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 III

FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz

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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.

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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.

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(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*

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1.6 *Decisions*

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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 III

FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz

(Study Group 3)

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Report 892	Computation of reliability for HF radio systems	VI

Text	Title	Volume
Study Programme 27B/6	Channel evaluation of ionospheric radio circuits	VI
Study Programme 27C/6	Operational frequency management of ionospheric radio circuits	VI
Study Programme 28D/6	Propagation factors affecting the sharing of the radio frequency spectrum between terrestrial systems involving ionospheric propagation	VI
Question 56/8	Frequency sharing between services in the band 4 to 30 MHz	VIII
Report 615	Transportable fixed radiocommunications equipment for relief operations	IX
Study Programme 44M/10	Compatibility between the MF sound-broadcasting service and other services using the same band	X
Question 1/10 and 11	Broadcasting-satellite service (sound and television): *Protection from interference*	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
Recommendation 971	A general terminology of telecommunications. *Terms common to CCIR and CCITT*	XIII
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

FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz

STUDY GROUP 3

Terms of reference:

To study questions relating to complete systems for the fixed service operating at frequencies below about 30 MHz and terminal equipment associated therewith.

1978-1982	*Chairman:*	T. DE HAAS (United States of America)
	Vice-Chairman:	H. KAJI (Japan)
1982-1986	*Chairman:*	H. KAJI (Japan)
	Vice-Chairman:	A. GUEYE (Senegal)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP 3 (1978-1982)

1. Introduction

The study period 1978-1982 saw a renewed interest in the work of the study group as evidenced by a significant increase in contributions over the previous study period. Equally significant is that many contributions are of special interest to developing nations. In addition, Resolutions and Recommendations from the WARC-79 led to the adoption of several new Questions and the formation of two Interim Working Parties, and resulted in some significant results during this study period.

2. Complete systems

2.1 *Factors affecting the quality of performance of complete systems of the fixed service* (Question 1/3, Study Programme 1A-3/3, 1B/3, 1C/3).

Protection of radio station against lightning and other electromagnetic disturbances (Question 31/3).

Frequency Sharing with other services below 30 MHz (Question 32/3).

Criteria to be used in differentiating between classes of operation (Question 33/3).

Interim Working Party 3/1, chaired by Dr. Kaji (Japan), was established to complete, as far as practicable, the tables in Recommendations 240-3 (Protection ratios) and 339-4 (Signal-to-noise ratios). Recommendation 339-4 was amended to provide values for single-sideband full carrier and single-sideband reduced carrier emissions, and for Multiple Frequency Shift Keying systems. The IWP will continue its work during the next study period.

Interim Working Party 3/2, chaired by Mr. Devereux (UK), was established to study protection ratios and other technical parameters required for classes of operation A and B (see Resolution 9 of the WARC-79). However, it was found that further study by Study Group 6 as well as by Study Group 3 is required before a Recommendation can be prepared, and this further study will be best carried out using the regular working methods of the study groups rather than by the IWP, which is therefore terminated. Nevertheless, very preliminary information is given in Report 860 which may serve as the basis for the further studies.

New Report 855 describes a new method of evaluating subjective test results of speech quality experiments. The system could be a very useful tool in obtaining more definitive values of required S/N and protection ratios for telephony systems.

Report 856 discusses reciprocal mixing in receivers using frequency synthesizers and provides a quantitative relationship between the synthesizer out-of-band noise characteristics and the degradation of the receiver output signal-to-noise ratio in the presence of strong out-of-band interference. The relationship given can easily be specified and facilitates performance comparison between various receivers.

Report 203-1 now includes a description of a method to predict the expected range of differential path delays caused by multipath propagation as a function of radio circuit length and for various levels of sunspot activity.

Report 861 contains a comprehensive summary of methods for protection of radio stations against lightning.

Several frequency bands below 30 MHz are now allocated on a shared basis to the fixed service and other services. Report 859 summarizes the factors to be taken into account in the study of sharing and stresses the need for collecting and analyzing data from actual shared use of frequencies.

2.2 *Use of HF ionospheric channel simulators* (Question 21/3)

A note was added in Annex I of Recommendation 520, referring to Report 203-1 for selecting differential time delay values for simulation of specific circuits.

2.3 *Remote control of HF receiving and transmitting stations* (Question 24-2/3)

Report 857 discusses characteristics of remote control systems for HF receiving and transmitting stations, in particular, relating to the connecting link and the mode of operation.

Report 329-3 discusses functional characteristics and requirements of remotely controlled HF receiving stations and includes an example of a practical implementation.

Report 858 provides two examples of practical implementations of remotely controlled HF transmitting stations.

3. Radiotelephony

Improvements in the performance and efficiency of radiotelephone circuits (Questions 13-2/3 and 27/3)

The description of the Syncompex system in Annex II of Report 354-4 has been updated to include the latest available information. Annex III has been added to the Report, describing a small automatic radiotelephone system which uses real time channel evaluation and is connected to the regular telephone network.

Report 862 describes tests and presents test results that show that the receiver configuration of the system described in Annex I of Report 176-5 is useful not only for receivers in complete frequency-band compression systems but also as a means to improve interference rejection of receivers in conventional single-sideband telephony systems.

Based on test results, Report 176-4 was amended to indicate that the signal distortion caused by interference close to or in the control channel is lower in the narrow-band Lincompex system described in Recommendation 475-1.

4. Radiotelegraphy

4.1 *Performance of radiotelegraph circuits* (Study Programmes 1A-3/3 and 17A-2/3; Questions 2-2/3 and 26-1/3)

Report 183-2 (Usable sensitivity of radiotelegraph receivers in the presence of quasi-impulsive interference) was transferred from Study Group 1, with deletion of the material not appropriate to Study Group 3.

Report 863 (Synchronization of channels in multi-channel VF telegraph systems using ARQ in long-range radio circuits) deals with the problem of timing-jitter resulting from signal regeneration at relay points, and suggests means to overcome this problem.

4.2 *Data Transmission* (Questions 12-1/3, 26-1/3 and 28/3)

Report 865 describes a system using spread spectrum techniques, having a data rate of 300 bit/s in a 3 kHz radio channel, and reports the improvement in performance as compared to the use of multichannel FSK with in-band diversity.

Report 864 describes a data transmission system capable of speeds of up to 2400 bit/s, using differential phase-shift keying and the facility for digital coding with time interleaving at speeds of 1200 bit/s and lower. In addition, required characteristics for the RF equipment with respect to phase-jitter, group delay distortion and intermodulation distortion are specified.

5. Questions and Study Programmes

A new CONSIDERING was added to Study Programme 1A-2/3 (Signal-to-noise ratios and protection ratios; bandwidth, adjacent channel spacing and frequency stability) referencing WARC-79 Recommendations Nos. 60 and 64, and a new paragraph 3.2 was added in the DECIDES to include the dynamic range of the receiver input circuits as a factor to be considered in determining adjacent channel protection ratios and required frequency separations. In addition, editorial amendments were made to reflect the new designations for emissions and minor changes in terminology.

Question 2-1/3 (Arrangement of channels in multi-channel systems for long-range radio circuits) was amended to be more precise.

Question 13-1/3 (Improvements in the performance and efficiency of HF radiotelephone circuits) was slightly amended to reflect Recommendation No. 65 of WARC-79.

Study Programme 17A-1/3 (Voice-frequency telegraphy on radio circuits) was amended to include the study of synchronous operation on long distance radio circuits using relay points.

Question 24-1/3 (Remotely controlled HF receiving and transmitting stations) was amended to reflect that the study of this Question is not limited to stations in the fixed service.

New Question 30/3 (Frequency tolerance of transmitters for the fixed service at frequencies below about 30 MHz) responds to Recommendation No. 69 of the WARC-79 and initiates studies to determine desirable frequency tolerances of transmitters (from a spectrum utilization efficiency point of view) and, where possible, to predict ultimate values of those tolerances.

Question 31/3 (Protection of radio stations against lightning and other electromagnetic disturbances) responds to Resolution No. 64 of the WARC-79. Recognizing and drawing the attention to the extensive work performed in the CCITT on the subject of lightning protection, this Question is intended to initiate studies specifically directed towards the protection of radio communication equipment. In addition to lightning, the scope of the Question includes other electromagnetic disturbances, for example, auroral effects, which may also result in deterioration of the performance of radiocommunication equipments.

Question 32/3 (Frequency sharing with other services below 30 MHz) initiates the studies of the problems of sharing of HF frequency bands between the fixed service and other services.

Question 33/3 (Criteria to be used in differentiating between classes of operation) responds to Resolution No. 9 and Recommendations Nos. 60 and 64 of the WARC-79 and Article 12 of the Radio Regulations. The studies resulting from this new Question will have to deal with a relatively new concept, i.e., the definition of classes of operation based on the need to use the spectrum for the service(s) provided.

6. Decisions and Opinions

Decision 45, in response to a request by the IFRB, established Interim Working Party 3/1 to complete, as far as practicable, the tables in Recommendations 240-3 (Protection ratios) and 339-5 (Signal-to-noise ratios).

Opinion 66 expresses the view that, for the time being, sharing between services at frequencies below 30 MHz requires consideration on a case-by-case basis and that further studies are needed to quantify the constraints imposed by the individual services involved in such sharing. Question 32/3 initiates those required studies within the terms of reference of Study Group 3.

7. Items of special interest to developing nations

The small automatic ratiotelephone system described in the new Annex III to Report 354-4 would appear to have significant applications for areas where wire-line telephone service does not exist and may economically not yet be practicable. This radiotelephone system provides a solution to the problem of selecting the optimum working frequency at any given time without operator intervention and, consequently, also without dependence on operator experience.

Reports 551, 857, 329-3 and 858 describe requirements for remotely controlled stations and practical examples of implementation of remotely controlled HF receiving and transmitting stations. Such stations have been reported to increase reliability and efficiency, and greatly reduce the need for skilled operating personnel.

The Syncompex radiotelephone technique described in the revised Annex II of Report 354-4 overcomes some of the problems of required accuracy of alignment which have in certain cases been experienced with the Lincompex system, at the expense of some degree of fidelity. In particular, satisfactory results have been reported for Syncompex with a frequency offset of up to 20 Hz. It is also noted that the compression/expansion control signal is transmitted via two FSK channels in parallel to provide in-band frequency diversity and thus a higher degree of reliability. It is further noted that the Syncompex equipment may be connected to a radio system at the audio input and output points, and thus can be added on to existing radio telephone systems with minimal interface requirements.

Report 861 describes methods of protecting radiotelecommunications equipment against the effects of lightning and other electromagnetic disturbances. HF radio stations are especially susceptible to these effects as they often have large antennas and long feeder lines associated with the station. The Report is of special interest to countries where lightning storms are common occurrences.

Question 30/3 seeks to determine the desirable frequency tolerances with a view to the reduction of the amount of spectrum required. The answers to this Question will be of significant importance to developing countries in their procurement of some types of radiocommunications equipment.

Question 33/3 and Report 860 deal with a relatively new concept, i.e., the definition of classes of operation based on the need to use the spectrum for the services provided. In many developing countries certain communications services can only be provided by means of HF radio, and consequently such services will receive the highest degree of protection.

Finally, Question 32/3 and Report 859 address the problem of frequency sharing with other services in the spectrum below 30 MHz which is of great importance to all countries.

8. Future work programme

With the advent of communications satellites a significant decline occurred in the traditional fixed service below 30 MHz, i.e., the provision of telephone and telegraph communications over great distances. This in turn led to a decline in the activity in Study Group 3 in the 1970-1974 and 1974-1978 plenary periods. However, there has been a growing recognition of the role of radiocommunication in the fixed service below 30 MHz in its ability to provide communications in areas where no other means of communication exists or where such other means are not economically feasible, e.g., in sparsely populated areas and this has been reflected in a renewed increase in activity in the 1978-1982 plenary period.

In the meantime, major advances have taken place in communications technology and related areas, such as integrated circuit technology and digital techniques. With the recognition of the new role of radiocommunications below 30 MHz, significant advances may be expected in equipment as well as in systems design and performance as these techniques are exploited. Some examples already can be seen in the results of this plenary period, e.g., the development of the automatic radiotelephone system described in Annex III of Report 354-4 and the use of synthesizers in radiocommunications equipment.

With the above in mind, significant work lies ahead in the area of interest of Study Group 3, both in response to Questions already existing and resulting from new Questions. A brief list of major items for the future work programme, as seen by the study group, is given below:

(a) Radio systems for use in developing regions and sparsely populated areas and improvements to systems for use under special conditions.

Reference: Questions 22/3 and 2-2/3; Study Programme 17A-2/3; Reports 863 and 354-4.

(b) Improved radiotelephone and radiotelegraph systems.

Reference: Questions 13-2/3 and 26-1/3; Report 354-4, 865 and 864.

(c) Improved equipments.

Reference: Study Programme 1A-3/3; Reports 550, 704 and 856.

(d) HF transmitting and receiving stations designed for operation with minimized requirements for skilled personnel, e.g., remote-controlled stations.

Reference: Question 14/3; Reports 551, 329-3, 705, 857 and 858.

(e) Efficient use of the spectrum, band compression techniques and improved protection ratio requirements.

Reference: Questions 25/3, 27/3 and 28/3; Reports 176-5, 177-1 and 862.

(f) Studies concerning frequency sharing between the fixed service and other services below 30 MHz.

Reference: Opinion 66, Question 32/3, Study Programme 1A-3/3, Decision 45, and Report 859.

SECTION 3A: COMPLETE RADIO SYSTEMS

3A a: Technical characteristics

Recommendations and Reports

RECOMMENDATION 240-3

SIGNAL-TO-INTERFERENCE PROTECTION RATIOS

(Question 1/3, Study Programme 1A/3)

(1953-1956-1959-1970-1974-1978)

The CCIR,

CONSIDERING

that knowledge of the signal-to-interference protection ratios for various classes of emission is needed,

UNANIMOUSLY RECOMMENDS

1. that the values of signal-to-interference protection ratios for stable conditions, below which harmful interference occurs, shown in Table I are presently considered appropriate for the emissions indicated;

2. that studies should be continued to provide values of signal-to-interference protection ratios for stable conditions where they are not shown in the Table and also to review the values that are shown;

3. that the studies in connection with Recommendation 339 and Study Programme 1A/3 should be continued, in conjunction with those of Study Programme 28A/6 for the purpose of determining whether the provisional values given for the fading allowances may be accepted or should be modified;

4. that meanwhile, the values given may be regarded as provisional total fading allowances (combined fading safety factors and intensity fluctuation factors) and may be used as a guide, in conjunction with the values for signal-to-interference protection ratios (for stable conditions), appropriate to the various classes of emission.

General Note. – Use of the recommended values only permits an estimate to be obtained, which may have to be adjusted for radio circuits of different lengths, depending on the grade of service required and on the specific propagation conditions on these radio circuits. In calculating the fading safety factor for rapid or short-period fading, a log-normal amplitude distribution of the received fading signal has been used (using 7 dB for the ratio of medium level to level exceeded for 10% or 90% of the time), except for high-speed automatic telegraphy services, where the protection has been calculated on the assumption of a Rayleigh distribution.

REFERENCES

CCIR Documents

[1953]: London, 443 (USA).

TABLE I – *Minimum required protection ratios and frequency separations**

WANTED SIGNAL	INTERFERING SIGNAL CLASS OF EMISSION																																			
	Telegraphy												Telegraphy								Telegraphy															
Class of emission	A1A Manual				A1B 50 baud(1)				A1B 100 baud				A2A Manual				A2B 24 baud				F1B 50 baud 2D = 280 Hz(1)				F1B 50 baud 2D = 400 Hz(1)				F7B 100 baud 2D = 400 Hz				F7B 200 baud 2D = ...			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz		
A1A telegraphy aural reception																																				
A1B telegraphy 50 baud printer B = 500 Hz					11	0.36	0.44	1.41	(2) 12	(2) 0.25	(2) 0.35										13	0.46	0.54	1.24					(2) 3	(2) 0.40	(2) 0.55					
A1B telegraphy 100 and 120 baud recorder B = ...																																				
A2A telegraphy aural reception																																				
A2B telegraphy 24 baud																																				
F1B telegraphy(3) 50 baud, printer $2D$ = 280 Hz; B = 500 Hz					1.0	0.2	0.28	0.6													7.0	0.32	0.39	0.67												
F1B telegraphy 50 baud, printer $2D$ = 400 Hz; B = 500 Hz									(2) 3	(2) 0.35	(2) 0.50																		(2) 2	(2) 0.45	(2) 0.60					
F7B telegraphy 100 baud, printer ARQ $2D$ = ... B = ...																																				
F7B telegraphy 200 baud, printer ARQ $2D$ = 400 Hz; B = 500 Hz									(4) 4	(4) 0.40	(4) 0.55																		(4) 4	(4) 0.50	(4) 0.70					
F7B(3) 50 baud printer $2D$ = 1200 Hz B = 1200 Hz — channel 1																									8	0.85	0.95	1.51								
F7B(3) 50 baud printer $2D$ = 1200 Hz B = 1200 Hz — channel 2																									18	0.98	1.1	2.06								
R3C phototelegraphy																																				
F3C phototelegraphy 60 rpm, B = 1000 Hz									15	1.00	1.20														15				15	1.10	1.20					
A3E telephony Double sideband — just usable																																				
A3E telephony Double sideband — marginally commercial																																				
A3E telephony Double sideband — good commercial																																				
R3E telephony single-sideband reduced carrier(6) — just usable																																				
R3E telephony single-sideband reduced carrier(6) — marginally commercial																																				
R3E telephony single-sideband reduced carrier(6) — good commercial																																				
J3E telephony single-sideband suppressed carrier(6) — just usable																																				
J3E telephony single-sideband suppressed carrier(6) — marginally commercial																																				
J3E telephony single-sideband suppressed carrier(6) — good commercial																																				
J7B multichannel V.F. telegraphy																																				
R7B multichannel V.F. telegraphy reduced carrier																																				

**Note.* – Under "class of emission", B represents the receiver bandwidth and $2D$ represents the total frequency shift. Column No. 1 gives the limiting values of signal-to-interference protection ratio (dB) when the occupied band of the interfering emission either falls entirely within the passband of the receiver, or covers it completely. Columns No. 2, 3 and 4 indicate the frequency separation necessary between the assigned frequency of a wanted signal and that of an interfering signal when the level of the latter is respectively 0,6 and 30 dB higher than the wanted signal. (As defined in No. 142 of the Radio Regulations the assigned frequency is the centre of assigned frequency band.)

(1) Bandwidth of interfering signals limited to 500 Hz.

(2) For a probability of character error P_c = 0.0001.

(3) For a probability of character error P_c = 0.001.

(4) For a traffic efficiency of 90%.

(5) Average degree of modulation 70%; sideband components extended to ±3 kHz.

TABLE I – *Minimum required protection ratios and frequency separations**

INTERFERING SIGNAL CLASS OF EMISSION																																				Provisional total fading allowances(11) for the protection of a fading signal against an interfering signal subject to fading and day-to-day intensity fluctuations. (See note 10) (dB to be added to values in columns numbered 1)	
F7B telegraphy				Phototelegraphy								Telephony(6)																Multichannel V.F. telegraphy									
50 baud 2D = 1200 Hz				R3C				F3C				A3E DSB(5)				H3E full carrier				R3E reduced carrier				J3E suppressed carrier				J7B suppressed carrier				R7B reduced carrier					
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		
dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			non-diversity	diversity
																																					27(7)
																																					27(7)
																																					12(8)
8	1.24	1.33	2.32																																		
18	1.33	1.51	3.08																																		
																																				20	
																																				20	
																																				17(9)	
																																				17(9)	
																																				17(9)	

(6) With the use of Lincompex terminals for the wanted signal, the figures in column No. 1 are reduced by ..... dB (to be determined). When the interfering signal is a telephony transmission using Lincompex terminals, the figures in column No. 1 are increased by ..... dB (to be determined).

(7) For protection 99.99% of the time.

(8) Based on 90% traffic efficiency.

(9) Based on 90% protection.

(10) The probability distribution of the ratio of two signals fading independently has been applied in accordance with Doc. [CCIR, 1953]. The combined intensity fluctuation allowance for two signals has been taken as 7 dB, which represents a compromise between the 0 dB allowance, appropriate to perfectly correlated intensity fluctuations of the two signals, and the 14 dB allowance appropriate to uncorrelated intensity fluctuations of the two signals.

(11) Combined allowances for fading safety factor and intensity fluctuation factor.

RECOMMENDATION 338-2

BANDWIDTH REQUIRED AT THE OUTPUT OF A TELEGRAPH OR TELEPHONE RECEIVER

(Question 1/3, Study Programme 1A/3)

(1953-1963-1966-1970)

The CCIR,

CONSIDERING

(a) the urgent need to determine the minimum separation between frequency assignments of stations operating on adjacent channels, in the range 10 kHz to 30 MHz;

(b) that the width of the frequency band, which is necessary at the output of the receiver, is one of the factors which determine the band of frequencies required for the overall system;

(c) that, for telegraphy, the permissible degree of distortion is not yet defined;

(d) that, for telephony, the bandwidth may depend, among other factors, upon the type of privacy equipment in use,

UNANIMOUSLY RECOMMENDS

1. that, for telegraphy, a provisional value for the bandwidth necessary at the output of the receiver, under average practical conditions, should be as follows:

1.1 for classes of emission A1A and A1B, the bandwidth in hertz, after the final detector stage, should be equal to 2.5 times the modulation rate in bauds;

1.2 for class of emission F1B, the bandwidth in hertz after the discriminator, should be equal to 1.4 times the modulation rate in bauds.

The extent to which these values can be applied, to permit closer spacing of adjacent channels, depends upon the degree and speed of amplitude variations due to fading and upon the differential fading of the frequencies corresponding to the two significant conditions of modulation;

2. that, for telephony, as a compromise between intelligibility and economy of bandwidth, the bandwidth necessary, for each speech channel at the output of the receiver, should be as follows:

2.1 in accordance with Recommendation 335, the upper limit frequency should be reduced to 3000 Hz or less but no lower than 2600 Hz. In the case of the improved radio telephone system using a linked compressor-expander (Recommendation 455), the bandwidth should be strictly preserved to not less than 3000 Hz;

2.2 the lower frequency limit of speech channels should be 250 Hz, and that of programme transmission channels should be 100 Hz;

2.3 for systems employing commercial privacy equipment, the necessary bandwidth for satisfactory service may require the use of an upper limit frequency greater than 2600 Hz (e.g. in five-band privacy equipment the necessary bandwidth is 2750 Hz, the upper limit being 3000 Hz).

