgent need for information relating to the types of system dealt with in this Question.

Note 1. — The Director, CCIR, is requested to inform the Chairman of the Special Autonomous Study Groups 3 (GAS 3) and 7 (GAS 7) of the setting of this Question and transmit to him the results of the studies.

Note 2. — See Report 379.

STUDY PROGRAMME 9A-1/9

**TECHNICAL CHARACTERISTICS OF SIMPLE RADIO-RELAY EQUIPMENT
OPERATING IN BANDS 8 AND 9 FOR THE PROVISION OF TELEPHONE TRUNK
CONNECTIONS IN RURAL AREAS**

(1970-1982)

The CCIR,

CONSIDERING

- (a) that while a number of CCIR Recommendations deal with the principal characteristics of 60 and 120-channel systems in the 2 and 7 GHz bands, for applications in rural areas and in particular the developing countries, systems of smaller capacity (6, 12, 24, 30, 48 or 60 channels) to operate in bands 8 and 9 are required;
- (b) that, in determining these technical characteristics, it is necessary to arrive at the most satisfactory compromise possible between the cost of the system and performance,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the general characteristics and standards to be adopted for simple, economic radio equipments which will provide trunk connections:

- in band 8, and
- in band 9

and which meet the following basic requirements:

- 1.1 exclusive use of solid state components;
- 1.2 capacity:
 - 1.2.1 up to 6, 12, 24 or 30 telephone channels;
 - 1.2.2 48 or 60 telephone channels;
 - 1.2.3 6 voice-frequency telegraph channels in the sub-baseband for both systems under § 1.2.1 and 1.2.2;
- 1.3 use of an appropriate type of modulation and optimization of its characteristics;
- 1.4 small power consumption;
- 1.5 ease of installation;
- 1.6 simple maintenance, i.e. it should be possible for the equipment to operate with periodic maintenance at long intervals and to entrust these operations to semi-skilled staff;
- 1.7 simple auxiliary equipment for measurements and tests.

Note. — Some flexibility may be required in connection with § 1.1 (use of solid state components exclusively) and § 1.4 (small power consumption), particularly when geographical conditions justify the use of trans-horizon paths.

STUDY PROGRAMME 9B-2/9

**AVAILABILITY AND PERFORMANCE OBJECTIVES FOR ANALOGUE
RADIO-RELAY SYSTEMS OPERATING IN BANDS 8 AND 9 FOR
THE PROVISION OF TELEPHONE TRUNK CONNECTIONS
IN RURAL AREAS**

(1970-1978-1982)

The CCIR,

CONSIDERING

- (a) that national circuits will be set up using simple equipment of the type studied in Question 9/9 and that these circuits might be used for international connections;
- (b) that all interruptions to traffic, including those caused by excessive noise, are factors affecting availability;
- (c) that the availability required of a system has a major bearing on system design and on the cost of its provision and operation;

- (d) that Recommendation 557 concerning the availability objective for a hypothetical reference circuit is not applicable to these national circuits;
- (e) that the CCITT, in its Recommendation G.123, § 4, has given a partial reply to the question of fixing a limit to the total noise for the national part of an international connection;
- (f) that Recommendation 395 concerning noise in real international circuits is not applicable to these national circuits,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of appropriate availability objectives for radio-relay systems operating in rural areas;
2. determination of appropriate noise power objectives in radio links operating in rural areas.

Note. — See Report 379.

QUESTION 10-2/9

RADIO SYSTEMS OPERATING IN BANDS 8 AND 9 FOR THE PROVISION OF SUBSCRIBER TELEPHONE CONNECTIONS IN RURAL AREAS

(1970–1982)

The CCIR,

CONSIDERING

- (a) that it is most important to make telecommunication media available to subscribers in rural areas and in particular to such subscribers in the developing countries;
- (b) that the Regional Plan Committee for Asia has drawn the attention of the CCIR to this need;
- (c) that single-channel and multiple access (e.g. radio concentrator) equipment appear to offer suitable solutions for this purpose;
- (d) that with such systems, subscribers would have access to the national network and, through that, to the international network;
- (e) that such subscribers must enjoy the same conditions, as far as the quality of calls is concerned, as do urban subscribers,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what should be the performance criteria applicable to radiotelephone circuits for rural subscribers, and how should they be specified;
2. what should be the general characteristics of subscriber radio equipment operating in bands above 30 MHz to ensure:
 - 2.1 that several rural subscribers, for economic reasons, may share the same radio terminal (party line);
 - 2.2 that the privacy of calls is safeguarded;
 - 2.3 that such rural subscribers may communicate with each other;
 - 2.4 that such subscribers may be connected to a manual or an automatic exchange;
 - 2.5 that to obtain a greater efficiency in the use of the frequency spectrum and for reasons of economy without appreciably reducing the grade of service, a number of rural subscribers should have access to a smaller number of telephone circuits (e.g. radio concentrators);
 - 2.6 that signals other than voice-frequency should be able to be transmitted (charge information, public phone signalling, etc.);
3. what should be the characteristics of simple subscriber radio equipment operating in bands above 30 MHz which meet the following basic requirements:
 - 3.1 a transmitter-receiver mounted on a mast or housed in a special case;
 - 3.2 low power consumption, with solid state components;
 - 3.3 independence from the mains supply;

- 3.4 possibility of connection to the nearest main station, which may be some distance away;
- 3.5 use of a very simple type of antenna and an inexpensive antenna support structure;
- 3.6 equipment not requiring skilled staff;
- 3.7 minimum maintenance;
- 3.8 a design that is easily adaptable to various configurations and service facilities;
- 3.9 that for some applications the transmitter-receiver sets be able to operate at different frequencies or be allocated different time slots and thereby have multiple access to a number of telephone circuits?

Note 1. — The Director, CCIR, is requested to inform the Chairman, Special Autonomous Study Groups 3 (GAS 3) and 7 (GAS 7), of the setting of this Question and to transmit to him the results of the studies.

Note 2. — See Report 380.

QUESTION 12-4/9

DIGITAL RADIO-RELAY SYSTEMS

(1965–1966–1970–1974–1978–1982)

The CCIR,

CONSIDERING

- (a) that the CCITT has recognized the need to study pulse-code modulation for the transmission of telephony and other kinds of information over cables and radio-relay systems;
- (b) that pulse-code modulation and other forms of digital signals may need to be transmitted over radio-relay systems and that such transmission may be required over international circuits;
- (c) that interconnection of digital radio sections or systems or their connection with associated equipment will usually be made at baseband frequencies;
- (d) that besides the interconnection interface of digital radio sections, which are a matter of study in CCITT Study Group XVIII, interconnection points other than *TT'* (see Fig. 1 of Report 938) may be appropriate for interconnection between digital radio-relay systems;
- (e) that the full transmitter output power of a digital radio-relay system is only required during periods of adverse propagation,

UNANIMOUSLY DECIDES that the following question should be studied:

- 1. what technical methods could be used to reduce the harmful effects of propagation; *
- 2. what are the preferred characteristics of radio-relay systems for the transmission of digital signals;
- 3. what performance objectives should be adopted for digital radio-relay systems;
- 4. on what basis should radio-frequency channel arrangements for digital radio-relay systems be established;
- 5. what are the preferred characteristics at interconnection points shown in Fig. 1 of Report 938 for each system capacity in digital radio-relay systems;
- 6. should the signal format be such that other features can be incorporated into the radio-relay system, for example error ratio measurement or the provision of a service channel;
- 7. should dynamic transmitter output power control be used in digital radio-relay systems?

Note. — See Recommendations 387, 594, 596 and Reports 378 and 930.

* The effects of propagation are studied as part of Question 25/9.

STUDY PROGRAMME 12B-1/9

PREFERRED CHARACTERISTICS OF DIGITAL RADIO-RELAY SYSTEMS

(1974-1978)

The CCIR,

CONSIDERING

that digital interconnection of radio-relay systems with other radio-relay systems or cable systems for the transmission of digital signals may be required,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. intermediate-frequency and radio-frequency characteristics of digital radio-relay systems;
2. coding and modulation techniques to measure or improve error-rate performance taking into account power requirements, design bandwidth and complexity.

Note. — See Recommendations 283, 387, 497, 596 and Reports 378, 607 and 788.

STUDY PROGRAMME 12C-1/9

**HYPOTHETICAL REFERENCE DIGITAL PATHS AND PERFORMANCE OBJECTIVES
FOR DIGITAL RADIO-RELAY SYSTEMS**

(1974-1978)

The CCIR,

CONSIDERING

- (a) that digital radio-relay systems of low, medium and high capacity are being designed;
- (b) that it is desirable for planning purposes to specify hypothetical reference digital paths;
- (c) that there is a need to specify the performance objectives for these reference paths;
- (d) that acceptable levels of interference into digital radio-relay systems operating in shared bands need to be determined,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the determination of suitable hypothetical reference digital paths and performance objectives for digital radio-relay systems;
2. the determination of suitable periods of time for the expression of these performance objectives;
3. the determination of the elements characteristic of the hypothetical reference digital path;
4. the division of the performance objectives amongst these elements for various average periods of time.

Note. — See Recommendations 556, 390 and Reports 378 and 779.

STUDY PROGRAMME 12E-1/9

**RADIO-FREQUENCY CHANNEL ARRANGEMENTS
FOR DIGITAL RADIO-RELAY SYSTEMS OPERATING IN FREQUENCY BANDS
BELOW ABOUT 12 GHz**

(1974-1978)

The CCIR,

CONSIDERING

- (a) that there may be economic and operational advantages in the use of digital radio-relay systems in each frequency band;

- (b) that low, medium and high capacity digital radio-relay systems will be required in the future;
- (c) that some administrations may wish to establish digital systems utilizing their existing radio-relay stations;
- (d) that existing Recommendations for frequency channel arrangements are used by various administrations for analogue radio-relay systems and attention should be paid to coexistence with such systems;
- (e) that these existing frequency channel arrangements may not be appropriate for the optimum design of digital radio-relay systems;
- (f) that the efficient use of the spectrum should be studied;
- (g) that additional information is needed to establish those characteristics of digital systems which are relevant to the optimization of frequency channel arrangements,

UNANIMOUSLY DECIDES that the following studies should be carried out:

determination of preferred radio-frequency channel arrangements for digital systems operating in frequency bands below about 12 GHz.

Note. — See Reports 782, 934 and 935.

STUDY PROGRAMME 12F-1/9

CHANNEL SPACINGS AND ARRANGEMENTS FOR DIGITAL RADIO-RELAY SYSTEMS

(1974–1982)

The CCIR,

CONSIDERING

- (a) that digital radio-relay systems are already in service and that systems of this type will come into more extensive use in the future;
- (b) that interference, both between and within digital radio-relay systems, could be minimized by the coordination of radio-frequency channel arrangements over a large geographical area;
- (c) that interference between digital and analogue radio-relay systems could be minimized by the coordination of radio-frequency channel arrangements over a large geographical area;
- (d) that economy in the use of the radio-frequency spectrum is important,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the channel spacing on the basis of the type of modulation and the permissible amount of interference;
2. utilization of cross-polarization to enhance the use of the frequency spectrum;
3. investigation of other features of the system that will affect the channel spacing;
4. influence of the choice of channelling arrangements on the overall capacity of a practical radio network.

Note. — See Reports 378, 610, 779 and 934.

STUDY PROGRAMME 12H-1/9

INTERCONNECTION AT BASEBAND FREQUENCIES FOR DIGITAL RADIO-RELAY SYSTEMS

(1978–1982)

The CCIR,

CONSIDERING

- (a) that the characteristics at the interface of digital sections will be determined by CCITT Study Group XVIII;

- (b) that TT' may also be used for interconnection of digital radio-relay systems instead of RR' shown in Fig. 1 of Report 938;
- (c) that there may be a need to interconnect at baseband frequencies within digital radio-relay systems, e.g., between transmitters, receivers, protection switching equipment, test equipment, etc. (points ZZ' and YY' shown in Fig. 1 of Report 938);
- (d) that interconnection should preferably be made only at digital rates corresponding to levels in a digital hierarchy or at simple multiples of such rates;
- (e) that the format of the signal may influence the radiated spectrum;
- (f) that radio systems should not use a signal format with a redundant level, since this is wasteful of radio spectrum, and therefore output line codes, such as those specified by CCITT Study Group XVIII, are inappropriate for use with digital radio-relay systems;
- (g) that the format of the signal at a point of interconnection must be such as to ensure the recovery of a timing signal, including the case where the clock signal may be provided separately from the information signal;
- (h) that the response to jitter is a fundamental characteristic of a digital transmission system and that it must be compatible with any jitter present on the input signal within limits to be specified;
- (j) that the permissible jitter on a signal fed into a digital multiplexer at point TT' is limited by the characteristics of the digital multiplexer, as may be determined by CCITT Study Group XVIII;
- (k) that, in general, it is unlikely that a radio-relay system will be able to exploit the format of the signal at the source (multiplexers and codecs) in order to satisfy the needs of timing recovery, spectrum control and error-ratio measurement,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the preferred characteristics including jitter at the interconnection point between digital radio-relay system for each interconnecting system capacity;
2. the characteristics including jitter at interconnection points YY' and ZZ' (see Fig. 1 of Report 938) for each system capacity;
3. the features of the signal necessary for timing-signal recovery, spectrum economy and error-ratio measurement;
4. the desirability of scrambling all digital inputs to a radio-relay system and, if so, the preferred characteristics of the scrambler;
5. the need to add redundancy to the signal and, if so, the form of such redundancy;
6. the necessity to measure error ratio in a digital radio-relay system;
7. the removal or propagation of code format violations at the point of interconnection;
8. the inclusion of a service channel into the transmitted bit stream and, if so, the preferred form of such a service channel;
9. any other features of the signal format necessary to ensure satisfactory operation of a digital radio-relay system when such a system forms part of a telecommunication network.

Note. — See Recommendation 596 and Reports 613 and 938.

STUDY PROGRAMME 12J/9

PREFERRED METHODS AND CHARACTERISTICS FOR THE SUPERVISION AND PROTECTION OF DIGITAL RADIO-RELAY SYSTEMS

(1978)

The CCIR,

CONSIDERING

- (a) that supervision of digital radio-relay systems is necessary;
- (b) that stand-by switching arrangements to increase the availability of digital radio-relay systems and to facilitate maintenance are under study;

- (c) that supervision and protection techniques may extend across international borders;
- (d) that the principles of supervision for digital radio-relay systems should take account of overall maintenance considerations for digital networks;
- (e) that the application of the supervisory techniques and stand-by switching arrangements used in FM-FDM systems to digital systems requires investigation;
- (f) that overall performance and availability are affected by the methods used for supervision and protection,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. preferred supervisory principles for digital radio-relay systems;
2. preferred arrangements, characteristics and applications of stand-by switching at baseband and intermediate frequencies;
3. effectiveness of special protection techniques for specific applications;
4. the effect of protection principles on overall performance and on availability objectives of digital systems.

Note. — See Report 787.

QUESTION 13-1/9

DIVERSITY TECHNIQUES FOR RADIO-RELAY SYSTEMS

(1965-1966-1970)

The CCIR,

CONSIDERING

- (a) that, in a radio-relay system, fading may lower the signal-to-noise ratio and impair the reliability of the system;
- (b) that these effects can, to a large extent, be mitigated by employing techniques of diversity reception;
- (c) that the optimum values of the various diversity parameters may be different for line-of-sight, diffraction, or trans-horizon radio-relay systems;
- (d) that the expression "diversity reception" should be taken in its widest sense,

UNANIMOUSLY DECIDES that the following question should be studied:

1. under typical conditions of fading encountered in radio-relay systems, whether line-of-sight, diffraction or trans-horizon systems, what are the relative advantages of the various types of diversity;
2. what is the optimum value of the chosen parameter for each type of diversity (antenna-spacing, frequency-spacing, time-difference, etc.);
3. in what way must the received signals be utilized to obtain the best possible resulting signal, due account being taken of the mechanism of propagation, the nature of the transmitted signal, the characteristics of available antennas, including adaptive arrays, the bandwidth occupied by the spectrum of the modulated wave, the complexity of the requisite equipment and its ease of operation;
4. what influence does the use of diversity have on the transmission bandwidth and quality;
5. what influence does the use of diversity have on interference that may be caused or suffered by the systems?

Note. — See Report 376.

QUESTION 16-1/9

**THE USE OF FREQUENCIES ABOVE ABOUT 12 GHz
FOR RADIO-RELAY SYSTEMS**

(1969-1978)

The CCIR,

CONSIDERING

- (a) that frequencies above about 12 GHz are being increasingly exploited;
- (b) that special propagation problems exist at frequencies above 10 GHz;
- (c) that new techniques are applicable to radio-relay systems operating at these frequencies, especially the frequencies above about 40 GHz that are not yet used,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what methods can be used to offset the effects of propagation on radio-relay systems operating above about 12 GHz;
2. what are the preferred modulation techniques for use at frequencies above about 12 GHz for radio-relay systems;
3. what are the preferred radio-frequency channel arrangements for the frequency bands above about 12 GHz, available for use by radio-relay systems;
4. what are the most suitable sections of the radio-frequency spectrum, particularly above 40 GHz, for use by radio-relay systems in the fixed service?

Note 1. — The effects of propagation on the design of radio-relay systems are studied under Question 25/9.*Note 2.* — See Recommendations 497, 595 and Reports 607 and 936.

STUDY PROGRAMME 16A-1/9

**RADIO-RELAY SYSTEMS OPERATING IN FREQUENCY BANDS
ABOVE ABOUT 40 GHz**

(1976-1978-1982)

The CCIR,

CONSIDERING

- (a) that radio-relay systems may make use of the fixed service frequency allocations above 40 GHz;
- (b) that techniques for the use of these frequencies are being considered by various administrations;
- (c) that the radio-wave propagation characteristics at these frequencies are known to differ in some respects from those of lower frequencies and that some of these differences might be exploited to advantage;
- (d) that the equipment techniques might differ from those used in the lower frequency bands,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the characteristics of radio-relay systems and equipment best suited for the exploitation of radio-frequency bands above about 40 GHz, especially with respect to bandwidth and frequency-channelling arrangements;
2. susceptibility of these systems to interference and their potential for causing interference to other systems.

Note. — See Report 783.

STUDY PROGRAMME 16B/9

**RADIO-RELAY SYSTEMS IN FREQUENCY BANDS
BETWEEN ABOUT 20 GHz AND 40 GHz**

(1982)

The CCIR,

CONSIDERING

- (a) that radio systems may make use of the fixed service frequency allocations between about 20 GHz and 40 GHz;
- (b) that techniques for the use of these frequencies are being considered by various administrations;
- (c) that radio-wave propagation characteristics at these frequencies are known to differ in some respects from those of lower frequencies;
- (d) that equipment techniques for the frequencies might differ from those used in the lower frequency bands,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the characteristics of radio systems and equipment best suited for the exploitation of radio-frequency bands between about 20 GHz and 40 GHz, especially with respect to bandwidths and frequency-channelling arrangements within these bands;
 2. susceptibility of these systems to interference and their potential for causing interference to other systems.
- Note.* — See Report 936.

QUESTION 17-1/9**CRITERIA FOR FREQUENCY SHARING BETWEEN RADIO-RELAY SYSTEMS
AND SPACE RADIOCOMMUNICATION SYSTEMS**

(1969–1978)

The CCIR,

CONSIDERING

- (a) that radio-relay systems are now widely employed throughout the world and make extensive use of the radio-frequency spectrum;
- (b) that the use of radio-relay systems is expected to continue to expand and that new systems are expected to operate with improved performance and make more efficient use of the radio-frequency spectrum;
- (c) that the use of space radiocommunication systems in shared frequency bands is expected to continue to expand;
- (d) that the continued development of terrestrial and space services is desirable;
- (e) that control of mutual interference between stations of the various services is necessary,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what levels of interference are acceptable and under what conditions do they apply to radio-relay systems in order to facilitate sharing with systems in the space radiocommunication service;
2. what limitations are acceptable to radio-relay systems to facilitate the operation of earth-station and space-station receivers in a shared environment?

Note. — See Report 789.

STUDY PROGRAMME 17A-1/9

**ANTENNA RADIATION DIAGRAMS OF RADIO-RELAY STATIONS
FOR USE IN SHARING STUDIES**

(1970-1978)

The CCIR,

CONSIDERING

- (a) that determination of criteria for frequency sharing between radio-relay systems and systems in the Space Radiocommunication Service requires a knowledge of the antenna gains of the radio-relay stations along all possible interfering paths;
- (b) that the reference diagrams for large earth station antennas may not be applicable for antennas of line-of-sight radio-relay systems;
- (c) that the use of reference radiation patterns for line-of-sight radio-relay antennas would facilitate interference calculations;
- (d) that different reference radiation patterns may be required for the various types of antennas in use,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. measurement of the radiation patterns in the vertical and horizontal planes for both polarizations of typical antennas used in line-of-sight radio-relay systems, including passive reflector (i.e. periscope) antennas, and passive repeaters;
 2. definition of reference radiation patterns for the different types of antennas.
- Note.* — See Report 614.

STUDY PROGRAMME 17B/9

**PROTECTION CRITERIA BETWEEN THE BROADCASTING-SATELLITE SERVICE
AND THE FIXED SERVICE**

(1982)

The CCIR,

CONSIDERING

- (a) that Resolution No. 701 of the World Administrative Radio Conference, Geneva, 1979, resolves to convene a regional conference for the detailed planning of the broadcasting-satellite service in the 12 GHz band and associated feeder links in Region 2, not later than 1983 (see Note 1);
- (b) that Resolution No. 31 of the WARC-79 requests the CCIR to study urgently the appropriate protection for terrestrial services operating in the band 12.2 to 12.7 GHz in each affected region, in the context of efficient planning of the broadcasting-satellite service in Region 2. Resolution No. 31 also requests the CCIR to prepare a special report on the subject for consideration by an appropriate preparatory meeting and as a guide for the work of the Regional Conference stipulated in (a) above;
- (c) that Resolution No. 34 of the WARC-79 requests the CCIR to make an urgent study of the technical provisions which may be appropriate for sharing in the 12.5 to 12.75 GHz band between broadcasting-satellite service stations in Region 3 and terrestrial stations in Regions 1 and 2,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the criteria for protection of the terrestrial fixed service in the concerned Regions in the band 12.2 to 12.7 GHz in the context of efficient planning of the broadcasting-satellite service in Region 2;
2. the technical provisions appropriate for the sharing in the band 12.5 to 12.75 GHz between stations in the broadcasting-satellite service in Region 3 and terrestrial stations in the fixed service in Regions 1 and 2.

Note 1. — The Administrative Council, at its 35th session (1980), proposed that this Conference should be held for five weeks starting 13 June 1983.

Note 2. — See Report 789.

STUDY PROGRAMME 17C/9

**PROTECTION CRITERIA BETWEEN THE BROADCASTING-SATELLITE SERVICE
(SOUND) AND THE FIXED SERVICE, WITHIN THE BAND 0.5 TO 2 GHz**

(1982)

The CCIR,

CONSIDERING

that Resolution No. 505 of the World Administrative Radio Conference, Geneva, 1979, resolves that the CCIR shall continue and expedite studies relating to the feasibility of sharing between the broadcasting-satellite service (sound) and the fixed service within the band 0.5 to 2 GHz,

UNANIMOUSLY DECIDES that the following studies should be carried out:

the feasibility of the sharing of frequencies between the broadcasting-satellite service (sound), intended for individual reception by portable and mobile receivers, and the fixed service within the band 0.5 to 2 GHz, and the appropriate sharing criteria where such sharing is feasible.

Note. — See Report 941.

STUDY PROGRAMME 17D/9 *

**FREQUENCY SHARING BETWEEN RADIO-RELAY SYSTEMS AND
SYSTEMS OF THE EARTH EXPLORATION-SATELLITE SERVICE
AND THE SPACE RESEARCH SERVICE**

(1982)

The CCIR,

CONSIDERING

(a) that radio-relay systems are widely employed throughout the world and make extensive and increasing use of several frequency bands;

(b) that there is potential for interference between radio-relay systems and both geostationary and non-geostationary satellite radiocommunication systems;

(c) that special consideration must be made of the unique characteristics of systems in space radiocommunication services other than the traditional fixed-satellite service;

(d) that Study Group 2 has undertaken some preliminary studies with regard to radio-relay systems sharing with the earth exploration-satellite service and the space research service;

(e) that the WARC-79 allocated these services to share additional frequency bands and at the same time requested the CCIR via Recommendation No. 706 to study certain aspects of the sharing criteria between radio-relay systems and passive sensors for the earth exploration-satellite service and the space research service operating in the band 18.6 to 18.8 GHz;

(f) that administrations will require agreed sharing criteria to carry out compatibility analysis under the Radio Regulations, such as Article 14,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the levels of interference from the earth exploration-satellite service and the space research service acceptable to radio-relay systems, including percentage of time considerations;
2. the constraints on the services which would be necessary and acceptable to facilitate sharing;
3. special considerations of sharing when non-geostationary satellites are used by these space services; and,

* This Study Programme should be brought to the attention of Study Group 2.

4. the feasibility and constraints on sharing these services when the space services employ passive or active microwave sensors.