RECOMMENDATION 339-5

BANDWIDTHS, SIGNAL-TO-NOISE RATIOS AND FADING ALLOWANCES IN COMPLETE SYSTEMS

(Question 1/3, Study Programme 1A/3)

(1951-1953-1956-1963-1966-1970-1974-1978-1982)

The CCIR,

CONSIDERING

(a) that the studies requested in Study Programme 1A/3 have not yet been completed, and that it is desirable to classify the important points with which future studies will have to deal;

(b) that there is a need for numerical values which take into account fading and fluctuations in field intensity;

(c) that, however, the information contained in Annex I to Recommendation 313 and Report 266 gives some results from which provisional data on fading allowances can be derived,

UNANIMOUSLY RECOMMENDS

1. that meanwhile, the values given in Table I should be adopted as provisional values for the signal-to-noise ratio required for the class of emission concerned;

2. that meanwhile, the values given in the last two columns of Table I, in conjunction with the estimate of the intensity fluctuation factor given in Note 4 to this Table, may be used as an aid to estimate monthly-median values of hourly-median field intensities necessary for the various types and grades of service;

3. that Table I be extended to include additional systems as the pertinent information becomes available;

4. that the studies in connection with Study Programme 1A/3 should be continued, in conjunction with those of Study Programme 28A/6, for the purpose of determining whether the provisional values given in the Table may be accepted or should be modified.

Note 1. – In these studies, the procedures given in Report 195 ~~and Reports 413, 414 and 415 (Oslo, 1966),~~ should be given full consideration.

Note 2. – Use of the provisional recommended values only permits an estimate to be obtained, which may have to be adjusted for radio circuits of different lengths depending on the grade of service required.

TABLE I – *Required signal-to-noise ratios*

Class of emission	Pre-detection bandwidth of receiver (Hz)	Post-detection bandwidth of receiver (Hz)	Grade of service	Audio signal-to-noise ratio (1) (dB)	RF signal-to-noise density ratio(2) (3) (dB): Stable condition	RF signal-to-noise density ratio(2) (3) (dB): Fading condition (4) non-diversity	RF signal-to-noise density ratio(2) (3) (dB): Fading condition (5) dual diversity
A1A Telegraphy 8 baud	3000	1500	Aural reception (6)	–4	31	38	
A1B Telegraphy 50 baud, printer	250	250	Commercial grade (7)	16	40		58
A1B Telegraphy 120 baud, undulator	600	600		10	38		49
A2A Telegraphy 8 baud	3000	1500	Aural reception (6) (19)	–4	35	38	
A2B Telegraphy 24 baud	3000	1500	Commercial grade (7) (19)	11	50	56	
F1B Telegraphy 50 baud, printer $2D$ = 200 Hz to 400 Hz	1500	100	$P_C = 0.01$ $P_C = 0.001$ $P_C = 0.0001$ } (8)		45 51 56 } (9)	53 63 74 } (9)	45 52 59 } (9)
F7B Telegraphy 100 baud, printer $2D$ = ..., ARQ			(10)				
F7B Telegraphy 200 baud, printer $2D$ = ..., ARQ			(10)				
F1B Telegraphy MFSK 33-tone ITA2 10 characters/s	400	400	$P_C = 0.01$ $P_C = 0.001$ $P_C = 0.0001$ } (8)		23 24 26	37 45 52 } (25)	29 34 39
F1B Telegraphy MFSK 12-tone ITA5 10 characters/s	300	300	$P_C = 0.01$ $P_C = 0.001$ $P_C = 0.0001$ } (8)		26 27 29	42 49 56 } (25)	32 36 42
F1B Telegraphy MFSK 6-tone ITA2 10 characters/s	180	180	$P_C = 0.01$ $P_C = 0.001$ $P_C = 0.0001$ } (8)		25 26 28	41 48 55 } (25)	31 35 41
F7B Telegraphy							
R3C Phototelegraphy 60 rpm	3000	3000			50	59	
F3C Phototelegraphy 60 rpm	1100	3000	Marginally commercial (22) Good commercial (22)	15 20	50 55	58 65	
A3E Telephony double sideband	6000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 33 } (18)	50 59 67(14)	51 64 75(14) } (20)	48 60 70(14) } (15) (20)
H3E Telephony single-sideband full carrier	3000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 33 } (18)	53 62 70(14) } (23)	54 67 78(14) } (20)	51 63 73(14) } (15) (20)
R3E Telephony single-sideband reduced carrier	3000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 33 } (18)	48 57 65(14) } (24)	49 62 73(14) } (20)	46 58 68(14) } (15) (20)
J3E Telephony single-sideband suppressed carrier	3000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 33 } (18)	47 56 64(14)	48 61 72(14) } (20)	45 57 67(14) } (15) (20)
B8E Telephony independent-sideband 2 channels	6000	3000 per channel	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 33 } (18)	49 58 66(14)	50 63 74(14) } (20)	47 59 69(14) } (15) (20)
B8E Telephony independent-sideband 4 channels	12000	3000 per channel	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 33 } (18)	50 59 67(14)	51 64 75(14) } (20)	48 60 70(14) } (15) (20)
J7B Multichannel V.F. telegraphy 16 channels 75 baud each	3000	110 per channel	$P_C = 0.01$ $P_C = 0.001$ $P_C = 0.0001$ } (8)		59 65 69 } (21)	67 77 87 } (21)	59 66 72 } (21)
J7B Multichannel V.F. telegraphy 15 channels 100 baud each with ARQ	3000	110 per channel	(10)				
R7B Multichannel V.F. telegraphy reduced carrier							
B7W Composite 16 channels 75 baud each 1 telephony channel(16)	6000	110 per telegraphy channel 3000 for the telephony channel	$P_C = 0.01$ $P_C = 0.001$ $P_C = 0.0001$ } (8)		60 66 70 } (17)	68 78 88 } (17)	60 67 73 } (17)

Footnotes to Table I

(1) Noise bandwidth equal to post-detection bandwidth of receiver. For an independent-sideband telephony noise bandwidth equal to the postdetection bandwith of one channel.

(2) The figures in this column represent the ratio of signal peak envelope power to the average noise power in a 1 Hz bandwidth except for double-sideband A3E emission where the figures represent the ratio of the carrier power to the average noise power in a 1 Hz bandwidth.

(3) The values of the radio-frequency signal-to-noise density ratio for telephony listed in this column, apply when conventional terminals are used. They can be reduced considerably (by amounts as yet undetermined) when terminals of the type using linked compressor-expanders (Lincompex) are used (see Report 354). A speech-to-noise (r.m.s. voltage) ratio of 7 dB measured at audio-frequency in a 3 kHz band has been found to correspond to just marginally commercial quality at the output of the system, taking into account the compandor improvement.

(4) The values in these columns represent the median values of the fading signal power necessary to yield an equivalent grade of service, and do not include the intensity fluctuation factor (allowance for day-to-day fluctuation) which may be obtained from Report 252-2 + Supplement (published separately) in conjunction with Report 322 (published separately). In the absence of information from these Reports, a value of 14 dB may be added as the intensity fluctuation factor to the values in these columns to arrive at provisional values for the total required signal-to-noise density ratios which may be used as a guide to estimate required monthly-median values of hourly-median field strength. This value of 14 dB has been obtained as follows:

The intensity fluctuation factor for the signal, against steady noise, is 10 dB, estimated to give protection for 90% of the days. The fluctuations in intensity of atmospheric noise are also taken to be 10 dB for 90% of the days (see Study Programme 1A/3). Assuming that there is no correlation between the fluctuations in intensity of the noise and those of the signal, a good estimate of the combined signal and noise intensity fluctuation factor is

$$\sqrt{10^2 + 10^2} = 14 \text{ dB}.$$

(5) In calculating the radio-frequency signal-to-noise density ratios for rapid short-period fading, a log-normal amplitude distribution of the received fading signal has been used (using 7 dB for the ratio of median level to level exceeded for 10% or 90% of the time) except for high-speed automatic telegraphy services, where the protection has been calculated on the assumption of a Rayleigh distribution. The following notes refer to protection against rapid or short-period fading.

(6) For protection 90% of the time.

(7) For A1B telegraphy, 50 baud printer: for protection 99.99% of the time. For A2B telegraphy, 24 bauds: for protection 98% of the time.

(8) The symbol P_c stands for the probability of character error.

(9) Atmospheric noise (V_d = 6 dB) is assumed (see Report 322).

(10) Based on 90% traffic efficiency.

(11) For 90% sentence intelligibility.

(12) When connected to the public service network: based on 80% protection.

(13) When connected to the public service network: based on 90% protection.

(14) Assuming 10 dB improvement due to the use of noise reducers.

(15) Diversity improvement based on a wide-spaced (several kilometres) diversity.

(16) Transmitter loading of 80% of the rated peak envelope power of the transmitter by the multi-channel telegraph signal is assumed.

(17) Required signal-to-noise density ratio based on performance of telegraphy channels.

(18) For telephony, the figures in this column represent the ratio of the audio-frequency signal, as measured on a standard VU-meter, to the r.m.s. noise, for a bandwidth of 3 kHz. (The corresponding peak signal power, i.e. when the transmitter is 100% tone-modulated, is assumed to be 6 dB higher.)

(19) Total sideband power, combined with keyed carrier, is assumed to give partial (two element) diversity effect. An allowance of 4 dB is made for 90% protection (8 bauds), and 6 dB for 98% protection (24 bauds).

(20) Used if Lincompex terminals will reduce these figures by an amount yet to be determined.

(21) For fewer channels these figures will be different. The relationship between the number of channels and the required signal-to-noise ratio has yet to be determined.

(22) Quality judged in accordance with article 23.1 of ITU publication "Use of the standardized test chart for facsimile transmissions".

(23) For class of emission H3E the levels of sideband signals and pilot-carrier corresponding to 100% modulation are each −6 dB relative peak envelope power (p.e.p.). SSB receiver used for reception.

(24) For class of emission R3E the pilot-carrier level of −20 dB relative to p.e.p. is applied and the level of the sideband signal corresponding to 100% modulation is 1 dB lower than the p.e.p.

(25) Dependent on fading rate, typical values shown.

REPORT 855

COMPUTER AIDED ANALYSIS OF SPEECH QUALITY

(Question 1/3)

(1982)

1. Introduction

Speech quality in the telecommunication environment is normally evaluated by the subjective method. This method, although simple, necessitates laborious and time-consuming work; an enormous amount of data must be collected to obtain reliable test results.

To cope with these difficulties, a new on-line system for evaluating speech quality has been developed in Japan.

2. Features of the system

The system has the following features:

- a microcomputer calculates accurately the subjective measurement of articulation index, percentage difficulty, and mean opinion score,
- five keyboards permit rapid and error-free retrieval of raw data on the speech quality evaluation made by the listeners,
- an audio cassette tape recorder enables the exchange of data between this system and a high performance data-processing unit (e.g. a large computer system).

This system, especially designed for permanent installation and use in a sound proof chamber, generates very low-level noise, is light in weight and small in size.

3. Configuration and function of the hardware

The configuration is depicted in Fig. 1 and comprises:

3.1 *Keyboard for listener*

This equipment replaces the conventional test chart and consists of the following keys and lamps:

- syllable keys: they keys represent 101 Japanese syllables and are used for calculating the articulation index.
- numerical keys: these ten keys are used for percentage difficulty and the categorized evaluation test.
- indicators: "TEST START", "TEMPORARY STOP", "READY FOR INPUT", "NOT IDENTIFIED", and "ENTER".
- lamp: "POWER".

In addition to these keys and lamps, an LED dot matrix display is provided to indicate and monitor the selected key.

3.2 *Central Processing Unit (CPU)*

This unit monitors and controls the entire system through a microcomputer. It also collects the raw data entered through the keyboards and calculates the subjective measurements.

4. Structure of the software

The software, which is stored on a floppy disc, has three modules for data-processing and one for input/output control.

4.1 *Module for articulation index*

This is for the 100 syllable articulation index. The collected data from the listeners' keyboards are checked and compared with the correct answers which have been stored on the floppy disc via the audio cassette recorder. After this comparison, this module calculates the articulation index for each classified group of syllables: for example, the ratio of the number of voiced fricative sounds and sounds incorrectly identified as unvoiced fricatives.

4.2 *Module for percentage difficulty*

This module calculates the ratio and distribution of the number of listeners who felt any difficulty in understanding the contents of the speech sample.

4.3 *Module for mean opinion score*

Listeners are requested to categorize the quality of speech samples into five groups (excellent = 4 points, good = 3 points, fair = 2 points, poor = 1 point, and bad = 0 point) and the weighted mean opinion score is obtained from these categories.

4.4 *Input/output module for data transfer*

This module deals with the transfer of data between the on-line system and the large computing unit.

This function is necessary, for example, for the detailed analysis of data such as the computation of confidence interval.

5. Conclusion

This on-line system provides an exact and time-effective procedure for subjective evaluation of speech quality. Although the system was designed originally for tests using Japanese words, it can be easily modified for other languages by re-programming the relevant modules.

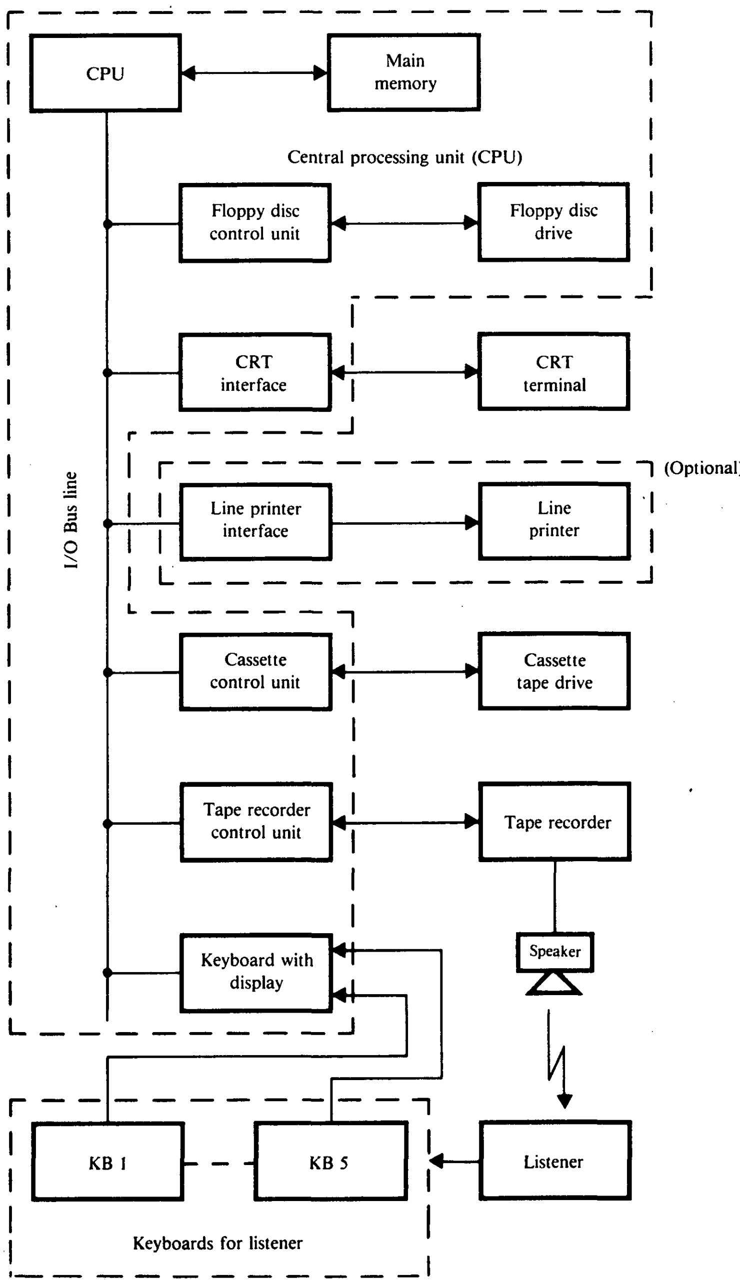

FIGURE 1 – *System block diagram*

REPORT 197-4 *

FACTORS AFFECTING THE QUALITY OF PERFORMANCE OF COMPLETE SYSTEMS IN THE FIXED SERVICE

(Question 1/3, Study Programme 1A/3)

(1963–1966–1970–1974–1978)

1. Urgent need for information

The attention of Administrations is drawn to the urgent need for the information requested in Study Programme 1A/3, for several classes of emission. As requested in Study Programme 1A/3, the establishment of minimum protection ratios for additional classes of emission under stable conditions should be given priority. It is realized that no Administration will be able to give all the answers, but partial answers are very welcome. This information will permit an improvement in the calculation of the probability of harmful interference between assignments and the consideration of the possibility of sharing.

Study Group 3 also needs the information to complete Recommendations 240 and 339 to bring them up to date.

The documents received allow only a very partial answer to some of the questions proposed.

2. Quality of performance of radio telegraph systems

A critical study of results of the tests made so far shows that a correlation exists between the efficiency factor measured and the telegraph distortion at the radio receiver output. On several circuits, where the efficiency factor was measured over periods of 15 minutes, a correlation coefficient of between 0.8 and 0.5 has been established [Frömmer *et al.*, 1965].

[CCIR, 1963-66] and [CCIR, 1966-69a], reports on tests which were carried out on short- as well as on long-range ARQ radio circuits, operated with a modulation rate of 192 bauds, to analyse whether a correlation can be shown to exist between the results of the efficiency factor measurements and the assessment of the signal performance of the radio circuits.

In many, but not in all cases, a certain degree of correlation could be shown to exist between the results of efficiency factor measurements and the signal strength. However, in moments where a strong signal is disturbed by interference this correlation does not exist.

From this, it may be concluded that the measurement of telegraph distortion is the most suitable measurement to permit a rapid and continuous assessment of transmission quality, if reference cannot be made to efficiency factor measurements.

An operational equipment developed to enable simultaneous monitoring of up to 40 telegraph channels at a single supervisory position is described in [CCIR, 1966-69b].

Operational use of this equipment has shown it to be of great value in identifying distortion due to unfavourable propagation conditions or misalignment of equipment, as well as providing a means of early detection of deterioration of propagation conditions. As a result, it was found that the efficiency factor of several circuits could be increased by a significant amount by timely initiating corrective measures.

By showing the level of the pilot carrier and the incidence of telegraph distortion on a chart recorder associated with a control panel for each receiver, a large group of radio receivers can also be controlled centrally as described in [CCIR, 1966-69c]. This is found to be a sensitive method of assessing the quality of the received signal and preferable to the use of the efficiency factor which is often determined by circumstances other than the propagation conditions over the radio path.

3. Evaluation of transmission quality

For evaluating transmission quality, "satisfactory operation factor" (SOF), η, is defined in [CCIR, 1966-69d], as the ratio of the time that the degree of distortion is within acceptable limits to the whole operating time. Degree of distortion is defined as that part of the total number of element transitions occurring in pre-determined amount from the ideal instants.

* This Report combines Reports 197 and 351 (Geneva, 1974).

Results of simultaneous observation of the transmission quality at the two reception points of a 3000 km duplex radio telegraph circuit are presented in [CCIR, 1970-74]. It was found that the difference between the satisfactory operation factor for the go and the return direction was always less than 5% (for any time of the day or night), and that the probability of coincidence of hourly values of η increases with the radio circuit quality [Bukhviner *et al.*, 1973].

Comparison of the transmission quality on a point-to-point circuit for systems with ARQ and without ARQ (200 bauds) showed that the system with ARQ could operate at a lower value of η, although this reduction was less than 5% for $\eta > 90\%$.

It was also found that η increases when the ratio, m, of the operating frequency to the MUF is raised; however, for $m \geqslant 0.65$ the value of η remains practically constant.

Experiments carried out on the analysis of HF radiotelegraph circuit quality over a latitudinal path of 9600 km, using space-diversity reception with a reception base of about 1000 km and automatic monitoring applying the SOF criterion, showed that double-channel automatic monitoring permitting analysis of the distortions versus time on each of the diversity channels was more efficient than single-channel automatic monitoring analysing circuit quality on one of the channels.

The tests proved that the advantage in using automatic monitoring on the SOF criterion increases according to overall reduction in channel quality [Bukhviner and Dubrovsky, 1974].

The experience gained since 1963 seems to indicate that the measurement of telegraph distortion is a more direct and appropriate way to assess transmission quality of radiotelegraph channels than the measurement of the efficiency factor.

To evaluate radio transmission quality, the use of the satisfactory operation factor, as defined above is proposed. However, in those cases where it is impossible to use the value of measured telegraph distortion for the assessment of the efficiency of ARQ-circuits, as for instance with a "flex" system, the measurement of channel efficiency might be operationally preferable.

Reports on measurements of the transmission quality of a number of radio-telegraph circuits in the U.S.S.R. made throughout the years 1966-1968 are contained in [CCIR, 1966-69d].

For these tests, the degree of distortion was considered acceptable when the number of transitions with distortion greater than or equal to 40% was less than 15 per minute. During the tests, the satisfactory operation factor was monitored automatically [Bukhviner, 1974].

Experimental tests on circuits of 2800, 5100 and 5400 km length showed an annual variation of the satisfactory operation factor with values between 0.87 and 0.92 in winter, and between 0.92 and 0.95 in summer [Bukhviner, 1974]. The correlation γ between the degree of element distortion and the character error rate is closer when the element distortion becomes more pronounced. For distortion exceeding 40%, γ was found to be greater than 0.85.

4. Number of transposition errors in automatic error-correction (ARQ) systems

In a study of the efficiency factor of a TOR circuit, under varying signal-to-noise conditions, a relation was derived between the efficiency, v, i.e. the probability of a correct character being printed and the attendant probability p, of a character error being printed as the result of a transposition [Van Duuren, 1961]. One gets different theoretical limits for flat fading, uncorrelated fading and selective fading.

It has now been shown experimentally that, under normal traffic conditions, the results are nearly those expected for flat fading, or between those expected for flat fading and uncorrelated fading. Under unfavourable conditions, the results are more characteristic of those expected for uncorrelated fading.

The dependence of p on v, as measured in narrow-band channels using frequency-shift keying, is shown in Figs. 1 and 2 for different receiving arrangements. There the impurity, which is the probability (p/v) of observing a character error in the printed copy at the receiving end, is displayed as a function of v. So, if the circuit efficiency is known, the number of printed character errors can be predicted.

Fig. 1 shows that, in terms of impurity, with flat fading the performance of reception without diversity is inferior to that of diversity reception. As fading simultaneously affects both mark and space frequencies, diversity reception will favour the branch with the stronger signal thus improving both the purity and efficiency of reception.

Fig. 2 shows the behaviour with selective fading. Here the reverse is observed. Diversity reception enlarges the impurity to be expected for a certain value of v. This means that, though the circuit efficiency is increased by diversity reception, the impurity as a function of v will not fall off as much as with reception without diversity.

For telegraph channels on which the errors occur in bursts, a two state Markov process gives a suitable model for calculations [Van Duuren, 1966]. In one state the probability of error is 0.5, in the other state the channel is error free. Moreover a third decision can be taken into account, when it is not sufficiently sure whether a mark or a space was received. This suggests that the use of such a third decision may materially reduce the appearance of undetected errors at the output of an ARQ channel.