Note. — See Report 942.

QUESTION 19-1/9 *

**LIMITATION OF SPURIOUS EMISSIONS AND
FREQUENCY TOLERANCES OF RADIO-RELAY SYSTEMS**

(1972-1982)

The CCIR,

CONSIDERING

Recommendations Nos. 66 and 69 of the World Administrative Radio Conference, Geneva, 1979,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what is the necessary limitation of spurious emission by radio-relay systems in order to protect other radio services;
2. what level of spurious emission by other radio services is acceptable in order to protect radio-relay systems;
3. what is the necessary limitation of frequency tolerances to be observed in radio-relay systems in order to obtain efficient frequency band utilization?

STUDY PROGRAMME 19A-1/9

**LIMITATION OF SPURIOUS EMISSIONS AND
FREQUENCY TOLERANCES OF RADIO-RELAY SYSTEMS,
AND THE EFFECT OF SPURIOUS EMISSIONS FROM OTHER SOURCES ON
RADIO-RELAY SYSTEMS**

(1974-1982)

The CCIR,

CONSIDERING

- (a) that spurious emissions by radio-relay systems and other services can introduce interference into other radio-relay systems;
- (b) that the interference between and within systems or services depends essentially on the type of service, the nature of the baseband signal, the modulation technique and the equipment (including the antenna system) involved;
- (c) that the radiation of spurious emissions by radio-relay systems could cause interference to other services and radio-relay systems, and that it is necessary to define limits for these emissions;
- (d) that the radiation of spurious emissions by other services could cause interference to radio-relay systems, and that it may be desirable to define limits for these emissions;
- (e) that Appendix 8 of the Radio Regulations applies only to the mean power of a transmitter and spurious emissions, and that there are a variety of emissions where the interpretation of the term "mean power" and its consequential measurement is difficult;
- (f) that the frequency tolerances may influence interference and efficient frequency band utilization;
- (g) that account must be taken of the transmitter spectrum distribution of the radio-relay system and of the total frequency difference between the wanted and the interfering signal;
- (h) that the Radio Regulations contain rules which are to be taken into account,

* This Question should be brought to the attention of Study Group 1.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the kinds of spurious emission, generated by radio-relay systems and other radio services which have to be considered;
2. the necessary limits and the acceptable levels of spurious emissions;
3. how these values are to be defined;
4. the appropriate reference points in the radio-relay system, at which these values should be defined?
5. the appropriate measurement techniques and reference measurement bandwidths for spurious emissions;
6. how the term "mean power" of Appendix 8 should be interpreted for radio-relay systems;
7. the necessary limits for frequency tolerances.

Note 1. — The results of these studies are to be communicated to Study Group 1.

Note 2. — See Reports 785 and 937.

QUESTION 20-1/9 *

TRANSPORTABLE FIXED-SERVICE RADIOCOMMUNICATION EQUIPMENT FOR RELIEF OPERATIONS

(1972-1982)

The CCIR,

CONSIDERING

- (a) that rapid and reliable telecommunications are essential for relief operations in the event of natural disasters, epidemics, famines and similar emergencies;
- (b) that, through damage or from other causes, the normal telecommunications facilities in disaster areas are often inadequate for relief operations and cannot be restored or supplemented quickly through local resources;
- (c) that the World Administrative Radio Conference (WARC), Geneva, 1979, has adopted Recommendation No. 1,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics and frequency bands for transportable radio-relay equipment to provide relief telecommunication when:

- the equipment is used to establish terrestrial access to a transportable earth station;
- only terrestrial relief telecommunication facilities are involved?

Note. — See Report 615.

QUESTION 22/9

LINE-UP AND MAINTENANCE MEASUREMENTS OF RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

(1974)

The CCIR,

CONSIDERING

- (a) that the performance of real radio-relay links has to be measured initially before being brought into service and subsequently at intervals for maintenance purposes;

* See also Questions 22/3, 22-1/4 and 22/8.

- (b) that the CCITT "M", "N" and "O" series of recommendations give methods of measurements and details of measuring equipment for use on transmission systems;
- (c) that the measurements for radio-relay links given by the CCITT and by the CCIR may not fully cover all the tests that are required;
- (d) that the International Electrotechnical Commission (IEC) is studying methods and conditions of measurement for simulated systems, but this does not necessarily ensure compatibility of measuring equipment which is geographically separated;
- (e) that Opinion 50 proposes coordination between the work of the IEC and the CCIR;
- (f) that it is essential to have full compatibility between the measuring equipments used at both ends of a link,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what measurements should be made to verify the performance of the link;
2. what methods of measurement should be used;
3. what parameters of the measuring equipment should be defined in order to enable satisfactory measurements to be made and to satisfy item (e) above?

Note. — See Recommendations 290, 305, 398, 399, 401 and Reports 612 and 613.

QUESTION 23/9

INTERFERENCE AMONG LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(1976)

The CCIR,

CONSIDERING

- (a) that the increasing use of line-of-sight radio-relay systems requires an intensive and very efficient use of the RF spectrum;
- (b) that interference from and to other line-of-sight radio-relay systems, with the same or other types of modulation, should be taken into account when line-of-sight radio-relay systems are being designed;
- (c) that an efficient use of the radio-frequency spectrum is achieved in the planning of new radio-relay systems if a certain amount of intra-system and inter-system interference is accepted and can be predicted using suitable calculation techniques;
- (d) that these interference effects can be reduced by a careful choice of the antenna characteristics and of the receiver selectivity,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the allowable values for long and short-term degradation of channel noise or error rate performance due to the aggregate of interfering line-of-sight radio-relay systems;
2. what are the principles for apportioning the allowable performance degradation in different line-of-sight radio-relay systems within the shared environment;
3. what are the principles for apportioning the allowable performance degradation between single sections of the radio-relay systems;
4. what are the preferred calculation techniques for predicting interference among various types of line-of-sight radio-relay systems?

Note. — See Reports 610, 779 and 780.

STUDY PROGRAMME 23A/9

EVALUATION OF INTERFERENCE AMONG LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(1976)

The CCIR,

CONSIDERING

- (a) that interference problems are of primary importance in the planning of radio-relay systems, in order to make efficient use of the radio frequency spectrum;
- (b) that the interference effects depend upon the characteristics both of the interfering signals (power level, carrier frequency, modulation system, etc.) and of the disturbed system (antennas, receiving filters, etc.);
- (c) that the determination of interference criteria requires the definition of analysis and calculation techniques to relate the characteristics of signals interfering with radio-relay links, with their effects on transmission quality;
- (d) that it is highly desirable to standardize the use of parameters suitable to define the interference effects in FDM-FM, SSB-AM and digital modulated radio-relay systems,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the interference sources which may affect radio-relay system quality and the system parameters (e.g. antenna diagrams) that are relevant to the determination of the power level of the interfering signals in fading or non-fading conditions of the interfered signal;
2. definition of parameters suitable to represent the effects of interference on the transmission quality of FDM-FM, SSB-AM and digital modulated radio-relay systems;
3. analysis and calculation techniques useful for evaluating the interference effects when the power level of the received signal is at its normal value as well as when it is near the receiver threshold level;
4. calculation and measurement of interference effects on the transmission quality of FDM-FM, SSB-AM and digital modulated radio-relay systems, in order to provide the necessary information for system planning and equipment design.

Note. — See Reports 610, 779 and 780.

QUESTION 25-1/9

**EFFECTS OF PROPAGATION ON THE DESIGN
AND OPERATION OF RADIO-RELAY SYSTEMS**

(1978–1982)

The CCIR,

CONSIDERING

- (a) that the performance of radio-relay systems can be seriously affected by multipath propagation;
- (b) that rain attenuation is also a significant impairment at frequencies above about 10 GHz;
- (c) that cross-polarization techniques are of interest for a more efficient use of the radio-frequency spectrum;
- (d) that absorption bands in the atmosphere due to oxygen and water vapour exist at various frequencies above about 20 GHz;

- (e) that special propagation conditions may be encountered in desert and jungle terrain, especially ducting *;
- (f) that there are frequently technical and economic advantages in using relatively long paths for microwave radio-relay systems, particularly where natural terrain facilitates the use of high antenna sites *;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what is the degradation of radio-relay system performance due to multipath fading, particularly for high capacity systems;
2. what are the effects of rain attenuation on radio-relay system performance, on the choice of optimum hop length and on system availability;
3. what cross-polarization decoupling can be achieved, both in faded and non-faded conditions;
4. what are the possible advantages in the use of the absorption bands for particular situations, when considerable additional propagation attenuation is required;
5. what would be the effects of the propagation conditions on the optimum characteristics for microwave radio-relay systems operating over desert and jungle terrain **?

Note. — See Report 784, and also Report 338 (Volume V).

QUESTION 26/9

RADIO-RELAY SYSTEMS FOR THE SIMULTANEOUS TRANSMISSION OF ANALOGUE AND DIGITAL SIGNALS

(1978)

The CCIR,

CONSIDERING

- (a) that simultaneous transmission of analogue and digital signals on radio-relay systems may be important from the point of view of baseband frequency occupancy;
- (b) that specific applications of radio-relay systems carrying simultaneously analogue telephone or television signals and digital signals are under development;
- (c) that no characteristics of radio-relay systems carrying both analogue baseband signals and digital signals simultaneously, exist,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the preferred transmission characteristics and values of the critical system parameters of radio-relay systems which carry simultaneously both analogue and digital signals?

STUDY PROGRAMME 26A/9

PREFERRED CHARACTERISTICS OF RADIO-RELAY SYSTEMS FOR THE SIMULTANEOUS TRANSMISSION OF FDM TELEPHONE CHANNELS OR ONE COLOUR TELEVISION SIGNAL AND DIGITAL SIGNALS

(1978)

The CCIR,

CONSIDERING

- (a) that radio-relay systems with a capacity of 960, 1260 and 1800 frequency division multiplexed telephone channels as described in Recommendation 380 may be used for transmission of digital signals below or above the baseband;

* This has been brought to the attention of the CCIR by the World Plan Committee with reference to the African Continent following its meeting in April 1980 (Paris).

** Administrations of the African countries are urged to participate in these studies and the urgent need for propagation data relevant to the African Continent is brought to the attention of Study Group 5.

(b) that radio-relay systems with a capacity of 1260 or 1800 FDM telephone channels may be used for transmission of an analogue colour television signal as given in Recommendation 270, as well as digital signals above the baseband,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the determination of the preferred transmission characteristics and the most critical system parameters for the provision of simultaneous transmission of analogue and digital signals under the following conditions:

- if the radio-relay system is to carry both FDM telephone channels and digital signals;
- if the radio-relay system is to carry an analogue colour television signal and digital signals.

Note. — See Report 786.

QUESTION 27/9 *

NEW TECHNIQUES FOR SPECTRUM SHARING AND BAND UTILIZATION FOR RADIO-RELAY SYSTEMS

(1982)

The CCIR,

CONSIDERING

(a) that advances in technology and new encoding, modulation and access schemes, are making practicable new sharing schemes that offer economical as well as technological advances for increasing the efficiency of spectrum sharing and band utilization;

(b) that rapid advances are being made in packet radiocommunication, multi-function techniques, and point-to-multipoint systems;

(c) that these techniques are used both on terrestrial fixed and mobile systems as well as by satellite schemes;

(d) that Recommendation No. 65 of the World Administrative Radio Conference, Geneva, 1979, invites the CCIR to carry out studies on these matters,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the new encoding and modulation techniques and access schemes that would lead to better sharing and utilization of the spectrum;

2. what are the technical and performance criteria for ensuring compatibility with existing radiocommunication systems?

Note. — See Report 940.

STUDY PROGRAMME 27A/9

POINT-TO-MULTIPOINT SYSTEMS FOR TELEPHONY, DATA OR VIDEO APPLICATIONS USING NEW TECHNIQUES FOR SPECTRUM SHARING AND BAND UTILIZATION

(1982)

The CCIR,

CONSIDERING

(a) that the expansion of point-to-point terrestrial radio-relay services and advances in technology have stimulated the introduction of related point-to-multipoint systems;

* This Question should be brought to the attention of Study Groups 1 and 4.

- (b) that point-to-multipoint applications may be implemented for either analogue or digital transmission techniques and may offer service advantages such as the rapid provision of connections;
- (c) that point-to-multipoint systems for telephony, data and video applications may form part of other systems such as integrated services digital network (ISDN);
- (d) that point-to-multipoint systems may operate in frequency bands where channelling plans have been recommended by the CCIR for point-to-point systems;
- (e) that point-to-multipoint systems may share frequency bands with other services and new frequency coordination techniques may be appropriate;
- (f) that criteria different from those adopted for point-to-point systems may be required to assess the spectrum efficiency of point-to-multipoint systems,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the appropriate modulation and baseband multiplexing techniques for point-to-multipoint radio systems for different types of transmitted signal and service requirements;
 2. factors to be considered in assessing performance and availability criteria for point-to-multipoint systems and the necessity to set objectives;
 3. the interface parameters at the points of interconnection with other systems;
 4. the characteristics of point-to-multipoint systems that influence their coordination with other systems sharing the same frequency band, and coordination techniques that might be adopted;
 5. factors which influence the spectrum efficiency and band utilization of point-to-multipoint systems compared with conventional point-to-point links, especially when specialized service requirements are considered such as the rapid and effective provision of connections in urban and rural environments;
 6. frequency bands allocated to the fixed service that are most appropriate to point-to-multipoint systems;
 7. the necessity to specify alternative frequency channelling plans for point-to-multipoint systems and determination of the most appropriate plans;
 8. the criteria for determining the boundaries of point-to-multipoint service areas;
 9. the parameters and calculation procedures suitable for determining the various effects of interference.
- Note.* — See Report 940.

QUESTION 28/9

MAXIMUM ALLOWABLE DEGRADATION OF THE FIXED SERVICE FROM SERVICES IN THE ADJACENT BANDS IN THE FREQUENCY RANGE 1 TO 20 GHz

(1982)

The CCIR,

CONSIDERING

- (a) that in order to evaluate the overall system performance all sources of interference must be considered;
- (b) that limited filtering of modulated signals at the band edges may cause mutual interference even though the frequency stability of both the wanted and interfering signals is well controlled and the interfering signal does not generate any spurious emissions;

(c) that the interference criteria for the coexistence of services within a frequency band may differ from that of services in adjacent bands,

UNANIMOUSLY DECIDES that the following questions should be studied:

1. what are the allowable values of long-term and short-term increases of radio channel noise or error ratio caused by the aggregate adjacent band interference sources;
2. what are the principles of apportioning this degradation over the length of a fixed system;
3. what are the principles of apportioning this degradation to each exposure;
4. what is the RF interference power at the input to the receiver which will generate the allowable amount of channel noise, error ratio, or reduction in availability;
5. what are the acceptable and practical means open to the fixed service to effectively limit degradation due to interference from services in adjacent bands?

QUESTION 29/9 *

**POSSIBLE LIMITS FOR REDUCING TRANSMITTER POWER AND
REPEATER DISTANCE OF RADIO-RELAY SYSTEMS
OPERATING IN THE BAND 2 TO 8 GHz**

(1982)

The CCIR,

CONSIDERING

- (a) that with the present design of terrestrial radio-relay systems operating in the band 2 to 8 GHz, the distances between stations amounts to 30 to 70 km and more;
- (b) that with such distances between stations, the signal fading depth can be great and a considerable effective radiated power is required to offset drops in signal level due to fading with a view to ensuring the required operating stability of the circuit and channel performance;
- (c) that this radiated power creates an unfavourable interference environment for other radio systems operating in shared frequency bands;
- (d) that one solution is to reduce the transmitter power, the energy consumption, and the interference potential, by shortening the repeater distance;
- (e) that a shortening of the repeater distances in radio-relay circuits reduces the fading depth and required antenna mast heights;
- (f) that due to a lower fading depth, it is possible to reduce the transmitter power provided that the long-term performance objectives are met;
- (g) that a lower effective radiated transmitter power reduces the primary energy consumption to such an extent that this requirement can be met by simple independent power sources;
- (h) that lower transmitter power in radio-relay stations considerably reduces the interference caused to satellite and earth-station receivers, and also mitigates mutual interference between terrestrial radio-relay circuits,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the appropriate limits for the reduction of the effective radiated power of transmitters of radio-relay circuits operating in the range 2 to 8 GHz (combined with reduced repeater distances), taking account of all technical and economic factors; improved electromagnetic compatibility conditions, the scientific and technical prospects for improving the technological possibilities for the development of radio-relay equipment and also improved means of transmission of various types of information on radio-relay circuits?

* This Question should be brought to the attention of Study Groups 1 and 5.

QUESTION 30/9 *

**SHARING CRITERIA BETWEEN THE FIXED, THE BROADCASTING AND
THE MOBILE SERVICE IN THE VHF/UHF BANDS**

(1982)

The CCIR,

CONSIDERING

(a) that Resolution No. 510 of the World Administrative Radio Conference, Geneva, 1979, requests the CCIR to study as a matter of priority, the necessary technical bases for planning, and for determining the sharing criteria between stations in the broadcasting service (sound), the fixed service and the mobile service, as an input to a Regional Conference for Region 1 and certain contiguous countries in 1982, for a plan on sound broadcasting in the band 87.5 to 108 MHz;

(b) that Resolution No. 702 of the WARC-79 resolves to convene a Region 3 conference to establish the sharing criteria and to ensure protection for stations in the fixed, broadcasting and mobile services,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the technical criteria for sharing and ensuring protection between the fixed, broadcasting and mobile services in the VHF and UHF bands allocated to these services by the WARC-79, especially in the band 87.5 to 108 MHz?

QUESTION 31/9 **

**TRANSMISSION OF ELECTRIC POWER
BY RADIO FREQUENCIES FROM A SPACECRAFT**

(1982)

The CCIR,

CONSIDERING

(a) that it may become technically feasible in the future to convert some portions of the Sun's radiation into electric power on board a spacecraft and to transmit that power to Earth by means of radio transmissions and that such power could augment the world's energy resources;

(b) that the possibility of such high power radiation may adversely affect the propagation of radio waves for other services through the ionosphere;

(c) that it would be necessary to ensure that the radio transmission of electric power from space did not give rise to harmful interference to radiocommunication services;

(d) that Recommendation No. 3 of the World Administrative Radio Conference, Geneva, 1979, recommends the CCIR to undertake various kinds of studies on this subject,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the interference effects of such radio transmission of power from space upon the fixed service?

Note. — Preliminary information on this radio energy transmission from space may be found in § 6.2.8 of the Report of the SPM (Special Preparatory Meeting for the WARC-1979, Geneva, 1978) as well as in the texts of Study Group 2.

* This Question should be brought to the attention of Study Groups 8 and 10.

** This Question and the outcome of the studies involved should be brought to the attention of Study Groups 2 and 6.

QUESTION 32/9 *

**PROTECTION OF RADIO-RELAY EQUIPMENT FROM
THE EFFECTS OF LOCAL LIGHTNING DISCHARGES**

(1982)

The CCIR,

CONSIDERING

- (a) that the WARC-79, in its Resolution No. 64, invites the CCIR to study the problem of lightning protection of radio equipment and to formulate a Recommendation in this matter;
- (b) that lightning damage at an isolated radio-relay station may often cause serious circuit interruption;
- (c) that lightning protection for a radio-relay station is more important than ever, since solid-state radio equipment is introduced;
- (d) that studies are going on in the CCITT ** on this matter and that the results of studies achieved have been published in the CCITT Handbook "Protection of telecommunication lines and installations against lightning" (published in 1974) and its additional Chapters 6, 7 and 8 (published in 1978);
- (e) that any duplication of, or inconsistency between, the work of the CCIR and the CCITT is to be avoided,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the appropriate precautions for the protection of radio-relay equipment from the effects of local lightning discharges?

Note. — See Report 932.

OPINION 13-1

JOINT STUDY GROUP CMBD (CCITT/CCIR) ON CIRCUIT NOISE AND AVAILABILITY

(Questions 2/9, 5/9 and 7/9)

(1959-1963-1970)

The CCIR,

CONSIDERING

- (a) that a Joint Study Group has been established by the CCITT, with participation by CCIR representatives, to study circuit noise, reliability and availability;
- (b) that certain aspects of the questions under consideration by the CCIR can usefully be studied by this Joint Study Group, that is to say:
 - permissible noise power for the transmission of voice-frequency telegraphy or data (part of Question 2/9);
 - permissible noise power for radio-relay systems using tropospheric-scatter propagation (part of Questions 2/9 and 7/9);
 - overall aspects of reliability and availability (part of Question 5/9),

IS UNANIMOUSLY OF THE OPINION

1. that the CCITT/CCIR Joint Study Group entitled "CMBD" should continue its work;
2. that this Joint Study Group be responsible for the studies indicated in § (b);
3. that the Director, CCITT, should continue to be responsible for the convening, organization and secretariat of this Joint Study Group.

* This Question should be brought to the attention of Study Group V of the CCITT and the results of the studies involved shall be transferred to the CCITT for consideration and inclusion in their Handbook.

** Questions 1/V, 5/V and 22/V of the CCITT.

OPINION 14-4

**PREFERRED FREQUENCY BANDS AND CENTRE FREQUENCIES FOR
RADIO-RELAY LINKS FOR INTERNATIONAL CONNECTIONS**

(1959-1963-1970-1974-1978-1982)

The CCIR,

CONSIDERING

- (a) that line-of-sight and near line-of-sight radio-relay links have already been established by many countries for international connections and that such networks are expanding;
- (b) that some countries may be considering the use of trans-horizon links for international connections;
- (c) that the CCIR has recommended preferred radio-frequency channel arrangements for analogue and digital radio-relay links (see Annex I);
- (d) that, for radio-frequency interconnection of links in international networks, agreement is necessary on specific radio frequencies as well as on the arrangement of radio channels within a band;
- (e) that specific radio frequencies can readily be defined in terms of the centre frequency of the radio-frequency interconnection arrangement;
- (f) that, for technical reasons, only certain preferred values of the centre frequency are acceptable in a given frequency band;
- (g) that there are various aspects of radio-wave propagation and equipment design that lead to the choice of particular frequency bands for certain capacities and types of radio-relay system;
- (h) that radio-relay links used for international connections must meet high standards of performance similar to those recommended by the CCITT for metallic circuits;
- (j) that it is essential to avoid interference to radio-relay links used for international connections, either from other radio-relay links or from other radio services (including harmonics), operated in the same or other countries,

IS UNANIMOUSLY OF THE OPINION

that the attention of Administrative Radio Conferences should be drawn to:

1. the technical advantages of international agreement on preferred frequency bands, within which international line-of-sight and trans-horizon radio-relay links may be established, using the radio-frequency channel arrangements recommended by the CCIR;
2. the technical advantages of preferred values for the centre frequencies of bands for line-of-sight and trans-horizon systems being established by international agreement;
3. the risk of interference between line-of-sight and trans-horizon links if these operate in the same frequency band and in the same geographical zone;
4. the need to avoid interference to radio-relay links used for international connections, from other radio services or harmonics radiated by them;
5. the progress that is being made in establishing parameters for radio-relay systems operating at frequencies above about 12 GHz and the fact that the technical factors entering into the selection of appropriate frequency bands are under study (see Question 16/9).

ANNEX I

TABLE I — CCIR Recommendations for preferred radio-frequency channel arrangements for radio-relay systems, used for international connections⁽¹⁾(²)

Recommendation	Maximum capacity in analogue operation of each radio carrier (telephone channels or the equivalent)	Capacity of each digital channel ⁽⁸⁾	Preferred centre frequency ⁽³⁾ f_0 (MHz)	Width of radiofrequency band occupied (MHz)
283	60/120/300/960 ⁽⁷⁾	low, medium	1 808 2 000 2 203 2 586 1 903	200 200 200 200 400
382	600/1 800	medium ⁽¹⁰⁾ (¹¹)	2 101 4 003.5 ⁽⁴⁾	400 400 ⁽⁴⁾
383	600/1 800	⁽¹⁰⁾	6 175	500
384	1 260/2 700	high	6 770	680
385	60/120/300		7 575	300
386	300/960 ⁽⁵⁾	⁽¹⁰⁾	8 350 ⁽⁵⁾	300 ⁽⁵⁾
387	600/1 800	low, medium ⁽⁹⁾	11 200	1 000
497	960	medium	12 996 ⁽⁶⁾	500
595		medium, high	18 700	2 000

(¹) The Recommendations referred to above apply to line-of-sight and near line-of-sight systems. For trans-horizon systems, it has not yet been possible to formulate preferred radio-frequency channel arrangements, but the attention of the Administrative Radio Conference is drawn to Recommendation 388 and to Report 286.

(²) Attention should also be drawn to Recommendation 389, Study Programme 4A/9 and to Report 284.

(³) Other centre frequencies may be used by agreement between the administrations concerned.

(⁴) In some countries, mostly in a large part of Region 2 and in certain other areas, a reference frequency $f_r = 3700$ MHz is used at the lower edge of a band 500 MHz wide (see Annex I to Recommendation 382).

(⁵) In some countries a maximum capacity of 1800 telephone channels or the equivalent on each radio-frequency carrier may be used with a preferred centre frequency of 8000 MHz. The width of the radio-frequency band occupied is 500 MHz (see Recommendation 386, § 7 and Annex I).