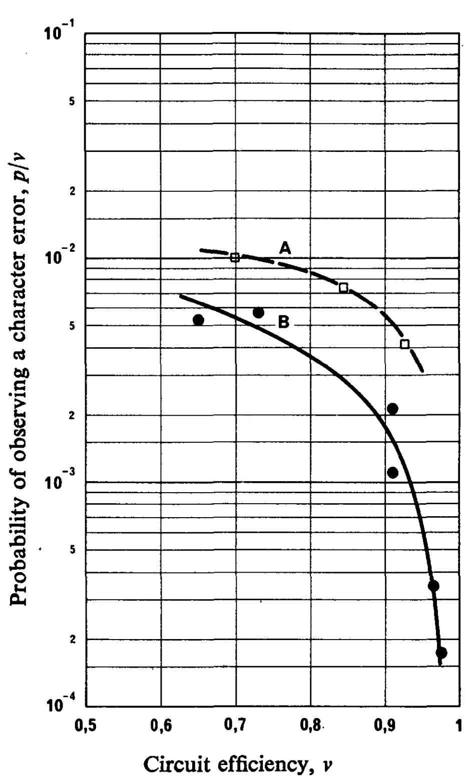

FIGURE 1 – *Probability of a character error (p/v) as a function of circuit efficiency, v, for flat fading*

Curve A: without diversity
B: with dual diversity

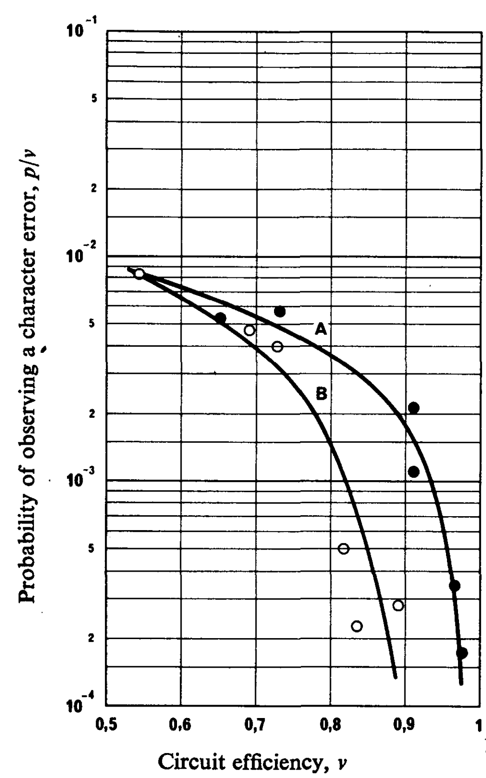

FIGURE 2 – *Probability of a character error (p/v) as a function of circuit efficiency, v, for selective fading*

Curve A: without diversity
B: with dual diversity, frequency or space

Calculations were made for selective and non-selective fading, and compared with results from several experimental circuits. The results with the model for selective fading fit closely the experimental curve. The values of error probability for non-selective fading are a factor of 50-100 higher in the region of practical interest.

5. Tables for the computation of distorted amplitude-modulation envelopes

When a signal consisting of a single frequency carrier modulated in amplitude by a sinusoidal signal passes through a dispersive medium (or filter) the envelope will be distorted. This distortion can be seen to depend on three parameters. For 6270 of such triplets, the envelope contour has been calculated in 24 points, and also the harmonics up to the eleventh [Egidi and Oberto, 1965 and 1969; Egidi and Oberto, 1969].

6. Error rates on long distance HF communications

On links operating in band 7 (HF), transmission errors are, as a rule, not distributed stochastically in time, but periods with a high error-density (error bursts) alternate with periods of low error-density. Error bursts occur when the comparatively narrow transmission channel (e.g. for 100 bauds) is affected by selective fading and thus, the signal-to-noise ratio temporarily falls to, or even below a certain critical limit. Consequently the fading distribution allows conclusions to be drawn as to the duration and frequency of the error bursts to be expected [Retting and Vogt, 1964]. The duration of a fading period is the time during which the receiving amplitude falls below a certain level relative to the mean receiving level.

According to [Retting and Vogt, 1964] the duration of fading and its frequency may differ widely. Short-term fades are much more frequent than long-term fades. In Fig. 3, the number of fades is given as a function of the signal level for various circuits. For a fading level of 10 dB below the median level, there were about eight fades per minute on the New York/Frankfurt-on-Main radio link. Only 1% of all fades on this link lasted longer than 1 s, whereas half the fades exceeded 200 ms (Fig. 4). This leads to the conclusion that the time between two successive fades, with a low concentration of errors, is, as a rule, several times longer than the fading period.

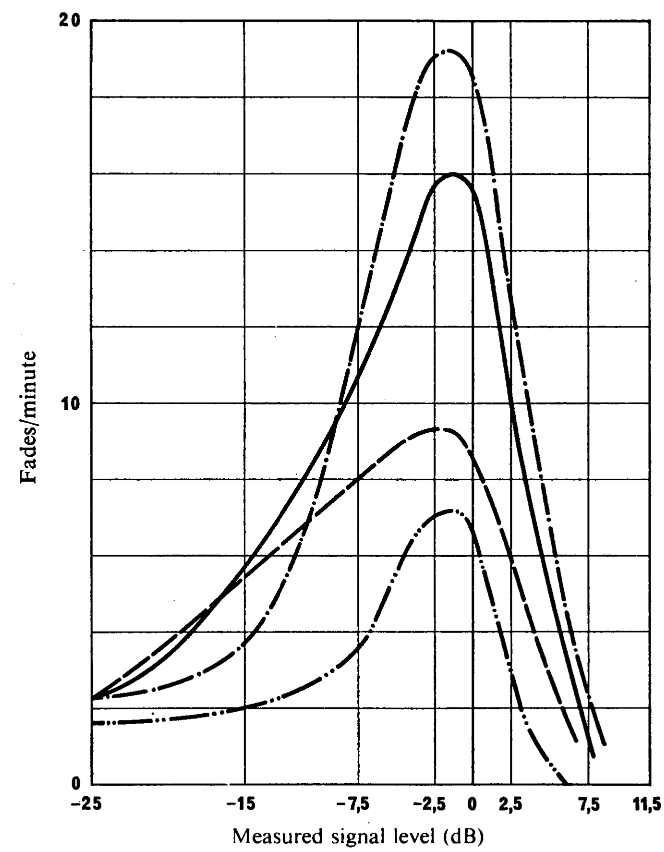

FIGURE 3 – *Number of fades per minute as a function of the signal level for various circuits (reception in Frankfurt)*

—·—·— New York
— — — Seoul
——— Buenos Aires
—··—··— Ankara/Cairo for September, 1961

Experimental results on long-distance radiocommunications (1500-6000 km) in the west-east direction in the U.S.S.R. have shown that the error rate depends not only on the signal-to-noise ratio but also on the distance.

After a classification of the possible states of a radiocommunication channel had been established by means of propagation models, it proved possible to identify the principle of this correlation. It was found that the percentage duration of models requiring a high signal-to-noise ratio on transmission paths less than 2000 km and longer than 3000 km was considerably higher than on optimum-length paths (2000-3000 km). It is clear from [Konopleva and Khmelnitsky, 1970; 1972] that this correlation with distance will be greater, the higher the transmission speed.

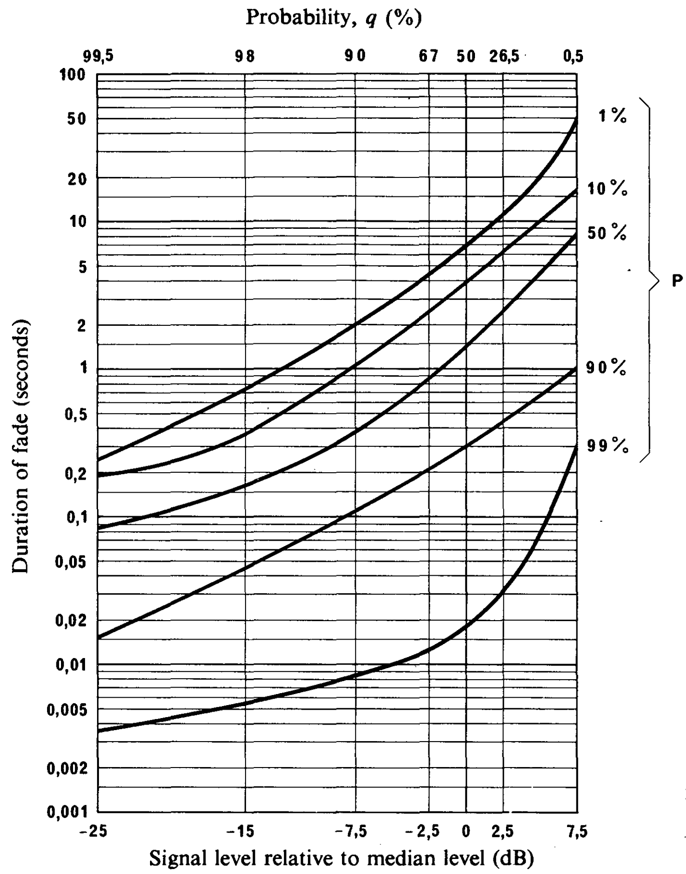

FIGURE 4 – *Duration of fades as a function of the level of the test signal*

Circuit: New York–Frankfurt-on-Main; 14 September, 1961; 1100 h Central European Time; frequency 13.79 MHz.

The figures on the right-hand side of the curves represent the percentage p of the number of fades for which a given duration of fade is exceeded. The measured values of signal levels are shown, together with the probability q that these levels will be exceeded.

7. Diversity reception and mutual signal correlation ratio

Experiments carried out in the U.S.S.R. have shown that the signal correlation ratio R (300 m distance between the antennas) depends on the path distance and on the relation f_{op}/MUF, where f_{op} is the operating frequency [CCIR, 1966-69e].

According to these experiments, the effectiveness of diversity reception decreases greatly when $R > 0.6$. For path lengths up to 1500 km the probability of $R > 0.6$ comes to 18% and for path lengths from 1500 to 3000 km this probability reaches 31%.

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REPORT 203-1

PATH TIME-DELAYS AND SHIFTS CAUSED BY MULTIPATH PROPAGATION ON RADIO CIRCUITS

(Question 1/3, Study Programme 1A/3)

(1963-1982)

1. Introduction

Delays occurring between the signals of individual radio circuits in radio-wave propagation have a considerable influence on the performance of narrowband radio channels (see Report 345). Inter-path delays (τ_d) should be distinguished from shifts (τ_s) (see Report 863).

The term "delay" is given to the time interval between pulses which correspond to the individual propagation paths on a radio circuit without pulse overlapping.

Shifts constitute deviations in the position of the signalling elements from the average element position on the time axis. Shifts occur together with path-time delays, but the value of the shift depends on the characteristics of the actual signal reception and transmission circuit equipment and may be several times greater than τ_d. Both the values of τ_d and τ_s must be known for correct radio circuit design and operation. The greatest difficulties are connected with the prediction of τ_d. A method of predicting τ_d has been developed in the U.S.S.R. [Khmenlnitsky, 1981].

This method of calculating τ_d was devised as a result of the process described below. Several medium latitude (30-60°) radio circuits were equipped with special measuring apparatus. On these circuits, experimental delay values were obtained for different states of the ionosphere. Ionospheric stations were used to record the current ionospheric parameters on the circuit. Studies showed that:

- the calculated values of τ_d (using the ionospheric parameters that occurred during the time of measurement and allowing for height differences in multi-hop paths) agree with the measured values within 20% which is adequate for an engineering appraisal of channel performance;
- the highest values of τ_d occur in periods when there is a single-layer ionosphere, so that attention will be focussed in future on these periods;
- the interval of τ_d values can be forecast for two to three months, since it is possible to predict the deviations of the ionospheric parameters from the mean monthly values for this period of time (the τ_d calculation method has been verified for medium latitude (30-60°) radio circuits).

2. Mean delay values

The monthly mean hourly ionospheric parameters display regular daily, seasonal and cyclical variations. The range of variation in mean monthly ionospheric parameters is such that the mean monthly values of τ_d may more than double throughout the year on an individual radio circuit.

From an analysis of the variations in the mean parameters, the highest τ_d values occur at night-time in winter. There may be a range in mean to quasi-maximum values of τ_d for a given period of sunspot activity.

Figure 1 shows the curves plotted for quasi-maximum τ_d as a function of radio circuit length for two sunspot activity values on medium latitude radio circuits (30-60°) [Khmelnitsky, 1981]. The τ_d values almost double in the transition from minimum (R_{min}) to maximum (R_{max}) sunspot activity.

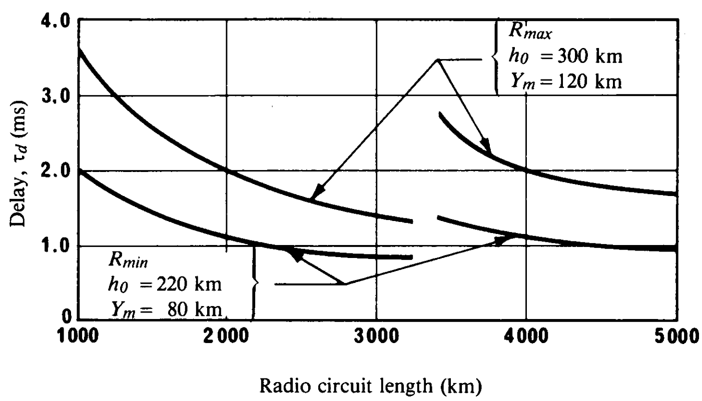


FIGURE 1 – *Delay as a function of radio circuit length*

R_{min}: minimum sunspot activity
R_{max}: maximum sunspot activity
h_0: height of lower limit of ionospheric layer
Y_m: half-thickness of ionospheric layer

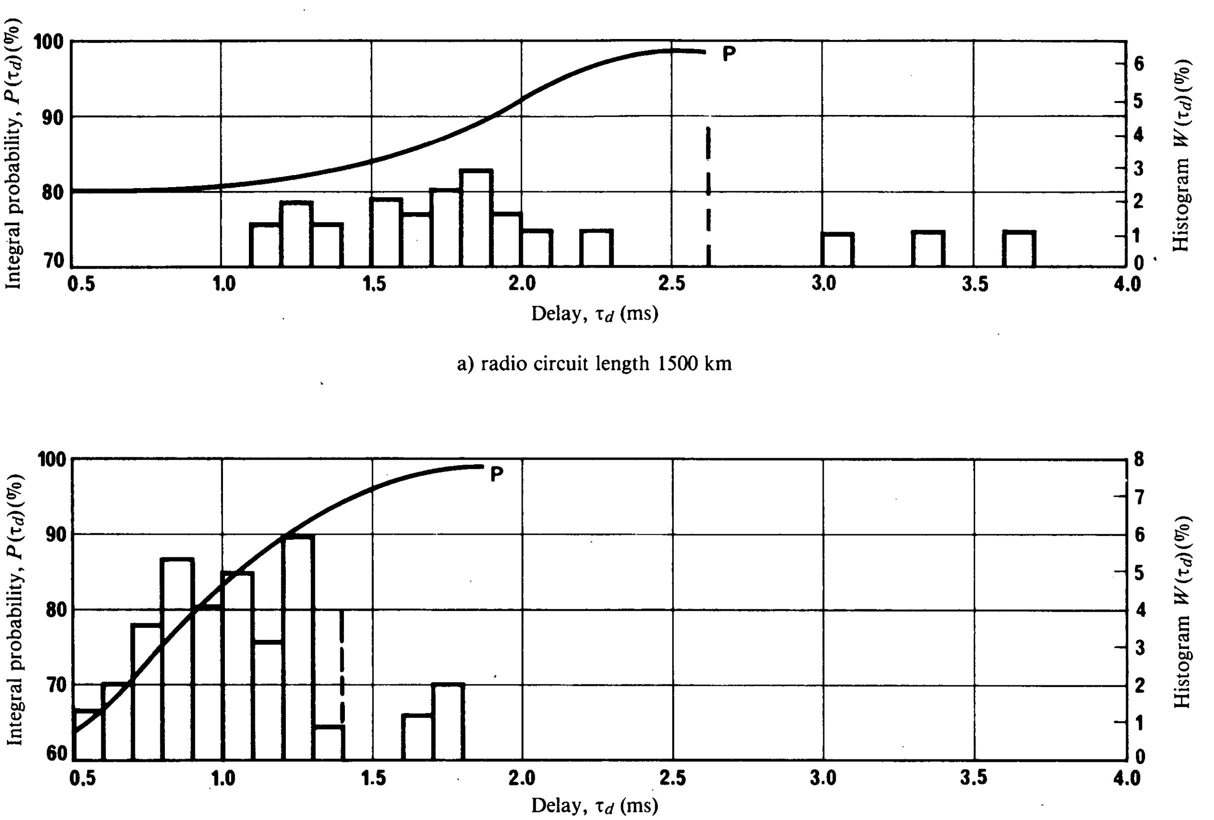
3. Delay fluctuations

The monthly mean values of τ_d for a given hour or the quasi-maximum values of τ_d may be taken as a basis for a rough estimate of expected circuit performance, but for a more precise evaluation we must know the τ_d distribution incorporating all possible delay values. Although there is as yet no method of predicting ionospheric parameters for individual days, a technique has been developed for determining the satisfactory operation factor of a circuit for a period in the order of a season (two to three months). The basis of this technique is given below.

Numerous comparisons of ionospheric data were made for periods of identical sunspot activity taken from data of various sunspot cycles. It was found that the cumulative distribution of the measured data of such corresponding periods show a correlation of up to 0.90 [Khmelnitsky, 1975]. This means that, to establish a distribution of ionospheric parameters for the forecast period, we can take the ionospheric parameters previously measured close to the expected level of sunspot activity.

In the calculation of the expected values of τ_d, there will naturally be obtained series without delay signals as well as series with τ_d. Fig. 2 shows an example of a cumulative distribution P and histogram $W(\tau_d)$ for data measured on 1500 and 3000 km radio circuits. These data include τ_d from 0.5 to 3.5 ms. For calculation purposes, it was assumed that the working frequencies used on each of the paths were only 10% below the optimum. The τ_d values obtained from Fig. 1 are represented by the vertical broken lines in Fig. 2.

It can be seen from P of Fig. 2a that, for a 1500 km radio circuit, the signal delay is less than 0.5 ms for 80% of the time and, for the other 20% of the time, lie between 1.1 and 3.5 ms. However, in practice, the operating frequency may be as low as 0.5 of the optimum frequency, in which case the larger values of τ_d may occur for more than 50% of the time. The method of calculating the delay is discussed in Khmelnitsky [1975].



a) radio circuit length 1500 km

b) radio circuit length 3000 km

FIGURE 2 – *Delay probability and τ_d distribution histogram*

Measurement period: maximum sunspot activity
winter, night-time

4. Measurements on HF radio circuits of the fixed service

4.1 *Summary*

Some 4000 facsimile pictures, received over a number of important radiotelegraph circuits terminating in London, during the period from sunspot minimum to sunspot maximum (1953 to 1957), have been examined, to ascertain the incidence of multipath propagation and to measure the dispersion of path-time delays. Multipath conditions were found to take place for a considerable proportion of the time throughout the whole period and path-time differences were observed up to 2.5 ms. The measurements were made on pictures received from New York (1420 pictures), Melbourne (1600 pictures) and Moscow (350 pictures), together with a few less frequently used circuits. The technique of measurement is outlined below and is similar to that given by Japan in a contribution to the VIIth Plenary Assembly.

4.2 *Method of measurement*

The facsimile transmissions use frequency modulation so that, in general, the received picture will be derived from the predominating path. If, due to fading, signals from different paths of unequal length predominate at different times, a sharp, straight line in the transmitted picture, at right angles to the line of scan, will appear as a jagged line in the received picture. By measuring the width of ripple of the received line, it is thus possible to determine the difference in propagation time over the shortest and longest paths that predominate from time to time during the transmission of the picture.

The spread in path-time delay, as seen on the facsimile pictures, was obtained by measuring the ripple on a line, at right angles to the direction of scan, which could be safely assumed to be sharp and straight when transmitted. A low-power microscope, having a graticule divided into squares, was used to measure the ripple. The magnification was adjusted so that one square represented a time difference of 2 ms for the machines most generally used. Displacements were estimated to the nearest 0.5 ms and, when a number of different delays were observed, only the maximum delay difference was recorded. In some cases, this maximum delay was not typical of the distortion throughout the picture as a whole.

A check was made under controlled conditions, using a fading machine which was adjusted to produce random fading with known differences in path-time delay and with various median signal levels on the two paths. The incidence of multipath observed in these tests was almost identical with that obtained by mathematical analysis.

4.3 *Measurement on facsimile pictures*

Each picture was examined to determine the maximum path-time delay difference. Since the values of delay were approximated to the nearest 0.5 ms, the probable distribution of differences in path-time delay between 0 and 2.5 ms was obtained by the usual method of apportioning the number of pictures at each value of delay, other than zero, equally between the adjacent delay ranges.

The incidence of multipath distortion on each picture was assessed according to four categories, viz: none, rare, frequent, continuous.

For each month, the percentages of pictures received for each range of delay difference and for each category of incidence were obtained. For simplicity, these monthly percentages have been averaged over a complete year, and the results are shown in Fig. 3.

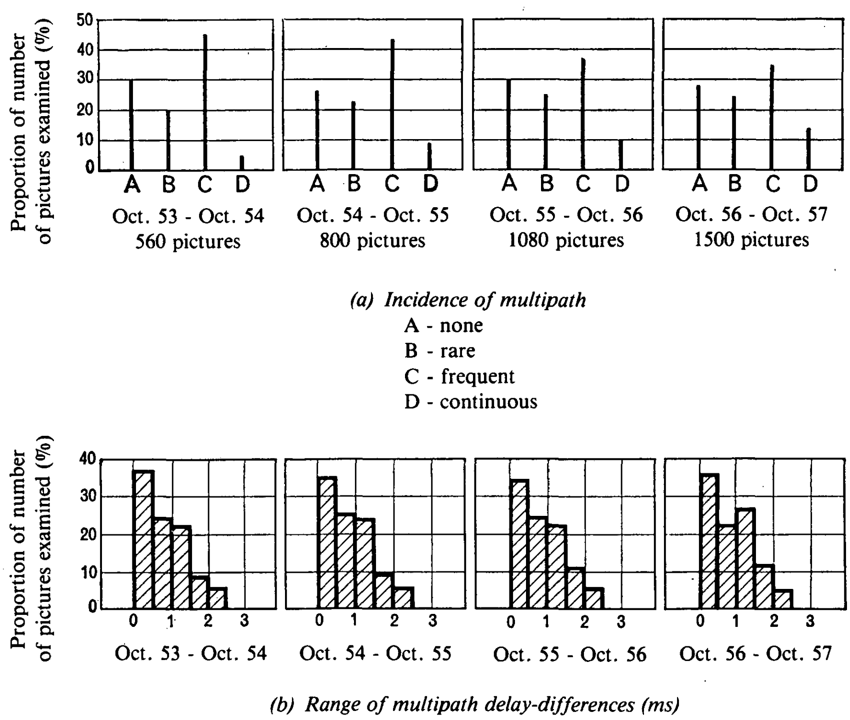


FIGURE 3 – *Multipath propagation on HF radio circuits of the fixed service*

4.4 *Discussion of results*

The results show that, for each of the four years 1953 to 1957, frequent or continuous multipath was in evidence on between 40 and 50% of the pictures analyzed. Approximately half the pictures affected by multipath showed path-time delay differences of 1 ms or more, and nearly 30% had delay differences of 1.5 ms or more.