(⁶) Reference frequency.

(⁷) The 960 channel capacity can only be used with the centre frequency 2586 MHz.

(⁸) The definition of the terms low, medium and high capacity digital systems is given in Report 378.

(⁹) Attention should also be drawn to Report 782.

(¹⁰) Attention should also be drawn to Report 934.

(¹¹) Attention should also be drawn to Report 935.

OPINION 50

**COORDINATION OF THE WORK OF THE CCIR
AND THE IEC * ON MEASUREMENTS FOR THE ADJUSTMENT
AND MAINTENANCE OF RADIO-RELAY SYSTEMS**

(1974)

The CCIR,

CONSIDERING

- (a) that it is essential to define and unify the measuring methods and the general characteristics of the measuring instruments to be used by administrations for the adjustment and maintenance of radio-relay systems;
- (b) that the IEC has been working in this field;
- (c) that any duplication of, or inconsistency between, the work of the CCIR and the IEC is to be avoided,

* IEC: International Electrotechnical Commission.

IS UNANIMOUSLY OF THE OPINION

1. that the CCIR should collaborate with the IEC in defining the measurements for the adjustment and maintenance of radio-relay systems and in determining the characteristics of the appropriate measuring instruments;
2. that the Director, CCIR, should keep in close touch with the IEC to prevent unnecessary duplication of work;
3. that the Director, CCIR, should provide the IEC with all relevant CCIR documents and invite the IEC to take account of the views expressed by the CCIR;
4. that, if necessary, the Director, CCIR, should propose a joint meeting of the CCIR and the IEC to settle any problems that cannot be settled by correspondence.

DECISION 55

**EFFECTS OF PROPAGATION ON THE DESIGN AND OPERATION
OF LINE-OF-SIGHT RADIO-RELAY SYSTEMS**

(Redrafting of Report 784)

(1981)

CCIR Study Group 9,

CONSIDERING

- (a) that Report 784 prepared by Study Group 9 which covers the subject of the effects of propagation on radio-relay systems is of considerable importance to system designers and planners;
- (b) that Report 784 at present contains only limited information on many topics which have been shown to have an important influence on both analogue and digital radio system performance;
- (c) that Report 784 contains information on certain topics which are common to Report 338 prepared by Study Group 5, and for which there is no clear boundary of responsibility between Study Groups 9 and 5;
- (d) that Resolution 24 provides for the establishment of Interim Working Parties, and lays down the conditions under which they work,

DECIDES

1. that an Interim Working Party 9/4 should be established with the following terms of reference:
 - 1.1 to redraft Report 784 (see Note);
 - 1.2 to prepare primarily by correspondence a draft Report for submission to the Interim Meeting in 1983;
 - 1.3 to invite the assistance of Study Group 5 in preparing this redrafted Report, in particular the draft of this Report should be submitted (through the Chairman of Study Group 5) for the comments of Interim Working Party 5/2 at one of its forthcoming meetings;
2. that initially Interim Working Party 9/4 shall consist of representatives of the Administrations of Germany (Federal Republic of), Australia, Canada, United States of America, France, Italy, Japan, Netherlands, United Kingdom and the U.S.S.R.

The Director, CCIR, is requested to circulate to administrations and other organizations participating in the work of the CCIR, a notice of the formation of the Interim Working Party with an invitation for other interested countries to announce before 1 June 1982, if possible, their participation and the names and addresses of their representatives;

3. that the Chairman of Interim Working Party 9/4 will be an expert designated by the Administration of Canada, after consultation with the Chairman of Study Group 9.

Note. — Account should be taken of the information contained in Doc. 9/417(Rev.1), particularly its Annex II, of the Final Meeting of Study Group 9 in 1981.

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

ALPHABETICAL INDEX OF KEY WORDS AND TERMS OF VOLUME IX

A

Adaptive equalization (equalizer) (Rep.285, Rep.376)

Adjacent channel interference (Rep.610, Rep.779, Rep.780)

Adverse propagation condition (Rec.393, Rec.594)

AFC (automatic frequency control) (Rep.785)

Alarms (Rep.787)

Allowable bit error ratios (Rec.594)

Allowable noise power (Rec.393, Rec.397)
 frequency division multiplex (Rec.393, Rec.397)
 hypothetical reference circuit (Rec.393, Rec.397)
 telephony (Rec.393, Rec.397)
 trans-horizon radio-relay systems (Rec.397)

Analogue radio-relay systems (Rec.276, Rec.283, Rec.384, Rec.403, Rec.404, Rec.447, Rec.497, Rep.137, Rep.287, Rep.289, Rep.374, Rep.375, Rep.443, Rep.444, Rep.612, Rep.786)
 auxiliary radio-relay systems (Rep.374, Rep.444)
 greater than 1800 telephone channels (Rep.287)
 interconnection (Rep.374)
 interruptions (Rep.443)
 measurements (Rep.612)
 multi-line switching (Rec.444, Rep.444)

Analogue television (Rec.387)
 radio-frequency channel arrangements (Rec.387)

Analogue/digital compatibility (Rep.782, Rep.934)

Angle diversity (Rep.376)

Antenna (Rep.614)
 coordination area (Rep.614)
 pyramidal horn reflector antenna (Rep.614)
 reference radiation patterns (Rep.614)
 side-lobe patterns (Rep.614)
 spill-over (Rep.614)
 gain (Rep.285)

APC (automatic phase control) (Rep.785)

Article 8 of the Radio Regulations (Rec.283, Rec.389, Rep.607, Rep.932, Rep.936)

ASK (amplitude shift keying) (Rep.940)

Audio frequencies (Rec.268, Rec.402)
 bandwidth (Rec.402)
 interconnection (Rec.268)

Auxiliary channels (Rep.287)

Auxiliary radio-relay systems (Rec.387, Rec.389, Rec.400, Rep.284, Rep.374, Rep.444)
 analogue radio-relay systems (Rep.284, Rep.374)
 baseband frequencies (Rep.284, Rep.374)
 below about 2 GHz (Rep.284)
 interconnection (Rep.284, Rep.374)
 modulation (Rep.284)
 noise (Rep.374)
 radio frequencies (Rep.374)
 service channels (Rec.389, Rec.400, Rep.444)

Availability (Rec.444, Rec.557, Rep.444, Rep.445)
 digital radio-relay systems (Rec.557)
 effects of propagation (Rep.445)
 figure of merit (Rep.445)
 hypothetical reference circuit (HRC) (Rec.557)
 hypothetical reference digital path (HRDP) (Rec.557)
 interruptions (Rec.557, Rep.445)
 mean time between failures (MTBF) (Rec.557, Rep.445)
 mean time to restore (repair) (MTTR) (Rec.557, Rep.445)
 multi-line switching (Rec.444)
 reliability (Rep.445)
 unavailability (Rec.557, Rep.445)

B

Bandwidth correlation factor (Rep.376)

Baseband (Rec.381, Rec.463, Rep.938)
 bit insertion (Rep.938)
 digital signal processing (Rep.938)
 interconnection (Rec.381, Rec.463, Rep.938)
 multiplexing (Rep.938)
 residues of signals (Rec.381, Rec.463)
 scrambling (Rep.938)
 television (Rec.463)

Baseband frequencies (Rec.290, Rec.380, Rec.398, Rec.401, Rep.284, Rep.374)
 auxiliary radio-relay system (Rep.284, Rep.374)
 frequency limits (Rec.380, Rec.398, Rec.401)
 interconnection (Rec.380, Rep.284, Rep.374)
 limits of band occupied by telephone channels (Rec.398, Rec.399, Rec.401)
 reference frequency (Rec.290)

Bit error ratio (BER) (Rec.594, Rep.613, Rep.930, Rep.938)
 integration time (Rep.594)
 measurements (Rec.594, Rep.613)
 monitoring (Rep.938)
 performance objectives (Rec.594, Rep.930)

Bit insertion (Rep.938)

Bit rate (Rep.938)

Broadcasting-satellite service (Rep.789, Rep.941)
 energy dispersal (Rep.941)
 interference (Rep.789, Rep.941)
 link budgets (Rep.941)
 power flux-density (pfd) limits (Rep.941)
 sound (Rep.941)
 spurious emissions (Rep.789)

Burst errors (Rep.937)

Burst signals (Rep.379)

C

CCITT (Rec.268, Rec.290, Rec.306, Rec.380, Rec.381, Rec.390, Rec.391, Rec.392, Rec.393, Rec.395, Rec.397, Rec.399, Rec.400, Rec.402, Rec.444, Rec.463, Rec.556, Rec.557, Rec.593, Rec.594, Rec.596, Rep.137, Rep.285, Rep.288, Rep.289, Rep.375, Rep.378, Rep.379, Rep.380, Rep.444, Rep.594, Rep.781, Rep.930, Rep.932, Rep.938)

CCITT Recommendations: J.14 (Rec.402, Rep.289, Rep.375), J.17, J.21, J.22, J.23, J.31, J.34 (Rep.375), G.104 (Rep.930), G.123 (Rep.379), G.143 (Rep.288, Rep.379), G.152, G.162 (Rep.379), G.211 (Rec.395), G.212 (Rec.390), G.213 (Rec.380), G.222 (Rec.393), G.223 (Rec.399, Rep.285), G.228 (Rec.399), G.232 (Rec.268), G.243 (Rec.381), G.352 (Rec.306), G.412, G.422 (Rec.268), G.423 (Rec.380), G.702 (Rec.390, Rec.556), G.703 (Rec.596, Rep.938), G.704 (Rep.787), G.721 (Rec.390), G.730 Series (Rep.379), G.821 (Rep.930), M.450 (Rec.290, Rec.380), M.500, M.510 (Rec.290), Series N (Rec.402, Rec.463), N.15 (Rep.375), O.151 (Rep.613), R.35, R.38A, V.23 (Rep.444)

CCITT Study Group V (Rep.932)

CCITT Study Group XII (Rec.398)

CCITT Study Group XV (Rep.375)

CCITT Study Group XVIII (Rep.379, Rep.930)

Cell arrangement and frequency plan (Rep.380)

Channel arrangement (see Radio-frequency channel arrangements)

Channel disposition (Rep.782, Rep.934)

CMBD (Rec.393, Rec.397, Rec.555, Rep.288, Rep.375)

Co-channel interference (Rep.610, Rep.779, Rep.780, Rep.931, Rep.932)

television transmission (Rep.931)

Coherent PSK (CPSK) (Rep.378, Rep.610, Rep.779)

Code conversion (Rep.938)

Coding and modulation techniques, comparison (Rep.378)

Combiner (Rep.376)

Compandor (Rep.379)

Compatibility, analogue/digital (Rep.610, Rep.934)

adjacent channel interference (Rep.610)

channel arrangements (Rep.610)

co-channel interference (Rep.610)

digital modulation (Rep.610)

digital radio-relay systems (Rep.610)

frequency-division multiplex (FDM) (Rep.610)

high capacity system (Rep.934)

interference (Rep.610)

Concentrator systems (Rep.380)

Continuity pilot (Rec.381, Rec.401, Rec.463, Rep.374)

deviation (Rec.401)

frequency (Rec.401)

interconnection (Rep.374)

telephony (Rec.401)

television (Rec.401)

Continuous uniform spectrum signal for noise measurement (Rec.399)

Conventional load (loading) (Rec.393, Rec.399, Rep.375)

Conventional test signal (Rep.375)

Coordination area (Rep.614)

Correlation coefficient (Rep.376)

Correlation distance (Rep.376)

CPSK (PSK with coherent detection) (Rep.378, Rep.610, Rep.779)

Cross-band diversity (defn) (Rep.376)

Cross-polarization discrimination (decoupling) (XPD) (Rep.287, Rep.378, Rep.379, Rep.610, Rep.782, Rep.784, Rep.934)

D

Data above the baseband (data above voice and data above video) (DAV) (Rep.786)

Data transmission (Rep.786)

Data under the baseband (data under voice) (DUV) (Rep.786)

dBq0ps (defn) (Rep.375)

DCPSK (PSK with differentially coherent detection) (Rep.378, Rep.610)

De-emphasis (Rec.275, Rec.405)
network (Rec.405)

Deviation (see Frequency deviation)

Differential gain (Rec.405, Rep.137)

Differential phase (Rec.405, Rep.137, Rep.289)

Digital modulation methods (Rep.378, Rep.610)

Digital radio concentrator system (DRCS) (Rep.380)