Multipath effects such as these are not particularly troublesome in facsimile transmission. Facsimile pictures have been used merely as a convenient means of obtaining data on incidence and delay difference over a long period on typical high-frequency fixed-service radio links. The effect of such multipath propagation could be more serious on telegraphy and data circuits, particularly where the path-time delay difference is appreciable in relation to the duration of the telegraph element. For example, a path-time delay difference of 2 ms would have an adverse effect on the performance of a telegraph circuit working at 200 bauds, since the delay difference is equal to 40% of the duration of the signalling element. Circuits working at lower modulation rates would be less affected by multipath propagation, since the path-time delay difference would be smaller in relation to the duration of the telegraph element. For example, a 2 ms delay difference would equal only 20% of the element duration at 100 bauds.

5. Measurement on meteorological broadcast services

Paragraph 4 of this Report shows the incidence of multipath propagation and path-time delay differences observed on typical point-to-point high-frequency radio circuits. More severe multipath effects may, however, be experienced when frequencies below optimum have to be used. Such circumstances often arise, for example, in high-frequency meteorological broadcast services, and an analysis has been made of meteorological charts received in the United Kingdom by facsimile transmission from Washington, D.C. and from Japan.

Some 1600 charts received during the period June to September, 1961, have been analyzed. Of these, 1000 were received from Washington and 600 from Japan. The method of measuring the path-time delay differences was similar to that described in § 4 of this Report. The results are tabulated in Table I below and are shown graphically in Fig. 4.

TABLE I

Multipath time-delay difference (ms)	Percentage of charts for each circuit	
	Washington, DC to United Kingdom (6000 km)	Japan to United Kingdom (9600 km)
0 – ½	10	0
½ – 1	20	5
1 – 1½	28	9
1½ – 2	21	10
2 – 2½	10	30
2½ – 3	6	26
3 – 3½	2	11
3½ – 4	2	6
4 – 4½	1	2

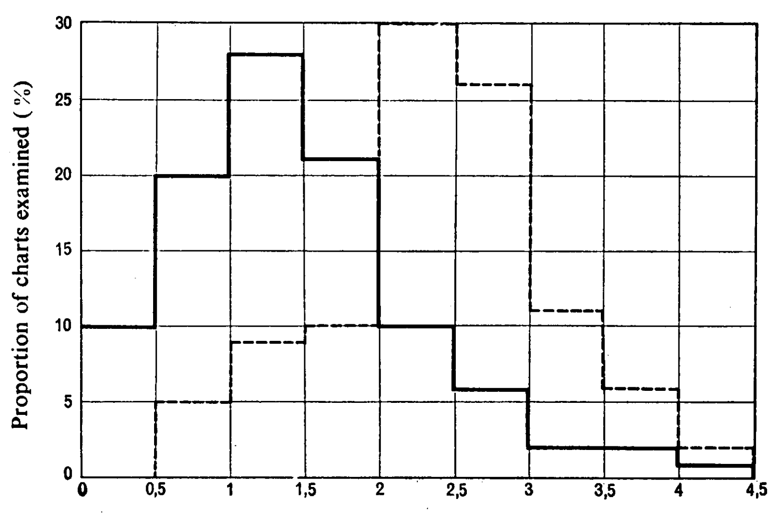


FIGURE 4 – *Multipath propagation on circuits of the meteorological broadcast service*

———— Washington, D.C. to United Kingdom

– – – – Japan to United Kingdom

REFERENCES

KHMELNITSKY, E. A. [1975], *Otsenka realnoi pomekhozashchishchennosti priema signalov v KV diapazone* (Assessment of real noise immunity in the reception of SW signals), Sviaz, Moscow.

KHMELNITSKY, E. A. [1981], Zapazdyvanie mezhdu signalami otdelnykh luchei na liniyakh KV radiosvyaz (Delay between individual path signals on SW radio circuits), *Elektrosviaz*, **4**.

REPORT 550 *

SHORT-TERM STABILITY OF FREQUENCY SYNTHESIZERS

(Question 1/3, Study Programme 1A/3)

(1974)

The phenomenon of the short-term instability of frequency synthesizers, i.e. the variation of instantaneous frequency about the mean value over time intervals less than about 0.1 second known as "jitter", is fairly well known. This phenomenon is particularly associated with synthesizers employing digital circuitry which are now being used increasingly in communications systems.

Jitter originates from two basic sources:

– frequency instability of the voltage-controlled oscillator including that due to discontinuous changes induced by the digital circuitry and to power supply ripple voltages,
– noise on the voltage control line to the oscillator.

It is of interest to know the extent to which this jitter is likely to affect various types of communication channels. [CCIR, 1970-74] records the results of observations of the degradation in quality of transmission brought about by introducing controlled amounts of jitter into communication channels incorporating a synthesizer device having a phase-locked carrier oscillator. The jitter source was either a sinusoidal voltage of frequency varying between about 5 Hz and 1 kHz or consisted of noise limited to bandwidths of between 5 and 50 Hz and was used to frequency modulate the carrier oscillator.

In the case of speech transmissions the assessments were made subjectively by six independent observers on the basis of:

(1) just perceptible impairment,
(2) limit of intelligibility.

Having regard to the nature of jitter produced by digital synthesizers, which tends to occur at frequencies below 100 Hz the frequency deviations found necessary to produce the conditions (1) and (2) above were as follows:

TABLE I

Class of Emission	Jitter modulation	R.m.s. Frequency Deviation (Hz)	
		(1)	(2)
R3E	Sinewave	20	200
R3ELN	Sinewave	6	20
R3ELN	Noise (20 Hz bandwidth)	8	(1)
R7B	Sinewave	20	(1)
R3C	Sinewave Noise (50 Hz bandwidth)	 10	 50

(1) Not measured.

* This Report should be brought to the attention of Study Group 1 in connection with Question 48/1.

Bearing in mind that, in the tests, all the impairment originated in the voltage-controlled oscillator and that, in actual transmissions, other impairments such as noise in the communication channel and frequency deviations due to the propagation path will be present, the performance of the synthesizers needs to be substantially superior to the figures given in column (1).

REFERENCES

CCIR Documents

[1970-74]: 3/4 (United Kingdom).

REPORT 704

CHARACTERISTICS OF FREQUENCY SYNTHESIZERS IN THE HF FIXED SERVICE

(Question 1/3, Study Programme 1A/3)

(1978)

1. Introduction

The availability on the market of a wide and increasing range of digital integrated circuits has over the past few years led to a complete reappraisal of the design approach to frequency synthesis. The reasons for this are largely economic. Early synthesizers tended to be much larger than the associated receiver, and this situation, although improved by the arrival of semiconductors, would still remain today had not the digital integrated circuit appeared. The modern frequency synthesizer consists generally of one or more printed circuit boards inside the associated receiver or transmitter. The digital approach to frequency synthesis together with the quest to maintain low cost have, however, created some new problems, and it is the purpose of this Report to consider how they affect modern communications equipment and how they may be minimized.

2. Forms of impurity

The output from a frequency synthesizer consists ideally of a signal of constant amplitude and frequency. All forms of impurity at the output can be resolved into departures from one or both of these ideals. In general, in communications systems the synthesizer outputs provide the switching signals of the associated mixers in the receiver or transmitter chain so that there is a considerable rejection of amplitude modulation effects, which rarely gives trouble, and which will not, therefore, be considered here. The constant frequency can be regarded as a linear increase of phase with time, and unwanted departures of phase from this ideal are responsible for the effects more commonly known as long-term frequency stability, short-term stability, phase "jitter", spurious sidebands and noise modulation. These effects are steady state in nature; there are, in addition, transient imperfections following switching such as finite loop lock time and phase settling time. Table I shows a summary of the impurities listed in order of "rate of change" of the impurity, and Fig. 1 shows these effects on a frequency basis. The Table commences with effects which represent the fastest rates of perturbation of the ideal linear increase in phase with time, corresponding to widespaced frequency components, and concludes with long-term stability errors which can be considered as a very slow departure from the ideal linearly increasing output phase with time.

3. Out-of-band effects

Out-of-band spurious signals and noise can be defined as disturbances from the ideal phase at rates equivalent to frequency spacings higher than 6 kHz, and may for example be specified at 20 kHz. Considering first spurious signals, these may be either discrete signals or one of a pair of FM sidebands on either side of the wanted frequency; the effect on the receiver is the same. Spurious responses are caused by high level unwanted signals from the antenna mixing with these synthesizer spurious signals to produce the receiver IF. The level of the worst spurious signal should ideally be better than about −106 dB in a synthesizer for a high grade receiver, although in practice, however, it is often difficult to achieve a performance of better than −90 dB. Wideband spurious signals usually result from ineffective shielding between signal sources or insufficient filtering in power supply lines. They also can arise from the phase detector when the loop comparison frequency is greater than 20 kHz.

TABLE I

Frequency separation	Nature of disturbance	Effect in equipment	Typical specified level	Method of detection	Typical cause
Beyond 6 kHz, may be defined at 20 kHz (out-of-band effects)	Discrete signal Noise	Spurious responses in receiver Degradation of S/N ratio by reciprocal mixing or by direct IF breakthrough	–80 to –100 dB –80 to –120 dB in 3 kHz band	Spectrum analyser or receiver Spectrum analyser or receiver	Insufficient filtering or shielding Variable oscillator design
200 Hz to 6 kHz (In-band-effects)	Discrete signal Noise	Audible tone on wanted signal Degradation of receiver ultimate S/N or error rate	–45 to –65 dB –45 to –65 dB in 3 kHz band	Spectrum analyser or receiver Spectrum analyser or receiver	Phase detector sidebands Variable oscillator design Mixer products
1 to 200 Hz (Close-spaced effects)	Discrete signal Noise	Warble on tone or SSB speech Telegraph distortion or error-rate	As FM: Deviation 1 to 10 Hz r.m.s. As phase jitter: 3° phase error over 10 ms period	FM deviation meter Phase jitter measuring equipment	Hum sidebands Semiconductor noise/supply hum
0.01 to 1 Hz (Short-term stability over 1 to 100 seconds)	Noise-like	Unstable frequency	1×10^{-7} per minute	Frequency counter	Transient temperature effects
Below 0.01 Hz (Long-term stability over 100 seconds to 1 year)	Slow random drift	Variation in tuned frequency of system	2×10^{-9} per day [1]	Frequency counter	Quartz crystal ageing, plus temperature effects

[1] Performance of the highest-grade common frequency standard at a large station, and for special types of emission.

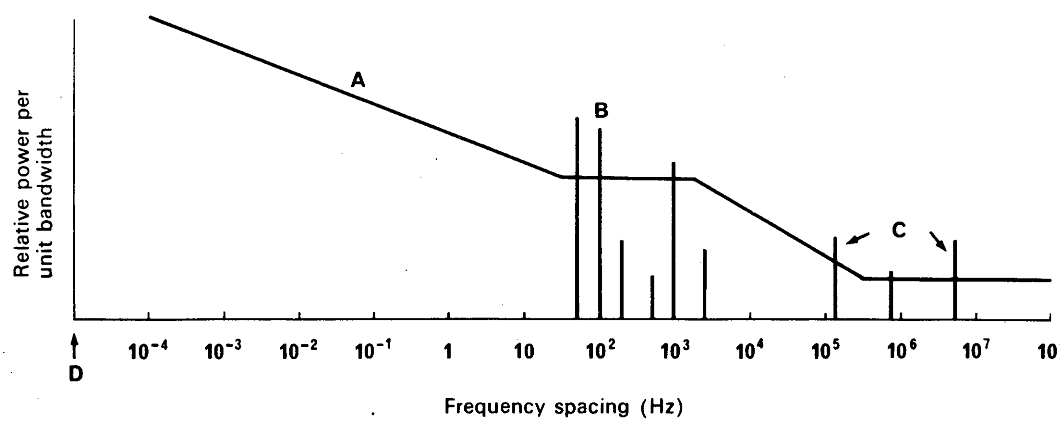


FIGURE 1 – *Synthesizer output – Typical frequency domain plot*

A: Noise
B: Hum
C: Discrete spurious signals
D: Wanted output

Wideband noise also represents departures from the ideal phase at rates usually greater than 20 kHz. In general, it can be considered in two regions. There is firstly a plateau of noise on either side of the wanted frequency extending to very high and very low frequencies. The level of the plateau depends upon the signal power level in the variable oscillator circuit, and upon the effective noise factor of the oscillator and following amplifiers. A typical level would be −120 dB in a 3 kHz bandwidth. Fig. 1 shows that at frequencies closer to the carrier, noise level rises from the plateau at lower frequency spacings, typically from about 200 kHz for a 70 to 100 MHz synthesizer. At 20 kHz from the carrier, the noise may be typically −90 dB to −100 dB relative to carrier in a 3 kHz band. The effect of this noise is to degrade the receiver signal-to-noise ratio by reciprocal mixing. This effect is shown in Fig. 2 which shows how a strong interfering signal mixes with the noise skirt to produce a signal at the receiver IF. At low frequency settings, where the synthesizer output frequency is close to the receiver first IF, the noise will appear in the receiver directly. Skirt noise is a function of the *Q* of the resonant circuit in addition to power level and noise factor of the variable oscillator.

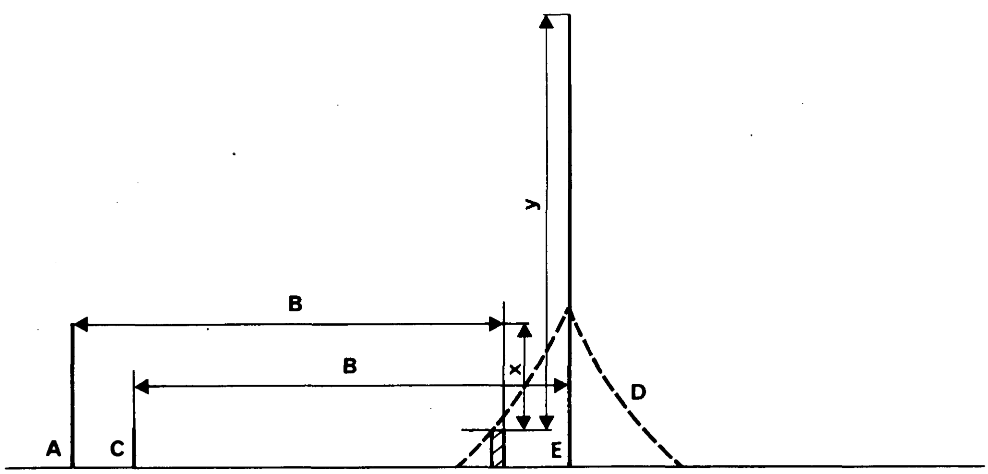


FIGURE 2 – *Reciprocal mixing*

A: Unwanted signal
B: Intermediate frequency
C: Wanted signal
D: Noise skirts
E: Synthesizer output
y: Achievable ratio
x: Adverse ratio (tolerable value of $x \leq y$)

4. In-band effects

In-band spurious signals and noise are defined as disturbances from the ideal phase with rates occurring at frequencies in the audio range, i.e. 200 Hz to 6 kHz. Spurious signals appear as audible tones on the wanted channel in SSB communications equipment, and a typical specification level would be −55 dB. Typical causes are phase discriminator sidebands (often 1 kHz) and mixer intermodulation products from the transfer loops. In-band noise appears as background noise on the audio channel and is independent of the received signal level, and so degrades the ultimate signal-to-noise ratio of the receiver at high signal levels. In-band noise can be improved by careful variable oscillator design and correct choice of phase-locked loop bandwidth.

5. Close-spaced effects

Close-spaced effects are disturbances from the ideal phase occurring at rates between 1 Hz and 200 Hz. Spurious signals in this band may be 50 Hz or 100 Hz hum sidebands or may be mixer intermodulation products. The effect in a receiver is to cause "warble" on SSB speech and especially on a tone. Low frequency noise from transistors and zener diodes are also possible causes. This effect is frequently specified as a frequency deviation and a typical allowable level in low cost equipment might be deviation of 1 to 10 Hz depending on system requirements. The second effect of this close type of spurious and noise is noticed as telegraph distortion on special keying systems for digital transmission such as "Kineplex" in which the signal phase is averaged and sampled at regular (say 10 ms) intervals. A typical phase "jitter" specification level is 3° averaged over a 10 ms period. In practice, it is found that 50 Hz hum sidebands are a major source of phase jitter. Several methods of measurement of close-spaced effects are possible:

(a) FM deviation meter,

(b) period counting equipment,

(c) zero-beat phase detection,

(d) error counts in the equipment,

(e) spectral analysis.

In method (b) the synthesizer output is heterodyned with a pure signal down to a low frequency (say 100 Hz) the period of which is then measured over a large number of complete cycles. From these results, the r.m.s. and peak deviations may be calculated. In method (c) the output is mixed down to zero beat in a phase detector and the detector output displayed on an oscilloscope. The vertical axis can be calibrated in terms of peak phase excursion. This method has the advantage that the nature of the modulating components may be observed in addition to displaying the peak phase jitter.

6. Short-term stability

Short-term frequency stability refers to changes in frequency, or departures from the ideal phase, over a period over which the contribution from the long-term effects of the frequency standard are negligible. It is caused by effects such as ambient temperature and humidity variation or supply voltage variation, and originates from the synthesizer itself in addition to the frequency standard.

The contribution from the standard is, in practice, principally a temperature effect. A Temperature Compensated Crystal Oscillator (TCXO) might have a stability of $\pm 2 \times 10^{-6}$ over the working temperature range while a precision oven-controlled frequency standard might have a stability of $\pm 2 \times 10^{-7}$ over the temperature range.

The contribution to short-term instability from the synthesizer itself has in general become a more serious problem for digital divider type synthesizers. Economic considerations dictate that a minimum number of cascaded phase-locked loops be used in a system, with the result that comparison frequencies are low and programmed divider division ratios are high. A changing ambient temperature necessitates a changing voltage controlled oscillator (VCO) output which in turn results in a change of phase difference between the loop and reference signals in a simple phase-locked loop. This changing phase appears at the synthesizer output as a change in frequency, and although it is strictly a transient effect as a result of the loop integration, it may manifest itself as a frequency error of many hertz over a period of several seconds. More complex designs of phase-locked loop can help to overcome this problem.

7. Long-term stability

Long-term frequency stability is a parameter controlled entirely by the reference frequency standard and is due to ageing of the quartz resonator and other components in the standard. It is quoted as a fractional change per unit time such as $\pm 2 \times 10^{-6}$ per year for a low cost TCXO that might be used in portable equipment, or $\pm 1 \times 10^{-9}$ per day for a precision oven-controlled quartz frequency standard for use in point-to-point communications systems.

RECOMMENDATION 454-1 *

PILOT CARRIER LEVEL FOR HF SINGLE-SIDEBAND AND INDEPENDENT-SIDEBAND REDUCED-CARRIER SYSTEMS

(Question 1/3, Study Programme 1B/3)

(1970–1978)

The CCIR,

CONSIDERING

(a) that although for conventional radiotelephone systems a level of −26 dB appears, theoretically, to be adequate, operational experience shows that significant improvements in operational time are secured with higher levels;

(b) that, for radiotelephone systems employing a frequency-modulated control channel, further protection of the pilot carrier is necessary to ensure end-to-end circuit gain stability;

(c) that on currently operated multi-channel radiotelegraph systems a level of −26 dB is, both theoretically and in operational experience, inadequate to ensure reliable action of the automatic frequency control system down to the failure point of the telegraph channels;

(d) that a standard level of reduced pilot carrier for all single-sideband and independent-sideband emissions would be operationally advantageous,

RECOMMENDS

1. that a standard pilot-carrier level of −20 dB ± 1 dB relative to transmitter peak envelope power be adopted for all fixed service single-sideband and independent-sideband reduced-carrier HF radio emissions.

ANNEX I

SIGNAL-TO-NOISE RATIOS IN SIDEBAND AND CARRIER CHANNELS

1. Channels with conventional terminals

The minimum usable signal-to-noise ratio of a channel depends on its function. With a conventional terminal, only the speech channel and carrier channel need be considered while in the case of Lincompex equipment the control signal channel must be considered as well.

The carrier branch provides both automatic frequency control and automatic gain control functions. When the signal-to-noise ratio in the carrier branch is approximately 10 dB on an r.m.s. basis, the noise peaks will exceed the carrier peaks. Then large perturbations or even reversals of carrier phase will result so frequently as to impair operation of the automatic frequency control. This may be taken as the failure point of the carrier branch inasmuch as the automatic gain control is somewhat less affected by noise. The noise bandwidth of the carrier branch of a receiver varies among individual designs; for example in the United States of America it is commonly 35 Hz while in the United Kingdom it is 70 Hz and receivers used in the Netherlands, France and Japan have intermediate bandwidths.

The minimum usable speech-to-noise ratio depends on the type of terminal equipment used. For conventional terminals under stable circuit conditions a value of 15 dB corresponds to marginally commercial quality (see Recommendation 339). If these conditions and the foregoing ratio are assumed, the corresponding carrier-to-noise ratio can be calculated by taking into account the respective bandwidths of the speech and carrier channel and the mean speech level relative to p.e.p. Although the latter varies among Administrations, as well as the carrier filter noise bandwidth, such a calculation shows that, in the absence of selective fading, a carrier level of −26 dB relative to p.e.p. should be adequate to ensure that the automatic frequency control is not noticeably disturbed by noise before the speech channel of a conventional circuit becomes uncommercial.

* The Administration of Pakistan reserved its opinion on this Recommendation. This Recommendation cancels Report 433 (New Delhi, 1970).

Recent operating experience in the United Kingdom has shown, however, that if the carrier-to-noise ratio is increased by 10 dB some 5% improvement in commercial channel hours is nevertheless realized.

2. Channels with Lincompex terminals

In a Lincompex system, there is a possibility of inadequate signal-to-noise ratio in the speech channel, in the pilot carrier channel and/or in the control signal channel. The control signal channel has a bandwidth of 200 Hz and the speech bandwidth is correspondingly reduced from the usual 2750 Hz of a conventional circuit to 2450 Hz to accommodate both the speech and control signals below 3 kHz (in accordance with Recommendation 455).

High noise in the control channel causes the circuit loss to fluctuate. This imparts a subjective "gritty" quality to the speech. The effect becomes excessive for control channel signal-to-noise ratios less than about 14 dB.

A speech-to-noise ratio of 7 dB has been found to represent just marginally commercial quality, taking into account the compandor improvement (see Note 3 to Table I of Recommendation 339).

It can be calculated that the minimum usable signal-to-noise ratios occur approximately together in the speech channel, the control signal channel and the carrier channel.

Thus the protection afforded to the carrier is commensurate with that of the control channel if selective fading is ignored. Nevertheless, the importance of the carrier in controlling the gain stability of up to four channels would appear to demand a higher signal-to-noise ratio, since in the Lincompex system gain stability is directly related to the performance of the automatic frequency control system.

3. Multichannel telegraph systems

The failure of a radiotelegraph channel equipped with automatic error-control facilities is not rigidly definable since it depends on the circuit efficiency that can be tolerated. At low values of circuit efficiency undetected character errors increase significantly and, for this reason, low efficiency circuits are unsuitable for telex operation. For other types of telegraph traffic, however, circuit efficiencies as low as 20% to 30% may be considered tolerable in certain circumstances. However, for the purpose of this assessment, a circuit efficiency of 50% is taken as the failure point. For a dual-diversity system working typical radio conditions, this corresponds to a median signal-to-noise ratio of approximately 8 dB in the telegraph channel, which, in a typical 100-baud system, has a bandwidth of 140 Hz.

According to Recommendation 326, it is typical of present practice that the mean power of each channel of a multi-channel telegraph system (class of emission R7B or B7B) be given by p.e.p./4n, when $n > 4$. Thus for a representative number of channels (say $4 < n < 10$), the power in a given telegraph channel will exceed that of a pilot-carrier of -26 dB relative to p.e.p. by at least 10 dB. But the carrier channel has an advantage with respect to noise bandwidth of only 3 to 6 dB since the ratio of the telegraph channel bandwidth to the carrier channel bandwidth is typically in range 2 to 4 (corresponding to a bandwidth range of 70 to 35 Hz). Therefore it is evident that the carrier channel will be at a net disadvantage and that a pilot carrier level of -26 dB relative to p.e.p. is inadequate over a wide range of circumstances to ensure reliable action of the automatic frequency control down to the failure point of the telegraph system.

The foregoing discussion makes no allowance for selective fading. It may be noted that in general the telegraph channels ordinarily derive substantial benefit from either space or frequency diversity while the carrier channel does not.

RECOMMENDATION 349-3

FREQUENCY STABILITY REQUIRED FOR SYSTEMS OPERATING IN THE HF FIXED SERVICE TO MAKE THE USE OF AUTOMATIC FREQUENCY CONTROL SUPERFLUOUS

(Question 1/3, Study Programme 1A/3)

(1963-1966-1970-1978)

The CCIR,

CONSIDERING

(a) that it is the practice with certain single-sideband (SSB) and independent-sideband (ISB) telephone systems, and with many telegraph systems, to employ automatic frequency control (a.f.c.) to adjust the receiver oscillator frequency in sympathy with variations in the frequency of the transmitted signal;

(b) that such automatic frequency control systems may give rise to difficulty under unfavourable conditions of propagation, at frequencies below 30 MHz;

(c) that the frequency stability, which can now be achieved, is much higher than that laid down in Appendix 7 to the Radio Regulations, and is approaching a value which could provide sufficient inherent stability to enable automatic frequency control to be dispensed with;

(d) that, with systems dispensing with automatic frequency control, the frequency error of the modulating and demodulating stages and of the radio-frequency translating stages at the transmitting and the receiving ends, together with the frequency error due to the propagation path, contribute to an overall frequency error;

(e) that the overall frequency error of the complete system is decisive and that as far as feasible this error should be shared equally by both the transmitting and the receiving ends;

(f) that, however, in certain cases when narrow-shift telegraph systems are employed, reasons other than frequency stability of the equipment may still require the use of automatic frequency control,

UNANIMOUSLY RECOMMENDS

1. that the values of permissible frequency errors given in Table I, should be considered as suitable for use on systems giving access to the public service network and dispensing with automatic frequency control;

2. that the figures in column (1) of Table I are decisive for the system, and that those given in the columns (2), (3) and (4) should be considered as an example as to how the overall frequency error could be split up into errors permissible in the parts constituting a complete system;

3. that, however, the use of automatic frequency control may be retained for telephone systems using Lincompex terminals, as set forth in Recommendation 455, and for multichannel voice-frequency telegraph systems on circuits where significant frequency deviations, due to propagation conditions, are encountered (see Annex I).

TABLE I

System	Maximum permissible overall error (Hz) (1)	Frequency error due to: Modulator stages (Hz) (2)	Demodulator stages (Hz) (3)	Frequency error due to the radio-frequency translating stages at both ends and to the propagation path(3) (Hz) (4)
1. Single-sideband and independent-sideband telephony	20	5	5	10
2. Radiotelegraphy:				
2.1 Two-tone multi-channel telegraphy with 340 Hz tone spacing and MCVF frequency-shift telegraphy with 340 Hz channel spacing	12(1)	3	3	6
2.2 Frequency-shift telegraphy F1B (e.g. 50 bauds, 200 Hz shift) and four-frequency diplex telegraphy F7B using narrow-band filters at the receiving end	12	3	3	6
2.3 Multichannel voice-frequency telegraph systems operating at modulation rates up to about 100 bauds, with 80 or 85 Hz frequency shift and 170 Hz channel spacing	12	3	3	6
2.4 F1B and F7B systems using a limiter/discriminator at the receiving end, modulation index ≈ 2 (e.g. 196 baud, 400 Hz shift)	20(4)	3	3	14
2.5 Phototelegraphy(2)	16	4	4	8

(1) See [CCIR, 1962a].

(2) For short-term frequency stability, see Recommendation 344. The figures under line 2.4 of this Table should be considered as provisional pending a reply by the CCITT to the questions put to it by the CCIR (see [CCIR, 1962b]).

(3) This is the maximum error at the demodulator in the frequency of the carrier, if transmitted.

(4) For radiotelegraph systems, which use a device at the receiving end to correct for possible bias distortion due to frequency error, values larger than those indicated in the Table may be permitted.

REFERENCES

CCIR Documents

[1962] Geneva: **a.** III/27; **b.** III/66(Rev.).

ANNEX I

FACTORS OTHER THAN FREQUENCY STABILITY WHICH MAY MAKE THE USE OF AUTOMATIC FREQUENCY CONTROL DESIRABLE

1. Introduction

The above Recommendation, which is a reply to Question 182 (Los Angeles, 1959), tabulates the permissible overall frequency errors for various systems.

2. Relationship between distortion and frequency error

A number of HF radiotelegraph circuits operating at modulation rates of about 100 bauds with a channel spacing of 170 Hz, use sub-carriers on independent-sideband transmissions.

Measurements made on various well-designed frequency-shift telegraphy receivers have indicated an increase in element distortion of approximately 1.25% for each 1 Hz frequency error. Poorer band-pass filter designs or narrower channelling will raise this distortion considerably.

It has been observed that frequency changes due to ionospheric propagation of up to 7 Hz may occur during periods of up to 15 min [Rishbeth and Garriott, 1964; Davies, 1963]. This can, therefore, result in an additional distortion of up to 9%, which could be reduced by the application of automatic frequency control. Further information about the statistical distribution of these phenomena would be desirable to permit fuller evaluation of their effect on circuit efficiency.

REFERENCES

DAVIES, K. [1963] Doppler studies of the ionospheric effects of solar flares. Proc. International Conference on the Ionosphere, 76-83.

RISHBETH, H. and GARRIOTT, O. K. [March, 1964] Relationship between simultaneous geomagnetic and ionospheric oscillations. *Radio Sci.*, Vol. 68D, **3**, 339-343.

REPORT 856

RECIPROCAL MIXING IN HF COMMUNICATION RECEIVERS IN THE FIXED SERVICE

(Question 1/3, Study Programme 1A/3)

(1982)

1. Introduction

Frequency synthesizers are widely used in modern high quality HF communications receivers. Besides having high frequency stability and accuracy, a frequency synthesizer is easy to operate and control. At present however the frequencies provided by the synthesizer are not always sufficiently pure, so that a considerable number of spurious components may accompany the wanted signals in its frequency spectrum. At the same time, on both sides of the wanted output there are noise skirts which degrade the interference rejection and noise characteristics of the receiver. In recent years, a new requirement has therefore appeared in the specifications of HF receivers, i.e. reciprocal mixing, defined as the degradation of the receiver output signal-to-noise ratio due to the mixing of strong interfering signals with the noise skirts of the synthesizer. Relevant reciprocal mixing effects were described in Report 704. This Report provides a quantitative relationship between the synthesizer out-of-band noise characteristics and receiver reciprocal mixing so that requirement for synthesizer out-of-band noise characteristics can easily be specified and performance comparison between various receivers facilitated.

2. Effects of reciprocal mixing

Reciprocal mixing in a receiver occurs when, during the reception of a wanted signal, a strong out-of-band interfering signal mixes with out-of-band skirt noise from the synthesizer, producing mixing products which fall into the receiver IF band, causing the receiver output signal-to-noise ratio to be degraded (see Fig. 1).

From Fig. 1, an equation showing the relationship between V_I and the following items, i.e. receiver output signal-to-noise ratio S_o/N_r, synthesizer output signal purity V_L/V_i as well as the wanted signal V_s, can be derived [Gao, 1977]:

$$V_{I(\mathrm{dB}(\mu\mathrm{V}))} = \left(\frac{V_L}{V_i}\right)_{\mathrm{dB}} - 10 \log B + V_{s(\mathrm{dB}(\mu\mathrm{V}))} - \left(\frac{S_o}{N_r}\right)_{\mathrm{dB}} \quad (1)$$

Where S_o is the signal at the receiver output and N_r represents the reciprocal mixing products only when V_s is sufficiently large so that the front-end noise of the receiver can be neglected.

Assuming the noise density at 20 kHz away from the wanted output of the synthesizer of a given receiver is -120 dB/Hz relative to the wanted output of the synthesizer, B = 2800 Hz, V_s = 40 dB(μV), S_o/N_r = 20 dB, the V_I = 105.5 dB(μV).

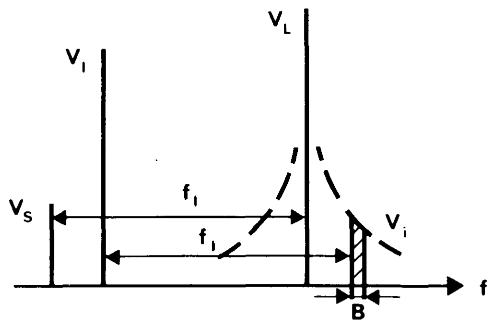


FIGURE 1 – *Reciprocal mixing*

B: bandwidth of the receiver (Hz)
f_I: first intermediate frequency
V_L: wanted output of the synthesizer
V_i: out-of-band noise density
V_I: a strong interfering signal at the receiver input
V_S: wanted signal

It can be seen from the above, given the wanted signal V_s, the signal-to-noise ratio S_o/N_r at the receiver output, and the bandwidth *B*, the allowable level of interference V_I rises as the out-of-band noise density of the synthesizer V_i is reduced. It should be noted that, in the above calculation, the effects of second and subsequent down conversions are not taken into account. This is justified because the oscillators used are usually fixed and would have significantly less problems in maintaining spectral purity.

3. Measurement of reciprocal mixing

Up to now, there is no internationally adopted method for measuring reciprocal mixing. The differences in the measuring methods lie in the specified level of receiver input signals and in the method of measuring reciprocal mixing products at the output.

Methods commonly used for testing are given in Table I below:

TABLE I

Case	Wanted signal level of the receiver	Method of measuring reciprocal mixing products at receiver output
1	No signal	Increase the interference level to double the noise power
2	0 dB (μV)	Increase the interference level to raise the noise power by 10 dB
3	10 dB (μV)	Increase the interference level to reduce the S_o/N_r by 10 dB
4	10 dB (μV)	Increase the interference level to make the S_o/N_r equal to 10 dB
5	40 dB (μV)	Increase the interference level to make the S_o/N_r equal to 20 dB

For the same receiver, different methods of measurement produce different results. Similarly, if different methods are applied to different receivers, direct comparisons of reciprocal mixing performance are impossible. Therefore, it is important to standardize the method of measurement.

In-depth studies and experiments suggest that the case 5 method might be a suitable standard as it is more accurate and approximates real operational conditions.

The said method is to apply a signal of 40 dB(μV) to the input of the receiver and in addition apply an interfering signal at 20 kHz away from the above signal. Adjust the interfering signal level until the output noise level is 20 dB below the wanted output signal. The interfering signal level can be specified as the parameter of the receiver reciprocal mixing.

By taking the average value of the said parameter of different receivers, the following (Table II) might be used as the typical and minimum values of reciprocal mixing and the relevant conditions for measurement.

TABLE II

Parameter	Conditions for measurement	Minimum value	Typical value
Reciprocal mixing	V_s = 40 dB (μV) S_o/N_r = 20 dB Δf = 20 kHz B = 3 kHz	100 dB (μV)	110 dB (μV)

Further studies are desirable and contributions from Administrations on this matter are invited.

REFERENCES

GAO ZHONGPING [2 March, 1977] Preliminary investigations on some main performance objectives of HF SSB receivers. *Telecomm. Sci. Express.*

3A b: Directivity of antennas

Recommendations and Reports

RECOMMENDATION 162-2

USE OF DIRECTIONAL ANTENNAS IN THE BANDS 4 TO 28 MHz

(Question 29/3) *

(1953-1956-1966-1970)

The CCIR,

CONSIDERING

(a) that there is serious congestion in the fixed-service bands between 4 and 28 MHz;

(b) that occupancy of the radio-frequency spectrum is represented, not only by occupancy in bandwidth and time, but also by the spatial distribution of the radiated power;

(c) that radiation outside the directions necessary for the service can be effectively reduced by the use of directional antennas;

(d) that Articles 5, 18 and 19 of the Radio Regulations would seem to justify explicit requirements for the use of directional antennas in these bands;

(e) that the Panel of Experts, in Recommendation No. 13 of its Final Report, Geneva, 1963, advocates the use of directional antennas for transmission and reception in the fixed service;

(f) that the request by the Panel of Experts in Recommendation No. 38 of its Final Report, and the urgent question of the IFRB, Question 29/3, ask for specification of reasonable standards of directivity for antennas in the various types of radio services in the bands between 4 and 28 MHz, with due regard to economy of cost;

(g) that the adoption of minimum standards for directional antennas would contribute to the solution of frequency sharing problems;

(h) that antenna performance materially better than these minimum standards is attainable at economic cost using modern techniques,

UNANIMOUSLY RECOMMENDS

1. Definitions

That the following definitions should be used in specifying the performance of directional antennas:

1.1 *Directive gain (G_0)* **

In a given direction, 4 π times the ratio of the intensity of radiation (power per unit solid angle (steradian)), in that direction, to the total power radiated by the antenna.

Note. – The attention of the Joint CCIR/CCITT Study Group for Vocabulary (CMV) is drawn to this new definition of directive gain, and it is asked to say whether this is in accordance with the definitions proposed by other international organizations, e.g. the IEC.

1.2 *Service sector (S)*

The horizontal sector containing the main beam of the antenna radiation and including the direction required for service. It is very close to twice the angular width of the main beam measured to the half-power (–3 dB) points.

1.3 *Interference sector (I)*

The horizontal sector outside the main beam

$$I^\circ = 360^\circ - S^\circ$$

* This Question replaces Question 20/1 (New Delhi, 1970).

** See No. 154 of the Radio Regulations for a definition of power gain.

Note by the Secretariat. – The term "Directive gain" was replaced by the term "Directivity" (see Recommendation 341).

1.4 *Minimum standard antenna*

The antenna having the specified minimum characteristics as regards directive gain and service sector at its operating frequency or frequencies.

1.5 *Economic standard antenna*

The antenna having specified characteristics as regards directive gain and service sector at its operating frequency or frequencies which are justifiable on economic grounds (i.e. by savings in the cost of providing a given transmitter output power).

1.6 *Antenna directivity factor (M)* *

The ratio of the power flux-density in the wanted direction to the average value of power flux-density at crests in the antenna directivity pattern in the interference sector. This is equivalent to the average improvement in signal-to-interference ratio achieved by using the actual antenna in place of an isotropic radiator in free space;

2. that the minimum standard antenna should have a directivity factor given by

$$M = 0.1\, f^2$$

f being the operating frequency in MHz;

3. that the economic standard antenna should have a directivity factor given by

$$M = 0.25\, f^2$$

4. that, for a radiated power of 5 kW or greater, the directivity factor, M, of the antenna used should be equal to or greater than that of the minimum standard antenna;

5. that, for a radiated power of 10 kW or greater, antennas having performances not worse than that of the economic standard antenna should be used to the extent practicable;

6. that, for transmitter powers below 5 kW, the power flux-density in the interference sector should not exceed that radiated in this sector from the minimum standard antenna with a total radiated power of 5 kW;

7. that, in the interests of reducing the effects of interference, the directivity factor, M, of the receiving antenna should be equal to or greater than that of the minimum standard antenna and should, as far as practicable, attain that of the economic standard antenna.

Explanatory notes

The values of directive gain and service sector appropriate to the specified values of M for the minimum standard antenna and the economic standard antenna respectively are given in the following Table I:

TABLE I

Operating frequency f(MHz)	Minimum standard antenna			Economic standard antenna		
	M	G_0(dB)	$S°$	M	G_0(dB)	$S°$
5	2.5	13.8	54	6.25	17.5	35
10	10	16.6	39	25	20.4	25
15	22.5	18.3	32	57	22.1	21
20	40	19.4	28	100	23.3	18

The antenna gain relative to a half-wave dipole above earth may be obtained by subtracting 8 dB from the value of G_0. It should be noted that the S value is the minimum bound at the directive gain specified and has been derived on the assumption that at least 40% of the total power is radiated in the main beam (a value appropriate to many rhombic antennas). Where (as is commonly the case) the (power) gain of the antenna (No. 154 of the Radio Regulations) is known, a suitable adjustement should be made to account for the efficiency of the antenna in deriving the directive gain.

* The derivation of the value of the directivity factor for any given antenna is explained in Report 356.

Furthermore, when calculated gains, based on constant-current formulae, are used to determine the *M*-factor, adjustment should be made to allow for the current decay along the actual antenna. Methods of making these adjustments are described in Report 356. (Geneva 1982)

No preferred polarization or type of antenna is established. Horizontal polarization offers better ground reflection characteristics and, for receiving, some reduction of interference due to man-made noise. Where reflection over sea water or over earth of very high conductivity takes place, the use of vertical polarization can enhance the low-angle performance needed for long paths. This important consideration is reflected in the computation of *M*, which includes a weighting factor $10/\Delta$, where Δ is the vertical angle of optimum radiation. There is no requirement for the transmitting and receiving antennas to have the same polarization characteristics because of the randomization of the polarization in the ionospheric transmission process.

The *M*-factors chosen are largely based upon the measured performance of typical rhombic antennas and typical antenna-arrays. The radiation characteristics of single rhombic antennas in the interference zone are, in general, somewhat inferior to other types of antenna (e.g. half-wave antenna arrays), a fact which is reflected in the *M*-factor. Provided the parameters are correctly chosen, the performance of antennas of differing types possessing the same *M*-factor is comparable.

REPORT 356-2

USE OF DIRECTIONAL ANTENNAS IN THE BANDS 4 TO 28 MHz

(Question 29/3)

(1966-1970-1974)

1. Introduction

Question 29/3 poses the problem of specifying reasonable standards for the directivity of antennas in the various types of radio service, and for various distances, in the bands between 4 and 28 MHz with due regard to economy of cost. This Report is mainly concerned with point-to-point circuits longer than 4000 km but, with suitable modifications, could be applied to shorter range circuits. The technique discussed requires a knowledge of the gain of the antenna under consideration and the angular widths in zenith and azimuth of its main beam of radiation. With this information a directivity factor is derived which, used in conjunction with certain other factors, for example, transmitter power and provision cost, may be used to assess the suitability of an antenna for any particular application.

2. Proposition

An antenna possessing a given directive gain which radiates all its power in a single beam could be regarded as having the best attainable performance of its class. Communication systems using such antennas for emission and reception could operate on a common frequency with a given spatial distribution without risk of mutual interference, the only condition being that each receiving antenna should "see" only the wanted transmitting antenna. With such an ideal arrangement the number of systems sharing the same frequency would increase as a function of the gain of the antennas because of their smaller angular beamwidth.

By making certain simplifying but justifiable assumptions, it can be shown that to a high degree of approximation there is a fixed relationship between the directive gain (relative to an isotropic radiator) and the angular widths of this single beam (to the null) as follows:

$$G = P_0/P = 32\pi^2/(\pi^2 - 4)\ \theta_0\varphi_0 = K/\theta_0\varphi_0 \qquad (1)$$

(θ_0 and φ_0 are the horizontal and vertical angular widths respectively, in radians and P, P_0 are the total powers radiated from the ideal antenna and the isotropic radiator respectively to produce the same field in the desired direction).

Practical antennas fall some way short of this ideal in that a proportion of the power is radiated (or received) in directions other than in the main beam.

If the directive gain of such an antenna is G' and the widths of its main beam are θ_0', φ_0', then from (1), the power radiated in the main beam:

$$P' = P_0 \theta_0' \varphi_0' / K \tag{2}$$

If this represents a fraction q of the total radiated power,

$$G' = q \cdot P_0/P' = qK/\theta_0' \varphi_0' \tag{3}$$

$$\text{or } q = G'\theta_0' \varphi_0'/K \tag{4}$$

Thus, from the measured or computed characteristics of an antenna it is possible to determine its radiation efficiency, i.e. the fraction of the total radiated power that is directed in the main beam.

The power radiated outside the main beam of a transmitting antenna which is liable to set up interfering signals is given by:

$$P_0 (1 - q)/G'$$

If this were distributed evenly over the residual hemisphere outside the lunar arc θ_0' the average power flux would be

$$P_0 (1 - q)/(2\pi - \theta_0')\, G'$$

Since the maximum flux in the main beam is $P_0/4\pi$, we can write

$$\frac{\text{Maximum useful signal power flux}}{\text{Average interfering signal power flux}} = \frac{G'(2\pi - \theta_0')}{(1 - q)\, 4\pi} \tag{5}$$

As is well known, the spatial distribution of flux outside the main beam will vary widely and values considerably in excess of the average will be found. It would seem appropriate to express this as a probability distribution in such a way that its effect in degrading the signal-to-interference ratio appears as a term in the directivity factor of the antenna. To do this would require a knowledge of the minor beam flux distributions of a large sample of practical antennas and because insufficient information of this nature is available an alternative approach must be adopted. The method used is to derive an antenna directivity factor based on the assumption that all the misdirected power appears as a number of equi-amplitude secondary beams and to apply an adjustment when individual secondary beam amplitudes are likely to be significant to a particular problem e.g. frequency sharing studies.

If the same power distribution (cosine-squared) as that assumed for the main beam is used then, for the secondary beams:

$$\left(\frac{F\,\text{max}}{F\,\text{average}}\right)^2 = \frac{2\pi^2}{\pi^2 - 4} = 3{\cdot}41 \text{ (5·3 dB)}$$

and we can then write,

$$\frac{\text{Maximum useful signal power flux}}{\text{Maximum interfering signal power flux}} = \frac{G'\,(2\pi - \theta_0')}{(1 - q)\, 4\pi \times 3{\cdot}41} \tag{6}$$

One further modification to the formula is necessary to take account of what has been called the "propagation match" of the antenna: various studies have shown that for long distances (>4000 km), circuit performance improves as the vertical angle of the main beam maximum of the antenna is reduced.

A weighting factor (appropriate for vertical launching angles between about 5° and 25°) allows for this effect and the equation for the antenna directivity factor becomes,

$$M = \frac{G' (2\pi - \theta_0')}{(1 - q) 4\pi \times 3{\cdot}41} \cdot \frac{10}{\Delta_m}$$

and expressing θ_0', φ_0' in degrees,

$$M = \frac{G' (360 - \theta_0')}{245{\cdot}6 \, \Delta_m \, (1 - q)} \tag{7}$$

where

$$q = \frac{G'\theta_0' \, \varphi_0'}{176\,600}$$

G' : directive gain of antenna expressed relative to an isotropic radiator (expressed as a ratio unless otherwise stated),

θ_0' : horizontal angular width of main beam in degrees (to first minimum points),

φ_0' : vertical angular width of main beam in degrees (to first minimum points),

Δ_m : vertical angle of main beam maximum (degrees).