Digital radio-relay systems (Rec.283, Rec.382, Rec.384, Rec.387, Rec.390, Rec.497, Rec.556, Rec.557, Rec.594, Rec.595, Rep.285, Rep.376, Rep.378, Rep.379, Rep.380, Rep.594, Rep.596, Rep.610, Rep.613, Rep.779, Rep.782, Rep.783, Rep.784, Rep.786, Rep.787, Rep.788, Rep.930, Rep.933, Rep.934, Rep.935, Rep.936, Rep.938, Rep.940, Rep.950)

above the second hierarchical level (Rec.556)

adaptive equalization (equalizer) (Rep.285, Rep.376)

adjacent channel interference (Rep.779)

alarms (Rep.787)

allowable bit error ratios (Rec.594)

analogue/digital compatibility (Rep.610, Rep.782, Rep.934)

ASK (amplitude shift keying) (Rep.940)

availability (Rec.557)

baseband (Rep.938)

baseband digital signal processing (Rep.938)

Bessel filter (Rep.779)

bit error ratio (Rec.594, Rep.613, Rep.930, Rep.938)

bit insertion (Rep.938)

bit rate (Rep.938)

burst signals (Rep.379)

Butterworth filter (Rep.779)

channel disposition (Rep.782, Rep.934)

characteristics (Rep.378)

Chebyshev filter (Rep.779)

co-channel interference (Rep.779)

code conversion (Rep.938)

coding and modulation techniques, comparison (Rep.378)

CPSK (PSK with coherent detection) (Rep.378, Rep.610, Rep.779)

cross-band diversity (defn) (Rep.376)

cross-polarization discrimination (XPD) (Rep.378, Rep.379, Rep.784)

data above the baseband (data above voice and data above video) (DAV) (Rep.786)

data under the baseband (data under voice) (DUV) (Rep.786)

DCPSK (PSK with differentially coherent detection) (Rep.378, Rep.610)

digital path (Rep.594)

digital radio concentrator system (DRCS) (Rep.380)

digital radio sections (Rec.556)

Digital radio-relay systems (*cont'd*)

diversity techniques (Rep.376)
 error burst (Rec.594, Rep.930)
 error ratio (Rep.779)
 error-free second (EFS) (Rec.594, Rep.930)
 eye diagram (pattern, aperture) (Rep.779, Rep.784)
 fade margin (Rep.783, Rep.784)
 fading attenuation (Rep.779)
 flat fade margin (Rep.378, Rep.784)
 frequency re-use (Rep.779)
 FSK (frequency shift keying) (Rep.610, Rep.940)
 Gaussian noise (Rep.779)
 hierarchical level (Rec.556)
 high and medium-high capacity digital radio-relay systems (Rep.934)
 high capacity digital radio-relay systems (above about 100 Mbit/s) (Rep.378, Rep.782, Rep.783, Rep.788, Rep.934, Rep.936)
 homogeneous frequency pattern (Rep.935)
 hop length (Rep.783)
 hypothetical reference connection (HRX) (Rec.594, Rep.930)
 hypothetical reference digital path (HRDP) (Rec.390, Rec.556, Rec.557, Rec.594, Rep.930)
 integrated services digital network (ISDN) (Rec.594, Rep.930)
 integration-time (Rec.594)
 inter-symbol interference (ISI) (Rep.285, Rep.378, Rep.613, Rep.779, Rep.784)
 interconnection (Rep.596, Rep.938)
 interference (Rep.610, Rep.779, Rep.788)
 intermediate frequencies (Rep.788)
 international digital connection (Rec.594)
 jitter (Rec.594, Rep.779, Rep.930, Rep.938)
 low and medium capacity digital systems (Rec.283, Rec.387)
 maximum power combiner (defn) (Rep.376)
 measurements (Rep.613)
 medium capacity digital radio-relay systems (above 10 Mbit/s up to 100 Mbit/s) (Rec.382, Rec.497, Rep.378)
 minimum dispersion combiner (defn) (Rep.376)
 multiple call dropout (Rec.594)
 net availability margin (NAM) (Rep.378)
 net fade margin (Rep.378, Rep.784)
 net or effective fade margin (Rep.784)
 net performance margin (NPM) (Rep.378)
 nodal capacity (Rep.378)
 noise sources (Rep.779)
 Nyquist bandwidth (Rep.378, Rep.786)
 packet radio system (Rep.940)
 parity check (Rep.613)
 performance objectives (Rep.930)
 point-to-multipoint (P-MP) systems (Rep.940)
 point-to-point systems (Rep.379)
 propagation (Rep.779, Rep.783, Rep.784)
 protection (Rep.787)
 protection switching (Rep.613, Rep.787)
 pseudo-random test sequence (Rep.613)
 PSK (phase shift keying) (Rep.379, Rep.607, Rep.610, Rep.782, Rep.786, Rep.936, Rep.940)
 QAM (quadrature amplitude modulation) (Rep.378, Rep.610, Rep.782, Rep.937)
 16-level QAM (Rep.378, Rep.782)

radio channel identification (Rep.787)
 radio-frequency channel arrangements (Rec.382, Rec.384, Rec.497, Rec.595, Rep.378, Rep.782, Rep.933, Rep.934, Rep.935, Rep.936)
 real digital paths (Rep.930)
 rural radio-relay systems (Rep.379, Rep.380)
 SCPC-MA (single channel per carrier multiple access) (Rep.940)
 scrambling (Rep.938)
 second hierarchical level (Rec.556)
 signature (Rep.378, Rep.784)
 small capacity digital radio-relay systems (up to and including 10 Mbit/s) (Rep.378)
 SSMA (spread spectrum multiple access) (Rep.940)
 subscriber telephone connections (Rep.380)
 supervision (Rep.787)
 symbol rate (Rep.378)
 TDM signal (Rep.379)
 telephony (Rec.556)
 time diversity (Rep.376)
 time division multiple access (TDMA) (Rep.380)
 timing errors (Rep.779)
 trans-horizon radio-relay systems (Rep.285)
 unavailability (Rec.557)
 2 GHz band (Rec.283)
 2.3 to 2.5 GHz band (Rep.933)
 4 GHz band (Rec.382, Rep.934, Rep.935)
 6 GHz band (Rec.384, Rep.934)
 8 GHz band (Rep.934)
 below about 10 GHz (Rep.934)
 10.7 to 11.7 GHz band (Rep.782)
 11 GHz band (Rec.387)
 13 GHz band (Rec.497)
 17.7 to 19.7 GHz band (Rec.595)
 17.7 to 21.2 GHz band (Rep.936)
 frequency bands between 20 GHz to 40 GHz (Rep.936)
 frequency bands above about 40 GHz (Rep.783)
 140 Mbit/s (Rec.384, Rep.935)
 up to 200 Mbit/s (Rep.935)

Diversity techniques (Rep.285, Rep.376)

adaptive equalizer (equalization) (Rep.285, Rep.376)
 angle diversity (Rep.376)
 bandwidth correlation factor (Rep.376)
 combiner (Rep.376)
 correlation coefficient (amplitude, frequency) (Rep.376)
 correlation distance (Rep.376)
 cross-band diversity (defn) (Rep.376)
 frequency correlation (Rep.376)
 frequency diversity (Rep.396)
 maximum power combiner (defn) (Rep.376)
 minimum dispersion combiner (defn) (Rep.376)
 multipath fading (Rep.376)
 short-term fading (Rep.376)
 space correlation (Rep.376)
 space diversity (Rep.376)
 time diversity (Rep.376)

Drop/insert systems (Rep.380)**E****Energy dispersal** (Rep.941)**Error bursts** (Rec.594, Rep.930)**Error-free second (EFS)** (Rec.594, Rep.930)**Error ratio** (see Bit error ratio)**Eye diagram** (pattern, aperture) (Rep.779, Rep.784)

F

- Fade margin** (Rep.783, Rep.784)
- Fading, precipitation** (Rep.783)
- Figure of merit** (Rep.445)
- Final Acts of WARC-79** (Rep.789)
- Frequency bands above about 40 GHz** (Rep.783)
 - digital radio-relay systems (Rep.783)
 - fading, precipitation (Rep.783)
 - high-capacity digital radio-relay systems (Rep.783)
 - hop length (Rep.783)
 - propagation (Rep.783)
- Frequency bands between 20 GHz and 40 GHz** (Rep.936)
 - point to multi-point services (Rep.936)
 - radio-frequency channel arrangement (Rep.936)
- Frequency bands 8 and 9, system** (Rep.379, Rep.380)
- Frequency correlation** (Rep.376)
- Frequency deviation** (Rec.276, Rec.401, Rec.402, Rec.404)
 - pilot channel (Rec.401)
 - pre-emphasis (Rec.404)
 - sound channel sub-carrier (Rec.402)
 - telephony (Rec.404)
 - television, peak-to-peak (Rec.276)
- Frequency diversity** (Rec.302)
- Frequency division multiple access (FDMA)** (Rep.379)
- Frequency division multiplex (FDM)** (Rec.275, Rec.290, Rec.380, Rec.385, Rec.391, Rec.392, Rec.393, Rec.395, Rec.396, Rec.397, Rec.398, Rec.399, Rec.401, Rec.404, Rep.286, Rep.288, Rep.396, Rep.610, Rep.781)
 - continuity pilot (Rec.401)
 - frequency deviation (Rec.404)
 - high capacity system (Rep.781)
 - interconnection (Rec.380)
 - interference (Rep.610)
 - international connection (Rec.380)
 - maintenance (Rec.290)
 - measurements (Rec.398, Rec.399)
 - noise in actual traffic (Rec.398)
 - pre-emphasis (Rec.275)
 - quadrature partial-response system (QPRS) (Rep.610)
 - telephony (Rec.275, Rec.290, Rec.404)
- Frequency modulation** (Rec.405)
- Frequency re-use** (Rep.614)
- Frequency sharing** (Rep.614, Rep.780, Rep.940, Rep.942)
 - passive sensors (Rep.940)
- Frequency spacing** (Rep.788)
 - high-capacity digital radio-relay systems (Rep.788)
- Frequency stability (tolerances)** (Rep.785)
 - AFC (automatic frequency control) (Rep.785)
 - APC (automatic phase control) (Rep.785)
 - statistical considerations (Rep.785)
- Frequency tolerances** (defn) (Rep.785)
- FSK (frequency shift keying)** (Rep.379, Rep.610, Rep.940)

G

- Gap-bridging link** (Rep.615)
- GAS 3, GAS 4, GAS 7** (see Special Autonomous Working Parties)
- Group-delay** (Rep.289)

H

- High capacity SSB** (Rep.781)
 - interference, to and from SSB (Rep.781)
 - interference, SSB/satellite (Rep.781)
- High-capacity digital radio-relay systems** (Rep.378, Rep.782, Rep.783, Rep.788, Rep.934, Rep.936)
 - frequency spacing (Rep.788)
 - intermediate frequencies (Rep.788)
- High-capacity radio-relay systems** (Rep.378)
- Homogeneous frequency pattern** (Rep.607, Rep.935)
- Homogeneous section** (Rec.380, Rec.390, Rec.391, Rec.392, Rec.393, Rec.555, Rec.593, Rep.612)
- Homogeneous section (for telephony)** (defn) (Rec.390)
- Hypothetical reference circuit (HRC)** (defn) (Rec.390, Rec.391, Rec.392, Rec.396)
 - more than 60 telephone channels (Rec.392)
 - terms and references (Rec.390)
 - trans-horizon radio-relay systems (Rec.396)
 - 12 to 60 telephone channels (Rec.391)
- Hypothetical reference circuit (HRC)** (Rec.390, Rec.391, Rec.392, Rec.393, Rec.396, Rec.397, Rec.555, Rec.557, Rep.375, Rep.612)
 - allowable noise power (Rec.393, Rec.397)
 - availability (Rec.557)
 - homogeneous sections (Rec.393)
 - noise objectives (clauses) (Rep.375)
 - noise, permissible (Rec.555)
 - sound programme circuit (Rep.375)
 - telephony (Rec.391, Rec.392, Rec.393, Rec.396, Rec.397)
 - television (Rec.555)
 - trans-horizon radio-relay systems (Rec.396, Rec.397)
- Hypothetical reference circuit for telephony** (defn) (Rec.390)
- Hypothetical reference connection** (Rec.594, Rep.930)
- Hypothetical reference digital path (HRDP)** (defn) (Rec.390, Rec.556)
- Hypothetical reference digital path (HRDP)** (Rec.390, Rec.556, Rec.557, Rec.594, Rep.930)
 - availability (Rec.557)
 - bit error ratio (Rep.930)
 - digital radio-relay systems (Rec.557)
 - digital transmission (Rec.557)
 - telephony (Rec.556)
 - unavailability (Rec.557)