For distances less than 4000 km, this factor may be omitted and instead the height of the antenna chosen to match the propagation conditions over the route.

3. Determination of directive gain

When the measured characteristics of antennas are available, particularly the (power) gain and angular beamwidths, calculation of the figure of merit, M, is straightforward provided the power efficiency of the antenna is known. In many instances, however, it will be necessary to evaluate paper designs and special care is needed in the case of the rhombic antenna. Although the angular dimensions of the main beam and the vertical angle of the main beam maximum can be predicted with sufficient accuracy by a calculation which assumes constant current in the antenna wires [Harper, 1941], the gain so calculated is generally optimistic and must be corrected before it can be used in the M factor formula. This correction may be considered in two parts.

3.1 *Adjustment for power dissipation in the termination,* C_t

This is, in effect, a conversion from measured (power) gain to directive gain and is given for various configurations in Figs. 1a and 3a.

3.2 *Adjustment for current decay along the antenna,* C_d

This adjustment is necessary to convert (power) gain calculated from constant current formulae to a value more nearly in conformity with the measured values on actual antennas and is given, for the same configurations, in Figs. 1b and 3b. For convenience these curves are combined in Figs. 2 and 4, which enable the calculated (power) gain to be converted directly to directive gain. The full-line portions of these curves represent the normal design range.

All the curves are derived from measurements made on the power efficiencies of rhombic antennas described in [CCIR, 1966-69] in which a linearly tapered current decay along the antennas was assumed. The antennas were of 3-wire construction having a surge impedance of 600 ohms. There is an important dependence of radiation efficiency upon surge impedance [Schelkunoff and Friis, 1952] and the lowest practicable value is desirable. Nevertheless there are constructional problems in reaching a value much below 600 ohms in the HF band.

4. Application

M-values for a number of antennas of various types are plotted in Fig. 5 and provide an indication of the variation with frequency of the performance of single antennas and antenna arrays, assessed from both measured (power) gains and from the gains calculated using the methods described in § 3. Curves, which it is considered represent reasonable standards of performance for these two classes of antenna, have been drawn on the diagram. The lower curve (labelled minimum standard antenna) is a best fit to the available experimental data and may be expressed as $M = 0.1f^2$. This is considered to be representative of the standard of performance to be expected from well-designed single rhombic antennas operated within a frequency band in which the ratio of highest to lowest frequency does not exceed 2.

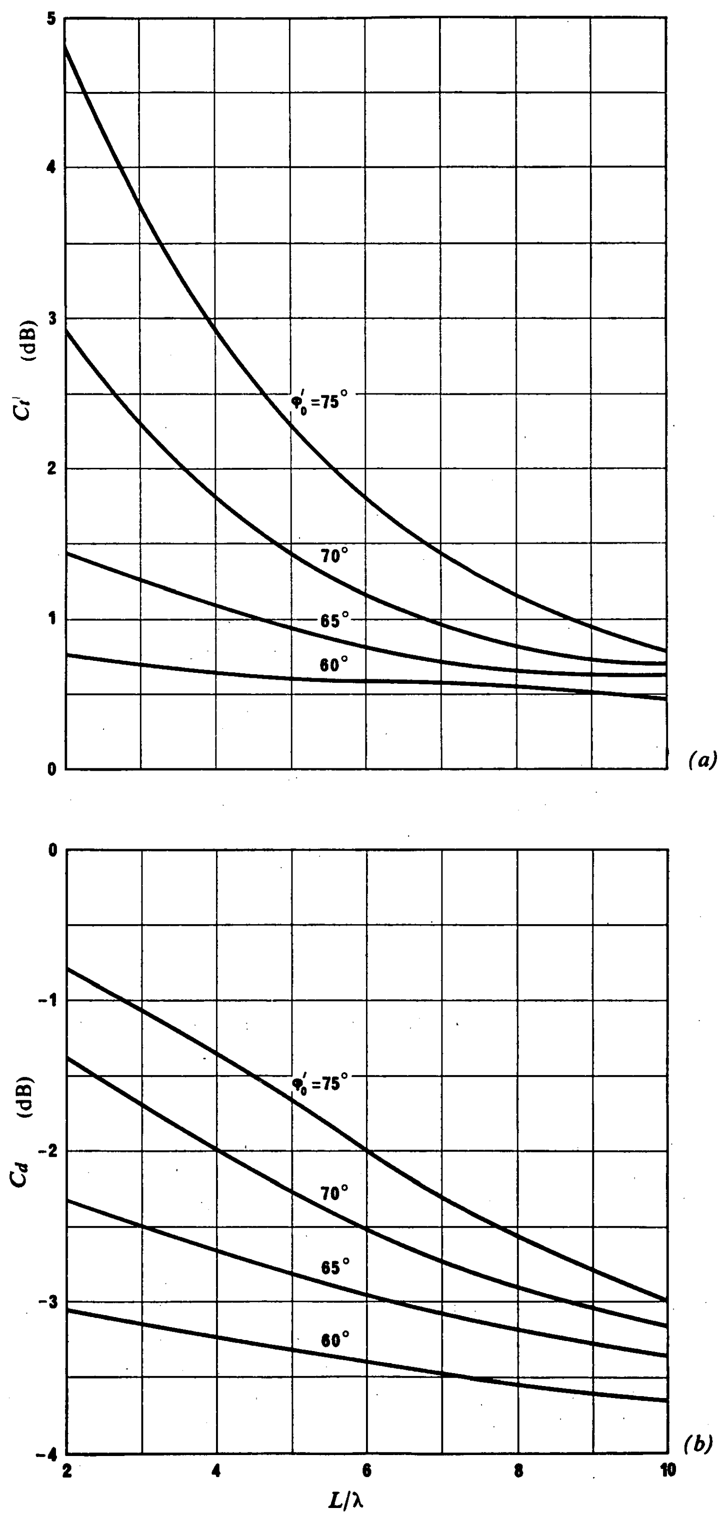


FIGURE 1 – *Gain adjustments for rhombic antenna 122 m/40 m*

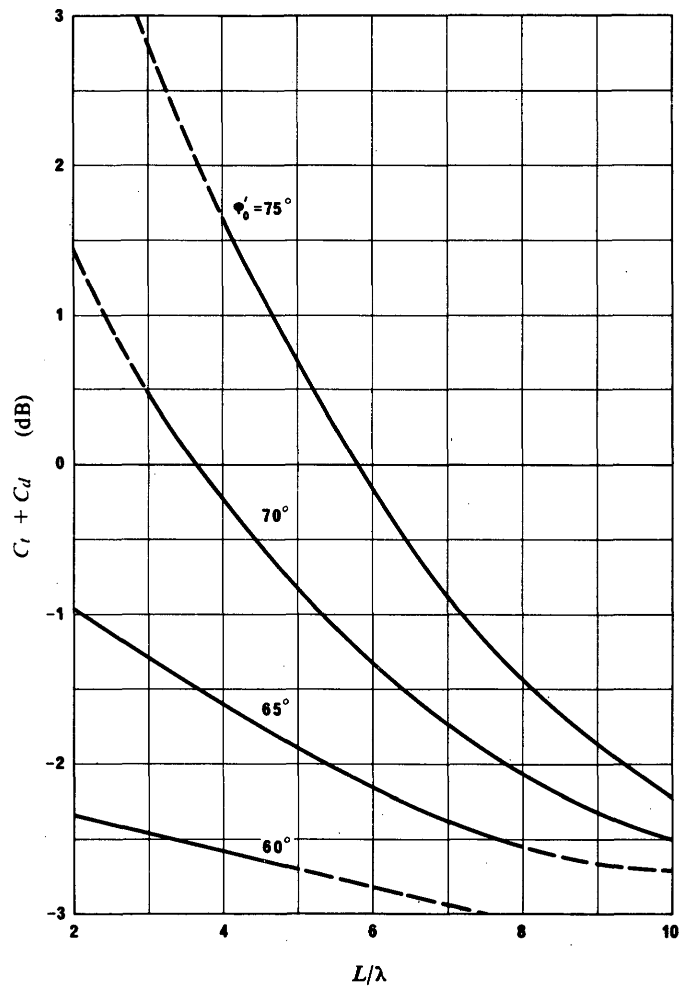


FIGURE 2 – *Combined gain adjustment for rhombic antenna 122 m/40 m*

The upper curve (economic standard antenna) which may be similarly expressed as $M = 0.25f^2$ represents a standard of performance which will normally only be achieved with antenna arrays. This higher standard necessarily involves a proportionally greater expenditure on antenna plant but, as has been proposed in [Watt-Carter and Young, 1963], some increase above the current level of expenditure can be economically justified.

For frequency planning and other allied studies the occurrence frequencies of secondary beams having amplitudes greater than the equi-amplitude crest value may be important. Within the range of M-values considered the results of the measurements made on practical antennas indicate that not more than 10% of the secondary beams will exceed the equi-amplitude crest value by 6 dB. Thus for an antenna having an M value of 40, the ratio of the levels of the main-beam intensity and the higher secondary beam intensity would be 10 dB. These secondary beams will usually be adjacent to the main beam.

5. The effect of snow, ice, and tides on antenna radiation patterns

[CCIR, 1970-74] reports the results of theoretical studies conducted to determine the effect of varying ground thickness of snow and ice on the radiation patterns of a horizontal half-wave dipole antenna and a vertical quarter-wave antenna. Tidal effects on the radiation patterns of these same antennas over sea water were also calculated.

For these studies, flat, homogeneous, and uniformly thick layers of snow, ice, and ground have been assumed.

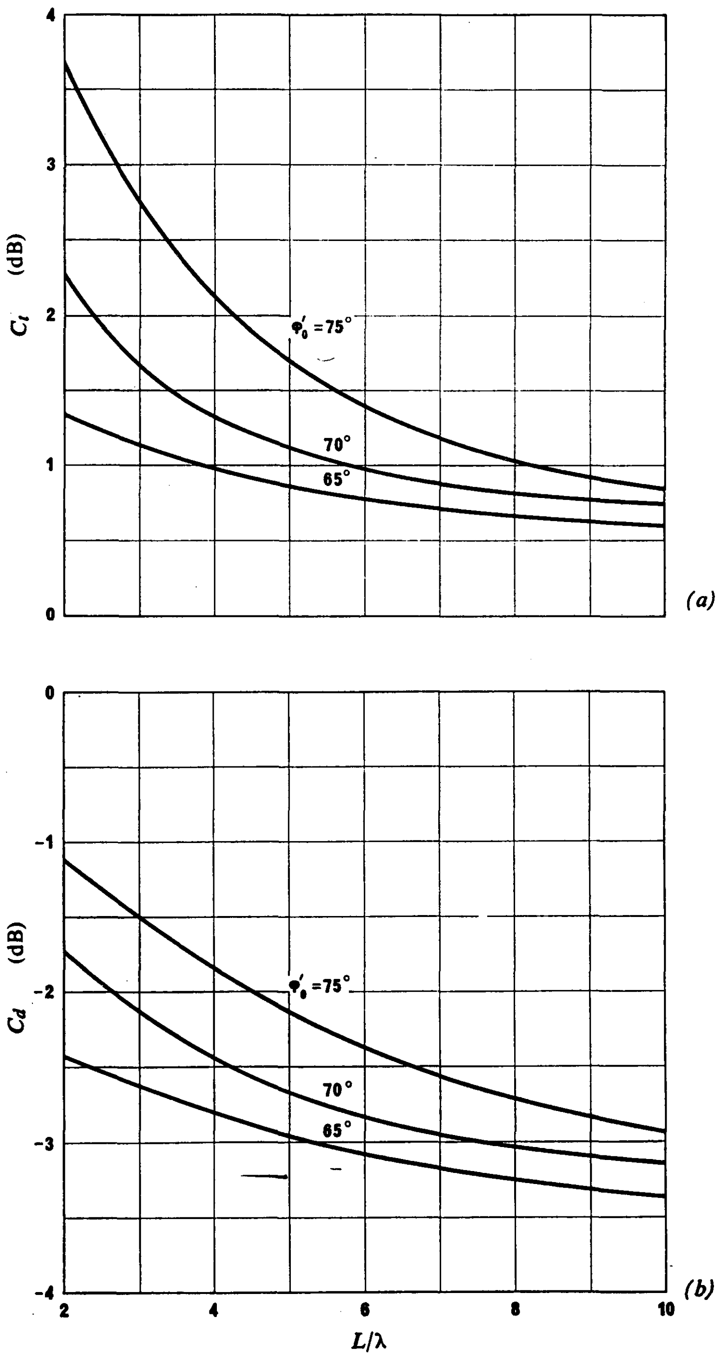


FIGURE 3 – *Gain adjustments for rhombic antenna 122 m/23 m*

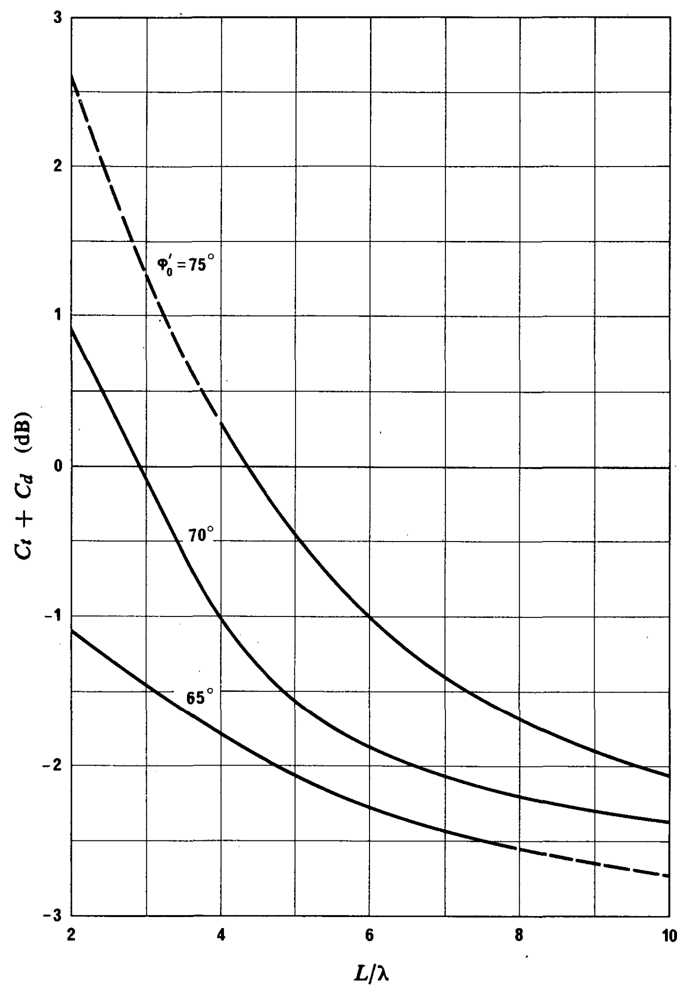


FIGURE 4 – *Combined gain adjustment for rhombic antenna 122 m/23 m*

For a horizontal dipole, the effect of 1 m of snow or ice is negligible. However, the effect of a tidal change of 3 m can result in a shift of about 5 degrees in the angle of maximum radiation in the vertical plane.

A vertical quarter-wave antenna is more noticeably affected by snow or ice, particularly for directions near the horizontal where a significant reduction in signal occurs. Corresponding changes in the power transmitted or received are given for 3 angles, at a frequency of 10 MHz, in Table I.

TABLE I – *Relative change (in dB) of the transmitted or received power due to a snow, ice or tidal change for 3 zenith angles*
(Frequency: 10 MHz)

	Zenith angle		
	45°	75°	85°
Vertical quarter-wave antenna on a ground plane to which 1.0 metre snow (dielectric constant of 1.2, conductivity of 10^{-5} S/m) is added	−0.5	−0.6	−1.3
Vertical quarter-wave antenna over sea water which is displaced by 1.0 metre salt ice (dielectric constant of 6.0, conductivity of 10^{-3} S/m)	−1.7	−3.4	−8.7
Vertical quarter-wave antenna over sea water which drops by 3.0 metres	−2.9	−0.4	−0.1

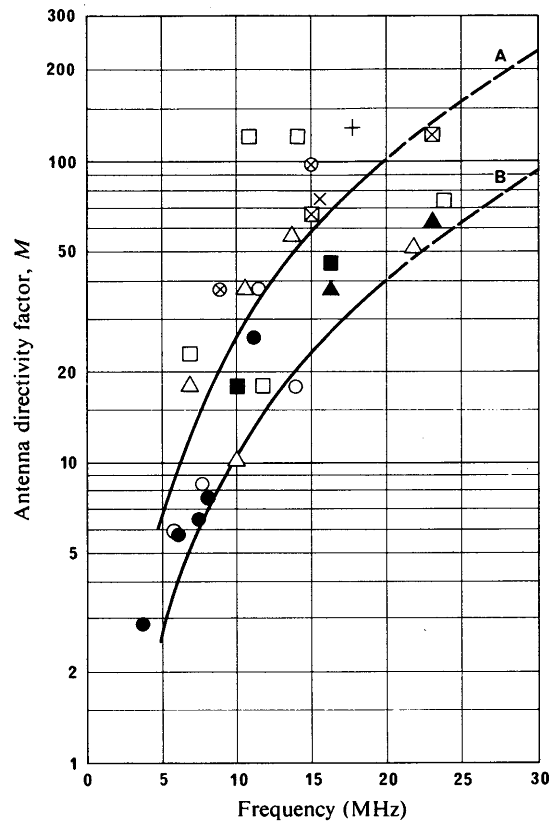


FIGURE 5 – *Antenna directivity factor, M, based on calculated gains*
(see Recommendation 162)

Curve A: Economic standard antenna

- ○* Rhombic antenna 125 m/65°/45 m
- □* Rhombic antenna 122 m/72.5°/23 m

} Complementary antennae

- ⊗ Rhombic antenna 158 m/71°/55 m
- ⊠ Rhombic antenna 158 m/75°/37 m

} Complementary antennae

Curve B: Minimum standard antenna

- ● Rhombic antenna 98 m/63°/45 m
- ■ Rhombic antenna 95 m/67°/32 m
- ▲ Rhombic antenna 90 m/69°/29 m

} Complementary antennae

- △* Rhombic antenna 96 m/70°/23 m

×* Dipole array HR 4/4/1.0
+* Dipole array HR 8/4/0.5

* Measured values of power gain, using airborne equipment.

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SCHELKUNOFF, S. A. and FRIIS, H. T. [1952] *Antennas – Theory and Practice.* John Wiley & Sons, Inc., NY, 466-469.

WATT-CARTER, D. E. and YOUNG, S. G. [September, 1963] Survey of aerials and aerial distribution technique in the HF fixed service. *Proc. IEE,* Vol. 110, **9**.

CCIR Documents

[1966-69]: III/21.

[1970-74]: 3/5 (Canada).

REPORT 106-1

IMPROVEMENT OBTAINABLE FROM THE USE OF DIRECTIONAL ANTENNAS

(Question 3/3, Study Programme 3A/3)

(1953-1956-1959-1970)

1. Introduction

Contributions by Administrations to the VIIIth Plenary Assembly, Warsaw, 1956, and to the Interim Meeting of Study Group III, Geneva, 1958, provide a basis for a preliminary report on the question of signal power gain and signal-to-interference discrimination, afforded in practice by rhombic antennas. The experimental observations given by [CCIR, 1958a and b] are summarized, as well as [CCIR, 1956a, b, c, d and e] which also refer to this Question. The relation of these preliminary results to the median gain, given by Recommendation 162 (Geneva, 1963), is indicated.

In the text below:

l = length of leg (m),

φ = half the obtuse angle (degrees),

h = height above ground (m).

2. Summary and discussion of reported results

[CCIR, 1958a] of the Federal Republic of Germany, contains a summary (Table I below) of median values of measurements made, using a rhombic of a type in general service in the Postal Administration, having l = 115 m, h = 20 m, φ = 75°. This first set of measurements was made relative to a *vertical antenna*; the results are otherwise expressed in Recommendation 162 (Geneva, 1963).

TABLE I

Frequency (MHz)	Median value of gain relative to main lobe (direction of optimum gain) (dB)				Azimuthal ranges (degrees)		
	Main lobe	In Arc A	In Arc B		Half of main arc	Arc $A_1 = A_2$	Half of arc B
			Unidirectional antenna	Reversible antenna			
10	0	-8	-21	-12	23	22	135
15	0	-6		-17	18	29	133
20	0	-8	-23	-15	13	24	143

In [CCIR, 1958b] there are also reported the results of observations of the gain of the rhombic antenna in the main lobe, relative to a half-wave horizontal antenna. These observations were, in the main, made at 15 MHz receiving WWV which transmits with an omnidirectional antenna, but there is also one set of observations made at 18 MHz receiving PPZ which transmits with a directional antenna. The data show the realized gain to be less than the plain-wave gain in the direction of maximum response and to have a striking variability with time of day and/or signal strength. The data are not adequate to establish a systematic diurnal variation, but the 15 MHz data suggest that the greatest values of gain are realized at times of high singal intensity. This result is contradicted by the observations at 18 MHz of transmissions from a distant directional antenna, which emphasizes the need for additional observations and draws attention to the virtually certain dependence of all such observations on the *directivity of antennas at both ends of the path.* Table II below gives the decile and median values of the gain realized in these tests.

[CCIR, 1956b] gives results of the power gain and discrimination of rhombic receiving antennas, that is, off-azimuth response relative to maximum response. The measurements were made receiving distant transmissions at 13 and 20 MHz, using a ring of 30 antennas having l = 81 m, h = 23 m, φ = 70°. The results are given in Table III for the main lobe and the forward arc (180°) excluding the main lobe, and for the backward arc.

TABLE II

Period	Gain 10 % (dB)	Gain 50 % (dB)	Gain 90 % (dB)
Receiving WWV 15 MHz			
11 – 22 June 1956 130 observations	12·9	9·1	6·7
28 July – 6 August 1956 117 observations	15·2	11·7	7·7
29 Sept. – 11 Oct. 1956 217 observations	12·9	10·7	6·8
28 Feb. – 23 Mar. 1957 405 observations	10·8	7·1	0·0
15 – 25 January 1958 162 observations	11·1	8·5	3·2
Receiving PPZ 18 MHz			
29 Sept. – 10 Oct. 1956	13·0	7·8	4·4

TABLE III

Frequency	Main lobe gain (dB)	Gain relative to half-wave horizontal dipole(1) (dB)					
		Forward arc (180°) excluding main lobe			Backward arc (180°)		
		Gain 10 %	Gain 50 %	Gain 90 %	Gain 10 %	Gain 50 %	Gain 90 %
13·4 MHz (New York)	11	–2·5	–11	–19·5	–8·3	–12·7	–17
20·4 MHz (Pretoria)	15	3·5	– 5·0	–13·5	–4·3	– 8·7	–13
20·4 MHz (Pretoria)	15	2·5	– 6·0	–14·5	–9·2	–13·6	–18

(1) Median and decile values are relative to the arc, except for the main lobe.