I

- IEC (International Electrotechnical Commission)** (Rep.445)
- IKL (isokeraunic levels)** (Rep.932)
- Impairments** (Rep.443)
- Industrial, scientific and medical (ISM) applications** (Rep.933)
- Integrated services digital network (ISDN)** (Rec.594, Rep.930)
- Integration time** (Rep.594)
- Inter-symbol interference (ISI)** (Rep.285, Rep.378, Rep.613, Rep.779, Rep.784)
- Interconnection** (Rec.268, Rec.270, Rec.275, Rec.276, Rec.306, Rec.380, Rec.381, Rec.390, Rec.403, Rec.463, Rec.596, Rep.284, Rep.374, Rep.938, Rep.939)
 - across a frontier (Rec.306)

Interconnection (*cont'd*)

analogue radio-relay systems (Rep.284, Rep.374)
 audio frequencies (Rec.268)
 auxiliary radio-relay systems (Rep.284, Rep.374)
 baseband (Rec.381, Rec.463, Rep.938)
 baseband digital signal processing (Rep.938)
 baseband frequencies (Rec.380, Rep.284, Rep.374)
 below about 2 GHz (Rep.284)
 continuity pilot (Rec.381, Rec.463)
 digital radio-relay systems (Rec.596, Rep.938)
 homogeneous section (Rec.380)
 intermediate frequency (Rep.939)
 intermediate-frequency characteristics (Rec.403)
 intermediate-frequency combiner (Rep.939)
 international connection (Rec.306, Rec.380, Rec.390, Rec.594)
 line-regulating pilot (Rec.381)
 procedure (Rec.306)
 radio-link control station (Rec.381, Rec.463)
 radio-link sub-control station (Rec.381, Rec.463)
 sense of modulation (Rec.276)
 telephony (Rec.268, Rec.381)
 television (Rec.270, Rec.275, Rec.463)
 trans-horizon radio links (Rep.939)
 video signal frequencies (Rec.270)
 video interconnection points (Rec.270)

Interference (Rec.302, Rep.286, Rep.289, Rep.610, Rep.779, Rep.780, Rep.781, Rep.785, Rep.788, Rep.789, Rep.937, Rep.940, Rep.941)

adjacent channel interference (Rep.610, Rep.779, Rep.780)
 broadcasting-satellite service (sound) (Rep.941)
 broadcasting-satellite service (Rep.789)
 co-channel interference (Rep.610, Rep.779, Rep.780, Rep.931, Rep.932)
 digital radio-relay systems (Rep.610, Rep.779, Rep.788)
 energy dispersal (Rep.941)
 frequency diversity (Rec.302)
 frequency tolerances (Rep.785)
 interference sources (Rep.779)
 noise sources (Rep.779)
 power flux-density (pfd) limits (Rep.941)
 satellite systems (Rep.937)
 single channel per carrier (SCPC) system (Rep.937)
 spurious emissions (Rep.937)
 time division multiple access (TDMA) (Rep.937)
 trans-horizon radio-relay systems (Rec.302, Rep.286)

Interference between FDM-FM (Rep.780)

sharing (Rep.780)

Interference, to and from SSB (Rep.781)**Interleaved frequency plans** (Rep.934)**Intermediate frequencies** (Rec.403, Rep.788, Rep.939)

analogue radio-relay systems (Rec.403)
 at harmonic frequencies (Rec.403)
 centre value (Rec.403)
 combiner (Rep.939)
 digital radio-relay systems (Rep.788)
 high-capacity digital radio-relay systems (Rep.788)
 impedance (Rec.403)
 interconnection (Rec.403)
 output and input voltages (Rec.403)

Intermodulation noise (Rep.612)**International connection** (Rec.268, Rec.306, Rec.380, Rec.390, Rec.594)

audio frequencies (Rec.268)

baseband frequencies (Rec.380)
 definition of the points (Rec.380)
 digital (Rec.594)
 frequency-division multiplex (FDM) (Rec.380)
 homogeneous section (Rec.380)
 procedure (Rec.306)
 telephony (Rec.268)

Interruptions (Rec.557, Rep.137, Rep.443, Rep.445)

analogue radio-relay systems (Rep.443)
 multi-line switching (Rep.137)
 switching (Rep.443)

ISI (see Inter-symbol interference)**J****Jitter** (Rec.594, Rep.930, Rep.938)**L****Lightning protection** (Rep.932)

IKL (isokeraunic levels) (Rep.932)
 keraunic level (Rep.932)

Line-of-sight radio-relay systems (Rec.283, Rec.380, Rec.381, Rec.382, Rec.383, Rec.384, Rec.385, Rec.391, Rec.392, Rec.395, Rec.401, Rec.403, Rec.404, Rec.555, Rep.933)**Line-regulating pilot** (Rec.381)**Link budgets** (Rep.941)**Link quality monitoring** (Rep.787)**Loss/frequency distortion** (Rec.290)**Low and medium capacity digital systems** (Rec.387)**Low capacity systems** (Rep.940)

point-to-multipoint (P-MP) systems (Rep.940)

Low-cost systems (Rep.379)**M****Main traffic concentrating station (MTCS)** (Rep.379)**Maintenance** (see also Measurements) (Rec.290, Rec.305, Rec.398, Rec.399, Rec.400, Rec.401, Rec.443, Rec.444, Rep.137, Rep.444, Rep.612, Rep.613, Rep.787)

alarms (Rep.787)
 auxiliary radio-relay system (Rec.400, Rep.444)
 continuity pilot (Rec.401)
 digital radio-relay systems (Rep.787)
 frequency-division multiplex (Rec.290)
 interruptions (Rep.443)
 link quality monitoring (Rep.787)
 loss/frequency distortion (Rec.290)
 multi-line switching (Rec.444, Rep.137)
 noise level (Rec.290)
 outage (Rep.443)
 pilot-frequency deviation (Rec.290)
 protection (Rep.787)
 protection channel (Rec.444, Rep.137)
 reference frequency (Rec.290)
 service channels (Rec.400, Rep.444, Rep.787)
 stand-by arrangements (Rec.305)
 supervision (Rep.787)
 switching (Rep.443)
 telephony (Rec.290, Rec.305)
 television (Rec.305)

Maximum power combiner (defn) (Rep.376)

Mean time between failures (MTBF) (Rec.557, Rep.445)

Mean time to restore (repair) (MTTR) (Rec.557, Rep.445)

Measurements (see also Maintenance) (Rec.290, Rec.398, Rec.399, Rep.612, Rep.613)

- analogue radio-relay systems (Rep.612)
- bit error ratio (BER) (Rec.594, Rep.613)
- continuous uniform spectrum signal for noise measurement (Rec.399)
- conventional load (Rec.399)
- digital radio-relay systems (Rep.613)
- frequency-division multiplex (Rec.398, Rec.399)
- noise (Rec.399)
- noise in actual traffic (Rec.398)
- noise measuring channels (Rec.398, Rec.399)
- noise performance (Rep.612)
- parity-check (Rep.613)
- protection switching (Rep.613)
- pseudo-random test sequence (Rep.613)
- telephony (Rec.398, Rec.399, Rep.612)
- television (Rep.612)

Medium capacity digital radio-relay systems (above 10 Mbit/s up to 100 Mbit/s) (Rec.382, Rec.497, Rep.378)

Methods of combining (Rep.376)

Microwave integrated circuit (MIC) (Rep.940)

Minimum dispersion combiner (defn) (Rep.376)

Minimum-shift keying (MSK) (Rep.940)

Modulation technique (Rep.610, Rep.779, Rep.937, Rep.940)

Multi-line switching (Rec.444, Rep.137, Rep.443, Rep.444)

- availability (Rec.444, Rep.444)
- protection channel (Rec.444, Rep.137)
- stop filters (Rep.137)

Multipath effects (Rep.784)

Multipath fading (Rep.376)

Multipath propagation (Rep.376)

Multiple call dropout (Rec.594)

Multiplexing (Rep.938)

Multipoint distribution service (MDS) (Rep.940)

N

Net availability margin (NAM) (Rep.378)

Net or effective fade margin (Rep.378, Rep.784)

Net performance margin (NPM) (Rep.378)

Nodal capacity (Rep.378)

Noise (Rec.290, Rec.398, Rec.399, Rec.593, Rep.288, Rep.374, Rep.375)

- auxiliary radio-relay systems (Rep.374)
- hypothetical reference circuit (Rep.375)
- in actual traffic (Rec.398)
- in real circuits (Rec.593)
- in trans-horizon radio-relay systems (Rep.285)
- in very long telephone connections (Rep.288)
- low-noise channels (Rep.288)
- measurements (Rec.290, Rec.398, Rec.399)
- noise measuring channels (Rec.398)
- sound programme circuits (Rep.375)
- telephony (Rec.398, Rec.399, Rep.288)

Noise clauses (Rep.375)

Noise figure (Rep.783)

Noise measuring channels (Rec.398, Rec.399)

Noise objectives (Rep.375)

- hypothetical reference circuit (HRC) (Rep.375)
- sound programme circuits (Rep.375)

Noise performance (Rep.612)

- measurements (Rep.612)
- telephony (Rep.612)
- television (Rep.612)

Noise, allowable power (Rec.393, Rec.397)

- hypothetical reference circuit (Rec.393, Rec.397)
- telephony (Rec.393, Rec.397)
- trans-horizon radio-relay systems (Rec.397)

Noise, permissible (Rec.555)

- hypothetical reference circuit (Rec.555)
- television (Rec.555)

Noise, psophometrically weighted (Rec.393, Rec.395, Rec.593)

Noise, real radio-relay links (Rec.392)

Non-availability criteria (Rec.393)

NTSC (National Television System Committee) (Rep.289)

Nyquist bandwidth (Rep.378, Rep.786)

O

OIRT (International Radio and Television Organization) (Rep.289)

One-minute mean power (Rec.392, Rec.393, Rec.395, Rec.397)

Operation (Rec.400)

Optimum deviation (Rep.285)

Order wire (Rep.786)

Orthogonal polarization discrimination (Rep.784)

Outage (see also Interruptions) (Rep.443)

Oxygen absorption coefficient (Rep.783)

P

Packet radio system (Rep.940)

Parity-check (Rep.613)

Passive sensors (Rep.942)

Path antenna gain (Rep.285)

Path attenuation (Rep.612)

(P-MP) (Rep.940)

Point of zero relative level (Rec.393, Rep.289, Rep.375)

Point-to-multipoint services (Rep.936)

Point-to-multipoint (P-MP) systems (Rep.940)

- interference (Rep.940)
- low capacity systems (Rep.940)
- modulation/access techniques (Rep.940)
- multipoint distribution service (MDS) (Rep.940)
- packet radio system (Rep.940)
- SCPC-MA (single channel per carrier) (Rep.940)
- TDMA (time division multiple access) (Rep.940)

Point-to-multipoint distribution (defn) (Rec.592)

Point-to-point systems (Rep.379)

Power flux-density (pfd) limits (Rep.941)

Power-control (Rep.378)

Pre-emphasis (Rec.275, Rec.402, Rec.404, Rec.405)

audio-frequency channel (Rec.402)
 frequency deviation (Rec.404)
 frequency-division multiplex (Rec.275, Rec.404)
 network (Rec.275)
 telephony (Rec.275, Rec.404)
 television (Rec.405)

Propagation (Rec.388, Rec.592, Rec.594, Rep.285, Rep.376, Rep.445, Rep.783, Rep.784, Rep.934)

adverse propagation condition (Rec.594)
 attenuation due to rainfall (Rep.784)
 attenuation due to gases (Rep.784)
 cross-polarization discrimination (decoupling) (XPD) (Rep.784, Rep.934)
 digital radio-relay systems (Rep.784)
 diversity techniques (Rep.376)
 effect on availability (Rep.445)
 fading on a single frequency (Rep.784)
 fade margin (Rep.783)
 multipath effects (Rep.784)
 multipath fading (Rep.376)
 orthogonal polarization discrimination (Rep.784)
 oxygen absorption coefficient (Rep.783)
 path antenna gain (Rep.285)
 precipitation fading (Rep.783)
 selective fading (Rep.784)
 short-term fading (Rep.376)
 signature (Rep.784)
 space diversity (Rep.784, Rep.934)
 trans-horizon radio-relay systems (Rec.388, Rec.592, Rep.285, Rep.376)
 tropospheric scatter (Rec.388, Rec.592, Rep.285)

Protection (Rep.613, Rep.787, Rep.789, Rep.941)

broadcasting-satellite service (sound) (Rep.941)
 broadcasting-satellite service (Rep.789)
 digital radio-relay systems (Rep.787)
 protection switching (Rep.613, Rep.787)
 radio channel identification (Rep.787)
 service channels (Rep.787)
 supervision (Rep.787)

Protection channels (Rec.444, Rep.137)

multi-line switching (Rec.444, Rep.137)

Pseudo-random test sequence (Rep.613)**PSK (phase shift keying) (2-level, 4-level, 8-level)** (Rep.379, Rep.607, Rep.610, Rep.779, Rep.782, Rep.786, Rep.936, Rep.940)**Psophometrically weighted noise power** (Rec.393, Rec.395, Rec.593)**Pyramidal horn reflector antenna** (Rep.614)**Q****QAM (quadrature amplitude modulation)** (Rep.378, Rep.610, Rep.782, Rep.937)**QPSK** (Rep.786, Rep.788)**R****Radiation patterns** (Rep.614)

coordination area (Rep.614)
 frequency re-use (Rep.614)
 frequency-sharing (Rep.614)
 pyramidal horn reflector antenna (Rep.614)
 side-lobe patterns (Rep.614)
 spill-over (Rep.614)

Radio channel identification (Rep.787)**Radio concentrator systems** (Rep.380)**Radio-frequency channel arrangements** (Rec.283, Rec.382, Rec.383, Rec.384, Rec.386, Rec.387, Rec.388, Rec.389, Rec.497, Rec.595, Rep.286, Rep.287, Rep.378, Rep.610, Rep.687, Rep.781, Rep.782, Rep.933, Rep.934, Rep.935, Rep.936)

auxiliary channels (Rep.287)

auxiliary radio-relay systems (Rec.387, Rec.389)

channel disposition (Rep.782, Rep.934)

digital and analogue compatible transmission (Rep.610)

digital radio-relay systems (Rec.283, Rec.382, Rec.384, Rec.497, Rec.595, Rep.378, Rep.782, Rep.933, Rep.934, Rep.935, Rep.936)

FDM telephony (Rec.497)

high and medium-high capacity digital radio-relay systems (Rep.934)

high capacity digital systems (Rep.782)

homogeneous frequency pattern (Rep.607, Rep.935)

low and medium capacity digital systems (Rec.283, Rec.387)

medium-capacity digital radio-relay systems (above 10 Mbit/s up to 100 Mbit/s) (Rec.382, Rec.497, Rep.378)

service channels (Rec.389)

single sideband (SSB) system (Rep.781)

telephony (Rec.385, Rec.387, Rep.781)

television (Rec.387, Rec.497)

trans-horizon radio-relay systems (Rec.388, Rep.286)

2 GHz band (Rec.283)

2 and 4 GHz bands (Rec.382)

2.3 to 2.5 GHz band (Rep.933)

4 GHz band (Rec.382, Rep.934, Rep.935)

5 GHz band (Rep.287)

6 GHz band (Rec.383, Rec.384, Rep.934)

7 GHz band (Rec.385)

8 GHz band (Rec.386, Rep.934)

below about 10 GHz (Rep.934)

10.5 to 10.68 GHz and 11.7 to 15.35 GHz (Rep.607)

10.7 to 11.7 GHz band (Rep.782)

11 GHz band (Rec.387)

13 GHz band (Rec.497)

17.7 to 19.7 GHz band (Rec.595)

17.7 to 21.2 GHz band (Rep.936)

140 Mbit/s (Rec.384, Rep.935)

up to 200 Mbit/s (Rep.935)

280 Mbit/s (Rec.595)

60, 120, 300 telephone channels (Rec.385)

up to 300 telephone-type channels (Rep.933)

600 to 1800 telephone channels (Rec.382, Rec.387)

up to 960 telephone channels (Rec.283)

960 telephone channels (Rec.386, Rec.497)

up to 1260 telephone channels (Rec.384)

1800 telephone channels (Rec.383)

greater than 1800 telephone channels (Rep.287)

2700 telephone channels (Rec.384, Rep.287)

3600 telephone channels (Rep.287)

Radio Regulations (Rec.283, Rec.389, Rec.595, Rep.284, Rep.607, Rep.785, Rep.932, Rep.936)**Radio-relay system** (defn) (Rec.592)**Real digital paths** (Rep.930)**Real radio-relay links** (Rec.392)**Reference radiation patterns** (see Radiation patterns) (Rep.614)

Relative power level (dBr) (Rec.399)

Reliability (Rep.445, Rep.937)

Relief operations (Rep.615)
transportable radiocommunications equipment (Rep.615)

Residual noise (Rep.612)

Return loss (Rep.938)

Rural radio-relay system (Rep.379, Rep.380, Rep.940)
channel separation (Rep.379)
concentrator systems (Rep.380)
digital radio concentrator systems (Rep.380)
digital radio-relay systems (Rep.379, Rep.380)
drop/insert systems (Rep.380)
frequency division multiple access (FDMA) (Rep.380)
interference (Rep.379, Rep.940)
low capacity systems (Rep.940)
low-cost systems (Rep.379)
main traffic concentrating station (MTCS) (Rep.379)
multipoint distribution service (MDS) (Rep.940)
point-to-multipoint (P-MP) systems (Rep.940)
point-to-point systems (Rep.379)
radio concentrator systems (Rep.380)
simple radio-relay equipment (Rep.379)
single channel systems (Rep.380)
small traffic stations (STS) (Rep.379)
subscriber telephone connections (Rep.380)
telephone trunk connections (Rep.379)
time division multiple access (TDMA) (Rep.380)
trunk connections (Rep.379)

S

Satellite systems (Rep.937)
single channel per carrier (SCPC) system (Rep.937)
time division multiple access (TDMA) (Rep.937)

SCPC-MA (single channel per carrier multiple access) (Rep.940)

Scrambling (Rep.938)

SECAM (séquentiel à mémoire) (Rep.931)

Selective fading (Rep.784)

Service channels (Rec.389, Rec.400, Rep.444, Rep.787, Rep.938)
auxiliary radio-relay systems (Rec.389, Rec.400, Rep.444)
availability (Rep.444)
control and operational channels (Rep.444)
control signals (Rec.400)
express voice channels (Rep.444)
express voice circuit (Rec.400)
omnibus voice channels (Rep.444)
omnibus voice circuit (Rec.400)
supervisory channels (Rep.444)
supervisory signals (Rec.400)

Side-lobe patterns (Rep.614)

Signal-to-noise ratios, television (Rec.555)

Signature (Rep.378, Rep.784)

Simple radio-relay equipment (Rep.379)

Simultaneous transmission, analogue/digital (Rep.786)
data above the baseband (data above voice and data above video) (DAV) (Rep.786)
data under the baseband (data under voice) (DUV) (Rep.786)
sub-carrier frequency (Rep.786)

Simultaneous transmission, television and sound programme signals (Rec.402, Rep.289)
interference (Rep.289)
intermodulation products (Rep.289)
sound sub-carrier frequencies (Rep.289)
transmission characteristics (Rec.402)

Single channel per carrier (SCPC) system (Rep.937)

Single channel systems (Rep.380)

Single sideband (SSB) (Rep.607, Rep.781)
radio-frequency channel arrangements (Rep.781)

Single-line combining (Rep.443)

Single-line switching (Rep.443)

Small capacity digital radio-relay systems (up to and including 10 Mbit/s) (Rep.378) (see also Low capacity radio-relay systems)

Small traffic stations (STS) (Rep.379)

Solar energy (Rep.380)

Sound programme circuits (Rep.375)
conventional test signal (Rep.375)
dBq0ps (defn) (Rep.375)
noise objectives (Rep.375)

Sound programme transmission (Rec.402, Rep.289, Rep.607)
interference (Rep.289)
point of zero relative level (Rep.289)

Sound sub-carrier frequencies (Rep.289)

Space correlation (Rep.376)

Space-diversity (Rep.784, Rep.934)

Special Autonomous Working Party 3 (GAS 3) (Rep.379, Rep.380)

Special Autonomous Working Party 4 (GAS 4) (Rep.379, Rep.380)

Special Autonomous Working Party 7 (GAS 7) (Rep.379, Rep.380)

Spectrum efficiencies (Rep.781)

Spill-over (Rep.614)

Spread spectrum (Rep.940)

Spurious emissions (Rec.302, Rep.789, Rep.937)
broadcasting-satellite service (Rep.789)
burst errors (Rep.937)
control (Rep.937)
reliability (Rep.937)
satellite systems (Rep.937)

SSMA (spread spectrum multiple access) (Rep.940)

Stand-by arrangements (Rec.305)

Stop filters (Rep.137)

Subscriber telephone connections (Rep.380)

Supervision (Rep.787)
alarms (Rep.787)
digital radio-relay systems (Rep.787)
link quality monitoring (Rep.787)
radio channel identification (Rep.787)
service channels (Rep.787)

Supervisory channels (Rep.786)

Switching (Rec.444, Rep.137, Rep.443)
multi-line switching (Rec.444, Rep.137, Rep.443)
single-line switching (Rep.443)
transfer time (Rep.443)

Symbol rate (Rep.378)

System capacity (Rec.398, Rec.399, Rec.401)

T

TDM signal (Rep.379)

TDMA (time division multiple access) (Rep.940)

Telephone trunk connections (Rep.379)

Telephony (Rec.268, Rec.275, Rec.290, Rec.305, Rec.381, Rec.385, Rec.387, Rec.391, Rec.392, Rec.393, Rec.396, Rec.397, Rec.398, Rec.399, Rec.401, Rec.404, Rec.556, Rep.612, Rep.781)

allowable noise power (Rec.393, Rec.397)

continuity pilot (Rec.401)

frequency-division multiplex (Rec.275, Rec.290, Rec.404)

hypothetical reference circuit (HRC) (Rec.391, Rec.392, Rec.393, Rec.396, Rec.397)

hypothetical reference digital path (HRDP) (Rec.556)

interconnection (Rec.268, Rec.381)

maintenance (Rec.290, Rec.305)

measurements (Rec.398, Rec.399, Rep.612)

pre-emphasis (Rec.275)

radio-frequency channel arrangements (Rec.385, Rep.781)

Television (Rec.270, Rec.275, Rec.276, Rec.305, Rec.387, Rec.401, Rec.405, Rec.463, Rec.497, Rec.555, Rep.607, Rep.612, Rep.931)

baseband (Rec.463)

continuity pilot (Rec.401)

deviation, peak-to-peak (Rec.276)

frequency deviation (Rec.276)

hypothetical reference circuit (HRC) (Rec.555)

interconnection (Rec.270, Rec.275, Rec.463)

maintenance (Rec.305)

measurements (Rep.612)

noise, permissible (Rec.555)

peak-to-peak frequency deviation (Rec.405)

pre-emphasis (Rec.405)

radio-frequency channel arrangements (Rec.387, Rec.497)

sense of modulation (Rec.276)

signal-to-noise ratios (Rec.555)

Television pick-up (Rep.607)

Television transmission (Rec.402, Rep.289, Rep.931)

co-channel interference (Rep.931)

interference (Rep.289)

Thermal noise (Rep.612)

Time diversity (Rep.376)

Time division multiple access (TDMA) (Rep.380, Rep.937)

Trans-horizon radio-relay system (defn) (Rec.592)

Trans-horizon radio-relay systems (Rec.302, Rec.388, Rec.396, Rec.397, Rec.593, Rep.285, Rep.286, Rep.376, Rep.939)

allowable noise power (Rec.397)

digital radio-relay systems (Rep.285)

diversity techniques (Rep.376)

hypothetical reference circuit (HRC) (defn) (Rec.396)

hypothetical reference circuit (HRC) (Rec.396, Rec.397)

interconnection (Rep.939)

interference (Rec.302, Rep.286)

intermediate-frequency combiner (Rep.939)

noise in trans-horizon radio-relay systems (Rep.285)

optimum deviation (Rep.285)

path antenna gain (Rep.285)

propagation (Rep.285)

radio-frequency channel arrangements (Rec.388, Rep.286)

telephony (Rec.397)

tropospheric scatter (propagation, system) (Rec.388, Rep.285, Rep.376)

Transportable microwave links (Rep.615)

Transportable radiocommunications equipment (Rep.615)

gap-bridging link (Rep.615)

relief operations (Rep.615)

transportable microwave links (Rep.615)

Tropospheric scatter (propagation, system) (Rec.388, Rep.285, Rep.376)

Trunk connections (Rep.379)

U

Unavailability (Rec.557, Rep.445)

Uniform-spectrum signal (Rec.399)

V

Very long telephone connection (Rep.288)

noise (Rep.288)

Video signal frequencies (Rec.270)

interconnection (Rec.270)

W

World Administrative Radio Conference (Geneva, 1979) (Rep.783, Rep.941, Rep.942)

World Administrative Radio Conference on the Aeronautical Mobile (R) Service, Geneva, 1978 (Rep.937)

World Administrative Radio Conference, Geneva, 1977 (WARC-BS-77) and WARC-79 (Rep.607)

Y

Yagi antennas (Rep.380)

16-level QAM (quadrature amplitude modulation) (Rep.378, Rep.782)