More detailed data are given in the same document; an examination of the data for all observed azimuths has been made, and median values of gain obtained for the arcs specified in Recommendation 162 (Geneva, 1963), as follows:

TABLE III*a*

Frequency	Median value(1) of gain relative to half-wave dipole (dB)			Azimuthal range (degrees) (Rec. 162-2)		
	Main azimuth	Arc *A*	Arc *B*	Half of main arc	Arc $A_1 = A_2$	Half of arc *B*
13·4 MHz (New York)	11	–5	–13	12	21	147
20·4 MHz (Pretoria)	15	2	–10	8½	18½	153

(1) Median values are relative to the arc, except for the main azimuth.

It is worth noting that values given in Table III*a*, with respect to discrimination against off-azimuth signals, are somewhat better than the values shown in Recommendation 162 (Geneva, 1963); it seems unlikely that values as favourable as those given in Tables III and III*a* are generally realized in practice. The value for arc *A* at 13 MHz is in fact better than might, at first sight, be expected; but, especially in arc *A*, the available data were not adequate to establish a median value with much confidence.

[CCIR, 1956c] summarized experimental observations of the power gain in the main azimuth, and for certain discrete directions off the main azimuth. The values of gain are for receiving rhombic antennas, expressed relative to a horizontal half-wave antenna at the same height. Directional antennas were also used at the transmitters for the measurements. The design data for the receiving antennas used at Amsterdam, for which observations are summarized in this document, are as follows:

TABLE IV

Antenna	*A*	*B*
Length *l* (m)	120	174.5
Height *h* (m)	33	29.5
Angle φ (degrees)	71	70
Design frequency (MHz)	14.5	7.5

The gain measurements for the main lobe were made on a long propagation path (7500 km), whereas some of the observations of gain off-azimuth were for a medium range path (3000 km). The results gave values of realized gain which are less than expected theoretically. The data showed marked variability of gain and/or discrimination with time of day and somewhat with season. Though the data did not establish a systematic seasonal dependence, there was an apparent tendency for the highest values of gain in the main azimuth to be observed during periods corresponding to maximum daylight on the path; a depression of gain appeared systematically in the morning hours on the path. These data were reported for 13 MHz which was not worked throughout the night hours. Values of gain in directions off the main azimuth also showed marked variability with time of day and season, but the data were not conclusive as to any systematic pattern. Table V summarizes the observations.

TABLE V

Antenna	Frequency (MHz)	Gain relative to half-wave horizontal antenna (dB)									
		Main lobe				Distance (km)	Azimuth relative to main lobe (degrees)	Off-azimuth			
		Hours of obs.	Gain 10%	Gain 50%	Gain 90%			Hours of obs.	Gain 10%	Gain 50%	Gain 90%
A	7.7	83	9.4	8.3	6.7	2000	317	17	8.5	5.6	2.4
	13.7	158	13.4	11.4	8.8	3200	236	49	−7.3	− 8.7	−10.3
	13.7					9300	143	56	−2.9	−10.7	−13.5
	13.7					2000	14	14	1.8	0.5	− 1.4
	13.7					5800	37	42	6.1	4.5	0.2
	17.6	46	14.2	13.3	12.1						
B	7.7	30	15.0	11.4	7.6						
	13.7	50	13.7	11.0	9.2						
	17.6	34	9.9	7.8	6.0						

[CCIR, 1956d] concludes that discrimination of greater than 15 to 20 dB cannot be relied upon; a number of observations are cited for values of discrimination (response outside the main lobe, relative to response in the main lobe), for a rhombic antenna having values of l = 120 m and φ = 70° (height unspecified). These are shown in Table VI; there were not enough data available to permit statistical analysis in terms of the arcs of Recommendation 162 (Geneva, 1963).

[CCIR, 1956a] draws attention to azimuthal variations of signals propagated over great distances via the ionosphere, in relation to realized directivity of antennas at great distances. Measured azimuths show only slight differences among the values of deviation for propagation paths of various lengths. 80% of the measurements showed less than ± 2° average deviation; 98% showed average deviation less than ± 4°. The shortest link observed (2000 km), showed the greatest deviation and the longest path the least deviation.

3. Conclusions

The results show striking variability of gain and/or discrimination with time, especially time of day and, to some extent, season of the year. There are undoubtedly important effects near times of sunrise and sunset, at times of signal failure on operating frequencies near the MUF, and at times of ionospheric disturbance when great azimuth deviations can be observed. Statistical correlation of values of gain with values of transmission loss would be of interest and the data expected from Study Programme 3A/3 may show whether, and under which circumstances, such a correlation exists. The data given above suggest the extent of azimuth deviation encountered during normal propagation conditions. It must be noted that, because of the influence of irregularities in the ionosphere, such as give rise to azimuth deviations, the directivity gain realized at the receiving terminal depends in a fundamental way on the directivity of the transmitting antenna – and vice versa. It is, therefore, important in carrying out observations (such as those outlined in Study Programme 3A/3) to specify the directivity of antennas at both terminals.

TABLE VI – *Median values of discrimination in decibels*
(Off-azimuth response relative to main lobe)

Difference in azimuth (degrees)	Frequency ranges (MHz)					
	10.3 to 12.2		13.3 to 14.5		14.5 to 15.6	
	Discrimination (dB)					
	Median	Median standard deviation	Median	Median standard deviation	Median	Median standard deviation
6					3.8	2.1
12½			12.5	2.0	8.9	2.5
18½					8.0	3.2
21					9.8	1.4
22			7.5	2.9		
25½	9.3	1.4				
27					13.5	1.7
39½					12.5	2.1
46½					14.5	1.4
52½					17.6	2.0
79½			19.8	2.8		
93			12.5	3.6		
109½			20.3	3.8		
117	15.5	2.1				
168½			11.8	3.4		

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REPORT 107-1

DIRECTIVITY OF ANTENNAS AT GREAT DISTANCES

(Question 3/3, Study Programme 3B/3)

(1959-1966)

1. Introduction

Methods of testing the directivity of antennas at great distances have been:

- the "statistical method", a comparison of numerous observations of the same signal on different fixed antennas at the same location but at different orientations [CCIR, 1951 and 1953];
- mechanical rotation of antenna structures with various approaches to data statistics [Pession, 1935, 1936, 1948; Silberstein, 1957];
- the "back-scatter" method, a comparison of back-scatter signals in a method similar to that of the statistical method [Beckmann and Vogt, 1955];

Most of the studies have been made at high frequencies, although at least one was performed in the standard MF broadcast band [Fine and Damelin].

References [Pession, 1935, 1936, 1948] and [Silberstein, 1957] indicate that, at moderately long distances the main lobes are on the average preserved, even under conditions of severe ionospheric disturbance. A more serious matter, which merits further study, is the question of preservation of nulls and front-to-back ratios. Reference [Fine and Damelin] indicates that these are not preserved at medium frequencies. Measurements of these effects are very difficult because of noise and interference. Besides, electrical balance, at both polarizations in antennas, feeders, and equipment antenna circuits, is a very critical matter in the realization of nulls and minima with rhombic antennas in ionospheric propagation [Brueckmann, 1958].

References [Miya *et al.*, 1957] and [Miya and Kawai, 1959] deal with non great-circle effects. These effects were noted in the 1930's [Keen, 1947].

The effect of the propagation medium on transmission loss at different antenna orientations is dealt with in [Norton, 1959].

The directivity of antennas is dealt with in the following documents:

- Question 3/3 – Directivity of antennas at great distances.
- Study Programme 3A/3 – Improvement obtainable from the use of directional antennas.
- Recommendation 162 – The use of directional antennas.

Note. – It is noteworthy that in the IRE Standards on transmitters, modulation systems and antennas, 1948, the definition of directivity is: "the value of the directive gain in the direction of the maximum value", thus differing from the usage in these documents.

2. Directivity in the vertical plane *

The results of measurements of the vertical angles of wave-arrival on a number of long distance HF routes received in the United Kingdom are reported [CCIR, 1963-66]. Some of the experiments and the method of measurement used are more fully described elsewhere [Low and Harris, 1963].

The results are summarized in Table I and may be regarded as typical of circuits with propagation paths in latitudes of 50° or below.

TABLE I – *Statistical summary of measurements of vertical angles of wave-arrival in the United Kingdom*

Transmitter	Distance (km)	Approximate frequency (MHz)	Months of measurements	Total number of measurements	Dominant vertical angle of wave-arrival not exceeded for the indicated percentages of all measurements		
					10 %	50 %	90 %
New York(1) (U.S.A.)	5500	13·4	May, June and July, 1961	4900	2°	9°	13·5°
Poona(1) (India)	7300	14·5	April, June and July, 1961	4434	3°	9°	13°
Sydney(1) (Australia)	17000	14·7	June and July, 1961	3780	4°	9°	13°
Barbados	6800	7·5	August, 1963 November, 1963 January, 1964	2954 798 437	2° 3° 3°	4° 6° 7°	7° 8° 10°

(1) These measurements were performed on antennae which were not particularly favourable to the reception of waves at low angles of arrival.

Conclusions are drawn that signals over long-distance HF circuits are propagated via modes with angles of wave-arrival below 10° for a high percentage of time. The lowest path attenuation and the highest effective antenna gain will therefore be achieved with antennas having directivity characteristics in the vertical plane which favour these propagation modes at both transmitting and receiving stations.

* Directivity in the vertical plane refers to the characteristics of an antenna measured from the ground in a vertical plane containing the transmitter and receiver.

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REPORT 327-3 *

DIVERSITY RECEPTION

(Question 3/1)

(1966-1970-1974-1978)

1. General

Diversity reception is frequently used, to eliminate to a large extent the effects of propagation irregularities on the quality of the signal transmitted.

2. Ionospheric transmission (HF and VHF)

2.1 *Types of diversity reception*

The following types of diversity reception are used [CCIR, 1963-66a, b]:

- spaced-antenna diversity using two or more antennas (usually of the same type);
- polarization diversity using two antennas for mutually perpendicular polarization;
- wave arrival-angle diversity using two or more antennas with different directivity patterns;
- frequency diversity between the spectral components of a single or multi-channel emission or using more than one frequency allocation at the same time;
- time diversity, the signal being repeated with a suitable delay.

The type of diversity used depends on the type of emission, and more than one kind of diversity can be used in a single receiving installation.

2.1.1 *Spaced-antenna diversity*

Spaced-antenna diversity reception is most widely used in the HF and VHF bands.

* Transferred from Study Group 1 to Study Group 3 by the XIVth Plenary Assembly, Kyoto, 1978.

With HF, according to [Grisdale *et al.*, 1957; Bramley, 1951; Khmelnitzky, 1960], the relation between the correlation coefficient and the antenna spacing is satisfactorily given by the expression:

$$\rho = \exp\left(-\frac{\chi^2}{2\chi_0^2}\right) \tag{1}$$

where χ is the antenna spacing and χ_0 the spacing at which the correlation coefficient is reduced to 0.61.

It is found that with the antennas spaced in the direction of propagation, the correlation coefficient sometimes decreases more rapidly than when they are spaced perpendicular to this direction [Grosskopf *et al.*, 1958]. In the former case $\chi_0 \approx 10\lambda$ and in the latter $\chi_0 \approx 15\lambda$. Earlier studies of the influence of the direction in which the antennas are spaced in relation to the direction of propagation showed that it has no significant effect on the effectiveness of diversity reception. This conclusion has since been confirmed by other works [Van Wambeck and Ross, 1951]. Consequently, the direction of the diversity has no appreciable significance; however, when the antennas are spaced less than 150 m apart, they should preferably be sited along the direction of propagation of the incident wave.

In communication systems using ionospheric scatter, the correlation coefficient of 0.61 is attained with a spacing of 30λ along the path of 2.5λ across the path [Aïsenberg, 1962] (see Report 266, § 6).

2.1.2 *Polarization diversity*

It would appear that polarization diversity could be used in all cases of ionospheric propagation. This applies both to earth and space communications.

Measurements on HF links [Grisdale *et al.*, 1957; Kurihara, 1955] have shown that signals received on closely sited dipoles perpendicular to each other show fairly independent fading. As a rule, the correlation coefficient lies between 0.09 and 0.5, which indicates that completely effective systems of diversity reception are feasible.

Tests carried out in the U.S.S.R. show that polarization diversity gives results comparable with those obtained with space diversity with a distance of 400 m between antennas [CCIR, 1963-66c] and that the reception performance characteristics show only a slight difference between horizontally, vertically or obliquely polarized antennas [CCIR, 1970-74]. In [CCIR, 1970-74], a method of comparative studies on the efficiency of various types of diversity reception [Dubrovsky and Malygin, 1970] is given which is based on the fact that there exists a close correlation between telegraph signal time distortions and erroneous characters in the reproduced text [Bukhviner and Malygin, 1969].

However, on links using scatter propagation and on line-of-sight microwave links, the polarization of the signal remains unchanged and signals transmitted with vertical or horizontal polarization fade almost synchronously [Sugar, 1955; Schukin, 1940].

Further comparative studies of reception with spaced antennas diversity (SAD) and polarization diversity (PD) were carried out at distances of 1500 to 4200 km in the 4 to 15 MHz band. Directional antennas of travelling wave type ("fishbone") were tested: symmetrical horizontal arrays (SHA) and non-symmetrical vertical arrays (NVA), the latter being positioned under the horizontal arrays. Each antenna contained two identical parallel arrays.

Determination of error rates with single (without diversity) telegraph reception gave the same results both with symmetrical horizontal arrays and with non-symmetrical vertical arrays. The efficiency of reception in dual polarization-diversity (one SHA-antenna and one NVA-antenna) and of spaced-antenna diversity (two spaced SHA-antennas, distance 400 m) proved to be also comparable.

Antennas for polarization-diversity are, however, cheaper and require a smaller site for erection. In view of this, polarization-diversity reception has its particular merits [CCIR, 1966-69a].

2.1.3 *Wave arrival-angle diversity*

Reception with wave arrival-angle diversity is at present used on scatter propagation links. Angle diversity may be obtained with a single parabolic reflector with a directivity diagram split into two lobes, by selecting the energy from the separate areas of the scatter volume. When the width of each lobe is small in comparison with the angular spacing between the receiver and the transmitter, the required diversity may be obtained with only a slight change in the wave arrival-angle, that is without the substantial loss in the strength of the incoming signal which may occur when the diversity angle is too great. The theoretical relation between the correlation coefficient and the size of the angle diversity along the azimuth [Kirby, 1956] shows that the correlation coefficient 0.61 may be attained when the angle diversity is nine-tenths of the width of the main lobe. Experimental data obtained on a trans-horizon link [Bray *et al.*, 1956] are in good agreement with those calculated. A calculation of the relation between the correlation coefficient and the size of the angle diversity with varying lobe widths is given in [Bolgiano *et al.*, 1958]; it is noted that with a decrease in the lobe width the correlation coefficient also decreases.

It is also noted [Shchukin, 1940] that on ionospheric scatter links, investigation of the fine structure of the signal, with angle diversity, revealed a lack of correlation in the diversity channels.

Antenna systems whereby diversity in the vertical plane can be obtained, such as the MUSA [Chisholm *et al.*, 1959] and the travelling wave antenna [Khmelnitzky, 1960] may be cited as examples of the application of angle diversity in the HF range.

2.1.4 *Frequency diversity and time diversity*

These two forms of diversity are discussed in § 2.2.

2.2 *Telegraphy reception in the HF band (band 7)*

In addition to the use of spaced-antenna diversity or polarization diversity, various forms of frequency and time diversity are employed. In this connection, ways of assessing the improvement due to diversity are considered and the combination of the outputs of the receivers used in diversity is discussed.

2.2.1 *Frequency diversity*

F1B emissions can be used as a form of frequency diversity, because the information given by the presence of the frequency corresponding to one of the significant conditions of modulation is repeated by the simultaneous absence of the frequency corresponding to the other condition: reception in two filtered channels can be used to give an improvement over other methods of reception (Report 195).

Since fading on frequencies separated by more than a few hundred hertz is largely uncorrelated in the HF band, this is a case of frequency diversity.

For the best performance of a frequency-division multiplex system, the frequencies corresponding to the two significant conditions of modulation of each channel should not be adjacent, e.g. in a three-channel system of six frequencies f_1 and f_4, f_2 and f_5, and f_3 and f_6 could be associated.

The term frequency-diversity is also used to describe the use of two channels of a frequency-division multiplex system to carry the same information. Diversity obtained by utilizing more than one frequency allocation is deprecated.

2.2.2 *Time diversity*

The use of automatic reception (ARQ system) in the event of failure is a form of time diversity, as it relies on conditions being different at the time of repetition. This system requires the use of a return link.

In the absence of such a return link, a time-diversity system [CCIR, 1963-66a] [Quarta, 1964] employing two transmission channels with a delay of about 2 s in the second transmission of the signal can be used. Time diversity is most useful in overcoming time-variant components of the distortion which rarely lasts more than 1 second.

2.2.3 *Assessing the merits of different kinds of diversity*

There are two methods of specifying diversity effectiveness:

2.2.3.1 *Diversity gain*, i.e. the reduction in transmitted power resulting from the use of the diversity method for equal element error-rate.

2.2.3.2 *Error-rate improvement factor*, i.e. the reduction in element error-rate resulting from the use of the diversity method for equal transmitted power.

It is suggested that both methods of specifying the effectiveness of diversity be used, and that the number of diversity channels and the level of non-diversity error-rate, at which the improvement is effected, be specified. Additional time or bandwidth required to effect the diversity improvement should be considered in rating the merits of diversity schemes.

For zero correlation and Rayleigh fading, both diversity gain and error-rate improvement factor can be read directly from Figs. 1 and 2 of Report 195. One loses 2 dB in dual diversity gain for $\rho = 0.4$ and 3 dB for $\rho = 0.7$.

2.3 *A3E reception in the HF band (band 7)* [CCIR, 1963-66d]

Although A3E signals are frequently received on single-sideband receivers and the conditions are such as described in § 2.4, double-spaced antenna and polarization diversity are used if double-sideband receivers are employed.

Combined automatic gain control is used, so that the gain of both receivers is controlled by the strongest signal, and the receivers are adjusted to have equal gain.

The outputs of the receivers can be either combined or selected. In combination the output due to the weaker signal and the noise due to the second receiver are present. Electronic switches can select the stronger of the two audio-frequency outputs if the difference is 2 dB or more, but the operation of such a switch is often audible.

2.4 *R3E, B3E and J3E reception in the HF band (band 7)*

2.4.1 Tests made with triple-spaced-antenna diversity have shown that with high-quality speech and music, improvements to "slightly better" or "much better" are obtained, but with telephone speech, little improvement was observed [CCIR, 1963-66e].

Three methods of using the audio-frequency outputs were employed:

- direct combination;
- combination with an audio-frequency delay of 1 and 2 ms for the second and third receivers;
- selection by an electronic switch.

The delay combination gave the best results; selection improved the signal-to-noise ratio, but the change of quality that often occurred when the switch operated was considered disturbing.

It is concluded that, as there is no distortion resulting from the selective fading of the carrier (as occurs with A3E), little advantage can be expected to result from diversity reception.

2.4.2 Tests made with dual-spaced-antenna diversity using triple segmented band splitting at audio-frequencies have shown that with telephone speech, improvements in reception quality were noted due to a reduction in selective fading effects and in frequency usage, which afforded at least one hour longer frequency utilization before frequency change was required, as compared with single receiver operation.

The tests were made in the Pacific area over long-haul circuits during the Mercury Project [CCIR, 1963-66f].

2.4.3 On the New York-Frankfurt HF telephone circuit, tests have been carried out with dual-frequency-diversity reception. With a view to offsetting the effects of selective fading, a diversity selection for each of the 5 partial AF bands (derived from a privacy device) was made.

Though this method reduced the fading probability and delivered a substantial increase in speech fidelity, no perceptible increase in intelligibility was recorded. Therefore, other methods, which effectively increase the quality of transmission, e.g. the method in which the signal-to-noise ratio is related to momentary speech values, seem to be more promising [CCIR, 1966-69b].

2.5 *F1B ionospheric-scatter reception in the VHF band (band 8)* [CCIR, 1963-66g]

At 38 MHz at 300 bauds with 11 kHz spacing between the frequencies corresponding to the two significant conditions of modulation, signals have been received using frequency-diversity between corresponding signals as well as spaced-antenna diversity. The effect of inequalities of gain in the two receivers were investigated, and of inequalities of gain in the channels corresponding to the two significant conditions of modulation. A 6 dB difference in receiver gain reduced the diversity gain by 3.4 dB for an error-rate of 1 in 10 000 or doubled the error-rate for a 20 dB signal-to-noise ratio. A 6 dB difference between the gains of the two channels reduced the diversity gain by 4.5 dB or increased the error-rate of 1 in 200 by a factor of 1.6. With both gain differences present at the same time, the error-rate was 10 times as great.

3. Output signal combination

According to the classification proposed in [Nemirovsky, 1960; Friis and Feldman, 1937] there are four basic ways of combining the signals in diversity reception [CCIR, 1963-66b].

3.1 *Antenna switching*

This system of diversity reception covers a number of methods known as non-optimum selection. The antenna switching circuit connects the spaced antennas to the receiver in a given order until the signal, the monitored parameter of which exceeds the specified limit, is found. This signal is used until its monitored parameter falls below the threshold; the search for the signal is then resumed.

The effectiveness of this system is analysed in [Friis and Feldman, 1937; Brennan, 1959; Ziouko, 1964], where it is shown [Brennan, 1959] that, for a negative correlation coefficient (-1) between the signals in the diversity antennas and with equal transmission coefficients in each diversity channel and a Rayleigh field-strength distribution, the non-optimum selection method is nearly as effective as the optimum auto-selection method. However, with a positive correlation coefficient, the effectiveness is greatly reduced [Friis and Feldman, 1937; Ziouko, 1964].

It would appear that diversity with non-optimum selection should be used for reception of A3E and F3E transmission and also in A1A, A1B and F1B telegraphy.

3.2 *Selective addition, sometimes known as diversity with optimum selection*

Unlike the system described above, this system simultaneously investigates the signals from N channels and selects the best. To achieve this in multiple diversity reception, N antennas and N receivers are required [Nemirovsky, 1960; Friis and Feldman, 1937].

It should be noted that, in diversity reception with automatic selection (optimum and non-optimum), switching gives rise to additional noise and its use is thus limited. Optimum selection with this method may be effected either at intermediate frequency or at audio frequencies or d.c. There is less noise when the intermediate frequency is used.

3.3 *Diversity with maximum-ratio addition (quadratic addition)*

Provided a number of conditions are fulfilled [Nemirovsky, 1960; Friis and Feldman, 1937], the maximum ratio between the signal energy and the specific noise power one can obtain by means of diversity is equal to the sum of the separate ratios in the diversity channels.

The optimum addition circuit weights the inputs in proportion to the signal-to-noise ratios in the corresponding sub-channels of the diversity system. The optimum system presupposes pre-detector coherent addition. It is optimum because it leads to the lowest element error-rate. Non-coherent addition gives a higher error-rate, but does not require phasing of the signals added (see Report 195).

3.4 *Diversity with equal amplification*

In this system, all the channels have the same amplification and the addition is effected linearly. Pre-detector linear addition ensures a degree of effectiveness closely approaching that obtained with quadratic addition. Non-coherent post-detector linear addition is less effective.

All the combination systems used in practice are related to the four methods enumerated above, or to combinations thereof.

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RECOMMENDATION 520-1

USE OF HIGH FREQUENCY IONOSPHERIC CHANNEL SIMULATORS

(Question 21/3)

(1978-1982)

The CCIR,

CONSIDERING

(a) that testing of HF transmission systems while in operation is time-consuming and costly;

(b) that some Administrations have reported good correlation between the results of laboratory tests conducted on simulators and the results of tests of a data transmission system in operation,

UNANIMOUSLY RECOMMENDS

1. that, when simulators are used to predict, in a qualitative sense, how well a particular system of data transmission may be expected to perform on HF circuits, the representative channel parameter combinations listed in Annex I be considered on a provisional basis;

2. that, for comparative evaluation of different systems of data transmission, the additional channel parameter combinations listed in Annex II be considered on a provisional basis;

3. that studies in connection with Question 21/3 be continued for the determination of the parameter combinations to be used in the simulation of specific circuits of a given length and for a specific period of time;

4. that further studies in connection with Question 21/3 be undertaken to establish the most significant channel parameter combinations in the evaluation of systems designed for the transmission of analogue signals.

ANNEX I

SIMULATOR PARAMETERS FOR QUALITATIVE TESTING

1. If applicable, it is desirable to perform all simulator tests in both diversity and non-diversity configurations to evaluate the effectiveness of the diversity combining scheme used. Back-to-back tests with additive noise should be completed prior to testing with the simulator to ascertain that the equipment performs properly.

2. Representative channel parameter combinations

2.1 Gaussian noise and flat fading: bit error probability as a function of energy-per-bit to Gaussian noise density ratio for a single fading path with no frequency-shift.

Suggested values for frequency spread (fading rate): 0.2 Hz and 1 Hz.

2.2 Gaussian noise, multipath and fading: bit error probability as a function of energy-per-bit to Gaussian noise density ratio for two independently fading paths with equal mean attenuation, equal frequency spreads and non-frequency shifts.

Suggested parameter values for general testing:

2.2.1 *Good conditions*

Differential time delay: 0.5 ms
Frequency spread: 0.1 Hz

2.2.2 *Moderate conditions*

Differential time delay: 1 ms
Frequency spread: 0.5 Hz

2.2.3 *Poor conditions*

Differential time delay: 2 ms
Frequency spread: 1 Hz

2.2.4 *Flutter fading* (if required)

Differential time delay: 0.5 ms
Frequency spread: 10 Hz

Note. – For simulation of specific circuits, delay values as a function of radio circuit length are given in Fig. 1 of Report 203.

2.3 Doppler, multipath and fading (if required): bit error probability as a function of frequency offset of both components of a two component multipath structure with equal mean attenuation, equal frequency spreads and no noise.

Suggested parameter values:

Differential time delay: 0.5 ms
Frequency spread: 0.2 Hz
Range of frequency offset: 0 to 10 Hz.

ANNEX II

ADDITIONAL PARAMETERS FOR COMPARATIVE TESTING

1. The following tests, in conjunction with those listed in Annex I, enable comparative evaluation of equipment.

2. Additional tests for comparative purposes

The following tests provide greater knowledge of the specific capabilities of a modem. In conjunction with the foregoing tests, this will enable comparative evaluation of equipment.

2.1 *Flat fading:* bit error probability as a function of frequency spread for a single fading path with no noise or frequency-shift.

Suggested range of frequency spread: 0.1 to 50 Hz.

The results of this test will show the capabilities of the modem with respect to frequency spread distortion in the channel and the effect of internal noise in the modem receiver (and RF receiver if it is used).

2.2 *Multipath and fading:* bit error probability as a function of the differential time delay of two independently fading paths with equal mean attenuation and equal frequency spreads and with no noise or frequency-shift.

Suggested parameter values:

Frequency spread: 0.2 Hz and 1 Hz
Range of differential time delay: 0.1 to 5 ms.

The result of this test will show the capabilities of the modem with respect to time spread and frequency spread distortion in the channel and the effect of internal noise and intermodulation distortion in the modem (and RF) receiver.

2.3 *Multipath and fading:* bit error rate as a function of the ratio of the mean levels of two independently fading paths with unequal mean attenuation, equal frequency spreads and with no noise or frequency-shift.

Suggested parameter values:

Differential time delay: 5 ms
Frequency spread: 0.2 Hz
Range of mean level ratios: –40 to 0 dB.

The results of this test will show the sensitivity of the modem to relative low strength path components with large time delays.

REPORT 549-1

HF IONOSPHERIC CHANNEL SIMULATORS

(Question 21/3)

(1974-1978)

1. Introduction

High frequency (HF) ionospheric radiocommunication is typically characterized by multipath propagation and fading. The transmitted signal usually travels over several modes or paths to the receiver via single and multiple reflections from the E and F layers. Because the propagation times over the several paths are different, the signal at the receiving antenna may consist of several multipath components spread in time over an interval of up to several milliseconds. The average heights of the ionospheric layers are usually increasing or decreasing with time, which introduces different frequency (Doppler) shifts on each of the multipath components. The ionosphere is also turbulent which causes fading of each component and a resultant fading of the composite received signal. All of these effects produce multiplicative signal distortion and degradation of the performance of communication systems.

If a CW signal is transmitted over an HF link the spectra of the received multipath components can appear as shown in the experimental example of Fig. 1. Four paths are present: 1E, 1F, 2F, and Mixed modes. While the two magnetoionic components in the 1E mode have about the same frequency spreads (fading rates), their frequency-shifts are significantly different, allowing them to be resolved in frequency. On each of the other three modes, both the spreads and shifts of the two magnetoionic components are essentially the same and they appear as one. The short-term multiplicative distortion characteristics of an HF channel can thus be described in terms of the parameters that specify the time-spread and frequency-spread characteristics; i.e., the differential propagation times on the several paths, and the strengths, frequency-shifts, and frequency spreads on each path. These parameters are subject to change, of course, on a diurnal and seasonal basis, as well as generally being different on different geographic circuits.

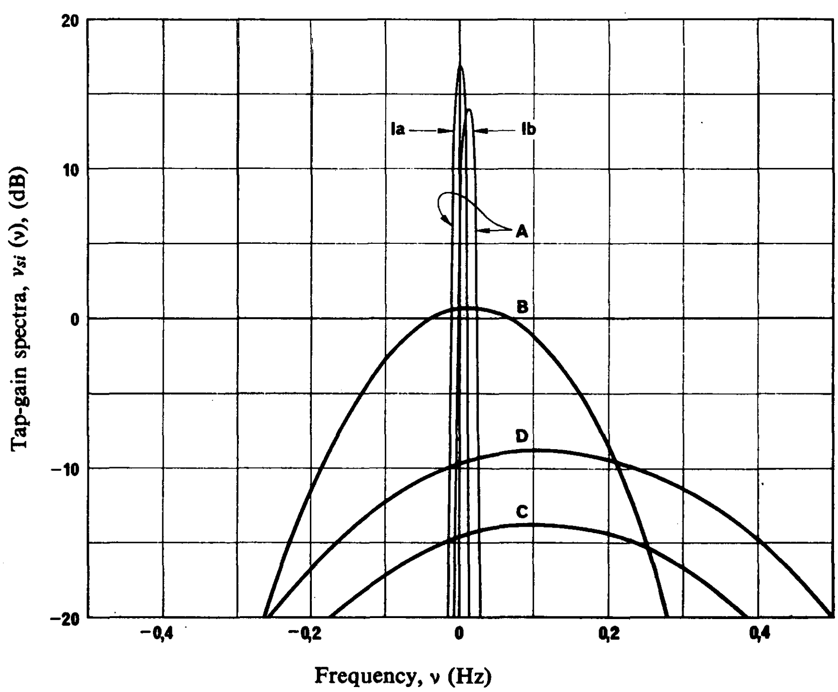


FIGURE 1 – *Power spectra of the multipath components of a CW signal*

A: Path $i=1$ (1E mode)
B: Path 2 (1F mode)
C: Path 3 (Mixed mode)
D: Path 4 (2F mode)

To compare the performance of two or more systems over real channels, they must be tested simultaneously, because propagation or channel conditions vary uncontrollably and cannot be accurately repeated at other times or over other links. Because of the disadvantages of on-the-air measurements there has been a rapidly increasing interest in developing measuring devices that can be used in laboratory experiments to obtain similar measurements: channel recorder-reproducers [Goldberg *et al.*, 1965] and channel simulators [Bray *et al.*, 1947; Law *et al.*, 1957; Freudberg, 1965; Di Toro *et al.*, 1965; Walker, 1965; Clarke, 1965; Chapin and Roberts, 1966; Adams and Klein, 1967; Zimmerman and Horowitz, 1967; Packer and Fox, 1969; Watterson *et al.*, 1969a].

The use of a channel simulator has the advantages of accuracy, regularity of performance, repeatability, availability, a large range of channel conditions, and lower cost, but these advantages are limited if the channel model on which the simulator design is based is not valid. The 12 simulators referenced above are based on 10 generally different channel models, and their capacities for simulating a range of real-time ionospheric conditions are limited in varying degrees.

This Report describes a Gaussian-scatter HF channel model for the multiplicative distortion, the experimental method used to confirm the validity and bandwidth limitation of this model, and one implementation of an HF simulator based on this model.

2. Gaussian-scatter model

A block diagram of the stationary Gaussian-scatter HF ionospheric channel model is presented in Fig. 2. The input (transmitted) signal is fed to an ideal delay line and delivered at several adjustable taps, numbered 1, 2, . . ., *i*, . . ., *n*, one for each ionospheric propagation mode or path. At each tap, the delayed signal is modulated in amplitude and phase by an appropriate complex random *tap-gain function*, $G_i(t)$. The delayed and modulated signals are summed with additive noise (Gaussian, atmospheric, and/or man-made) and/or interference (unwanted signals) to form the output (received) signal. For the Gaussian-scatter channel model each tap-gain function is defined by

$$G_i(t) = \tilde{G}_{ia}(t) \exp(j2\pi\, \nu_{ia} t) + \tilde{G}_{ib}(t) \exp(j2\pi\, \nu_{ib} t) \qquad (1)$$

where the *a* and *b* subscripts identify the two magnetoionic components that are generally present in each mode or path. The tildes indicate that $\tilde{G}_{ia}(t)$ and $\tilde{G}_{ib}(t)$ are sample functions of two independent complex (bivariate) Gaussian ergodic random processes, each with zero mean values and independent real and imaginary components with equal r.m.s. values that produce Rayleigh fading (i.e., that they are Gaussian-scatter functions). The exponential factors in Equation 1 are included to provide the desired *frequency-shifts* (Doppler), ν_{ia} and ν_{ib}, for the magnetoionic components in the tap-gain spectrum.

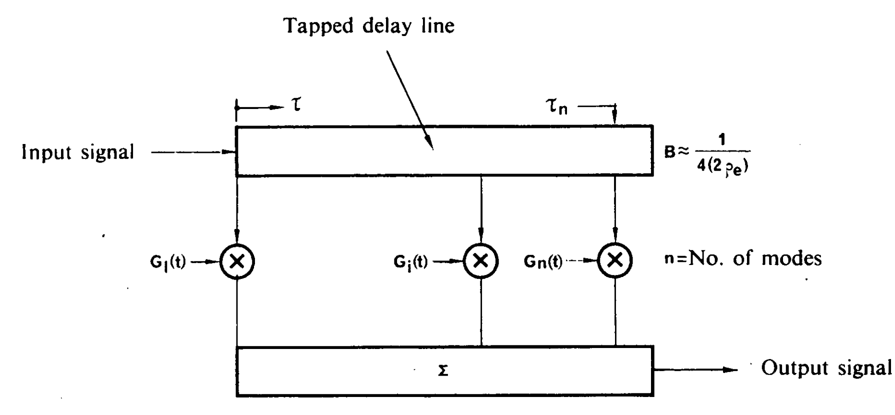


FIGURE 2 – *Block diagram of HF ionospheric channel models*

Each tap-gain function has a spectrum, $v_i(\nu)$, that in general consists of the sum of two magnetoionic components, each of which is a Gaussian function of frequency, as specified by

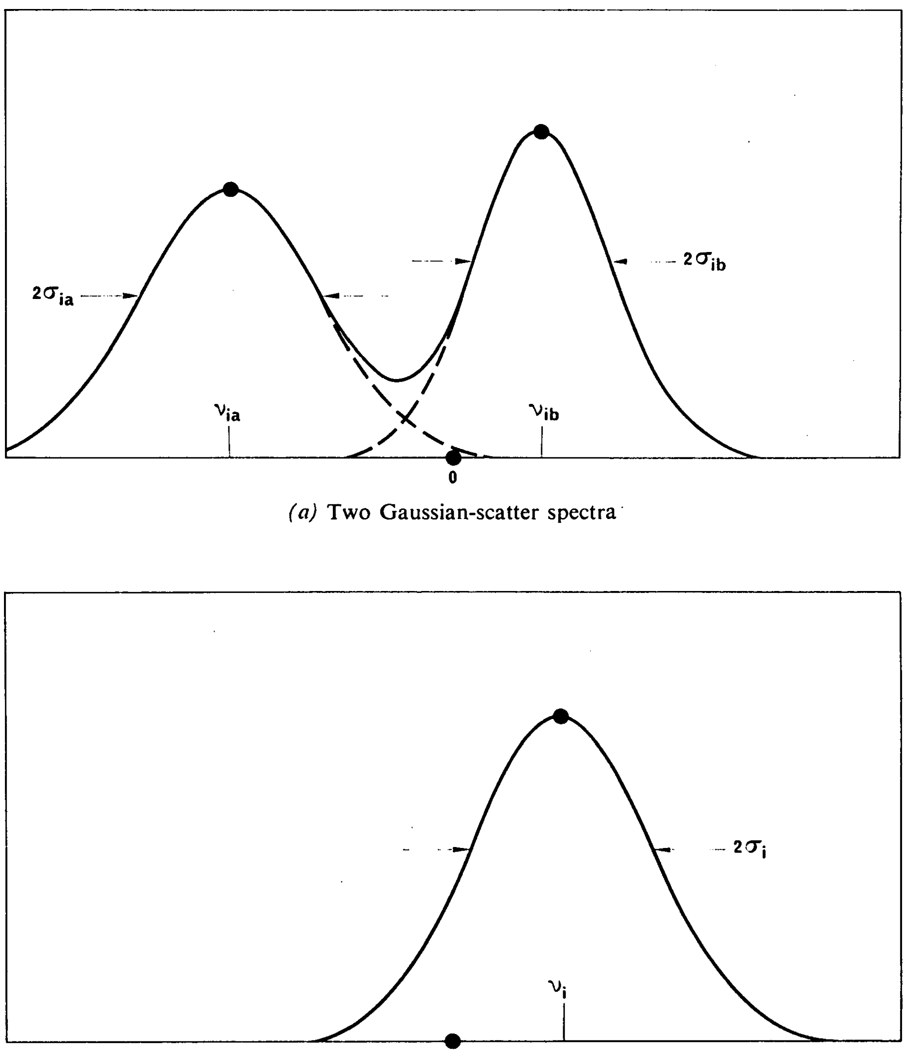
$$v_i(\nu) = \frac{1}{\tilde{A}_{ia}\sqrt{2\pi}\,\sigma_{ia}} \exp\left[\frac{-(\nu-\nu_{ia})^2}{2\sigma_{ia}^2}\right] + \frac{1}{\tilde{A}_{ib}\sqrt{2\pi}\,\sigma_{ib}} \exp\left[\frac{-(\nu-\nu_{ib})^2}{2\sigma_{ib}^2}\right] \tag{2}$$

$\tilde{A}_{ia}$ and $\tilde{A}_{ib}$ are the component *attenuations*, and the *frequency spread* on each component is determined by $2\sigma_{ia}$ and $2\sigma_{ib}$. Equation 2 is illustrated in Fig. 3a. Six independent parameters specify a tap-gain function and its spectrum: the two attenuations, $\tilde{A}_{ia}$ and $\tilde{A}_{ib}$, the two frequency-shifts, ν_{ia} and ν_{ib}; and the two frequency spreads, $2\sigma_{ia}$ and $2\sigma_{ib}$.

The tap-gain function described by (1)-(2) is general in that it applies when the spectra of the two magnetoionic components are significantly different and when the difference in their delays is negligible (less than about one-fourth of the reciprocal of the channel bandwidth of interest). Only one of the two terms in (1)-(2) is required in the following two cases:

– for some low rays, the frequency-shifts and frequency spreads of the two magnetoionic components are nearly equal, their spectra nearly match, and a single term can be used with the tap-gain spectrum in Fig. 3b;

– the two magnetoionic components in high rays often have a significantly large difference in delay. In this case, separate delay-line taps with appropriate spacing should be used, with each of the two corresponding tap-gain functions and spectra consisting of a single term, again as illustrated in Fig. 3b.



(a) Two Gaussian-scatter spectra

(b) One Gaussian-scatter spectrum

FIGURE 3 – *Tap-gain spectra in validated Gaussian-scatter model*

3. Experimental verification of Gaussian-scatter model

To determine the validity and bandwidth limitation of the Gaussian-scatter model, special channel-measuring equipment was developed and used for day-time and night-time HF ionospheric measurements over a 1294 km mid-latitude link in two 12-kHz bands. Three selected 10- to 13-min samples of data were analyzed to determine the validity of the three hypotheses that completely specify the channel model:

3.1 each tap-gain function is a zero-mean complex Gaussian-random function, as defined in general by Equation 1;

3.2 each tap-gain function is independent of the other tap-gain functions;

3.3 each tap-gain spectrum generally consists of the sum of two Gaussian functions of frequency, as specified by Equation 2.

For each sample, appropriate statistical tests were used to determine the validity of each of the above hypotheses.

Since the channel model has discrete paths with zero time-spread, while each ionospheric mode always has at least a small time-spread, the accuracy with which the channel model can represent an ionospheric channel decreases with increasing bandwidth; the smaller the time-spread on the ionospheric modes, the greater the bandwidth over which the model maintains a suitable accuracy. The data were also analyzed to determine the accuracy of the model with respect to bandwidth.

The statistical tests confirm the validity of all three hypotheses and thereby, the validity of the model. For the three samples of data, the model was found to be accurate over a bandwidth about one-fourth of the reciprocal of the effective time-spread on the ionospheric modes ($2\rho_e$ in Fig. 2); i.e., 2.5 kHz for the night-time sample and 8.0 and 12 kHz for the day-time samples. The experimental verification of the channel model is described in detail in [Watterson *et al.*, 1969b and 1970].

The importance of the shape of the tap-gain spectrum should be noted. Theoretical analyses have been made [Bello and Nelin, 1962] of the performance of digital communications systems for a single-path Rayleigh-fading channel with two different tap-gain spectra: a single-pole filter spectrum of the form $1/(1 + \rho_1\nu^2)$ and a Gaussian spectrum of the form $\exp(-\rho_2\nu^2)$. For constants ρ_1 and ρ_2 that gave equal half-power bandwidths, the single-pole spectrum gave substantially greater signal distortion and higher probability of error than did the Gaussian spectrum. In the experimental measurements and analyses that validated the Gaussian-scatter channel model, the statistical tests not only showed that it was highly probable that the Gaussian-spectrum hypothesis of 3.3 was valid, but they also showed that it was highly probable that a single-pole tap-gain spectrum was *not* valid.

4. Specular components

Although the experimental verification of the Gaussian-scatter HF channel model was limited to only a few samples of data on one link, other ionospheric measurements [Balser and Smith, 1962; Shaver *et al.*, 1967; Boys, 1968] have shown that the majority of ionospheric modes exhibit Rayleigh fading, which further confirm the model. It appears probable, therefore, that the Gaussian-scatter channel model can accurately represent a major portion of typical HF ionospheric links. However, the Gaussian-scatter model almost certainly is not valid for all HF ionospheric channels. Specifically, there is evidence that specular (non-fading) components can be present on high rays [Balser and Smith, 1962] and the ground wave present on a short link is essentially specular. Further, specular components are easily obtained in a simulator and can prove useful in non-HF applications (such as VLF-LF channel simulation). When a specular component is present it will have the same frequency offset as the corresponding mode spectrum. Thus, in Fig. 3 specular components would appear as Dirac-delta functions at ν_{ia}, ν_{ib} and ν_i, as applicable.

Based on present knowledge of ionospheric characteristics, it appears that the Gaussian-scatter model best describes most HF channels, and that specular components should be used with caution (except for a ground wave).

5. Simulator description

An HF channel simulator based on the Gaussian-scatter-plus-specular model has been built [Watterson *et al.*, 1969a] and used in laboratory tests. It consists of a delay unit, four tap units, each of which provide the frequency-shifts and fading illustrated in Fig. 3b, and a summing unit that adds the outputs of the four tap units with additive noise and/or interference. The four tap units enable single (no) diversity simulation with up to four independent paths, or dual diversity simulation with two paths for each diversity branch.

The delay unit accepts input signals at baseband (0.3 to 12 kHz) and samples them at a 50-kHz rate. Each serial ten-bit sample is delivered to a chain of LSI shift registers with 20-μs adjacent tap spacings and a maximum delay of 10 ms. The delayed digital signals from the selected taps are reconverted to feed the four tap units.

In each tap unit, the delayed baseband signal is converted to an intermediate frequency (IF) of 525 kHz plus or minus a selectable amount of frequency-shift. The local oscillator used in the frequency conversion is a specially designed synthesizer that provides selectable frequency-shifts of 0, ± 0.01, ± 0.02, ± 0.05, ± 0.2, ± 0.5, ± 1, ± 2, ± 5, ± 10, ± 20, ± 50, ± 100, ± 200, or ± 500 Hz. Other frequency-shifts can be obtained from external synthesizers. The double-sideband intermediate-frequency signal drives ± 45° phasing networks in the tap unit that deliver signals in quadrature. Each quadrature signal is multiplied by independent baseband Gaussian noise with the same low-pass Gaussian power spectrum. The multiplier outputs are summed to form the complex-Gaussian scatter component that is fed via an adjustable attenuator to the summing unit. The intermediate-frequency signal is also fed directly to the summing unit via an adjustable attenuator to provide the specular component. Both the specular and the scatter attenuators are adjustable over a 100 dB range.

The two baseband Gaussian noise generators in each tap unit each consist of a random-binary-sequence generator (with independent bits) that drives a 3-pole active RC filter. The spectrum of the noise, which is determined by the filter response, deviates from the ideal Gaussian shape by less than 0.7% maximum. Because the cut-off frequency of the low-pass filter is about one-hundredth of the bit rate of the random sequence that drives it, the amplitude distribution of the noise from the filter is extremely close to Gaussian. The RC networks in the filters and the frequency of the random sequences are switched to provide frequency spreads of 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, or 500 Hz. The r.m.s. noise voltages from the filters are the same for all values of frequency spread.

The specular and scatter intermediate-frequency signals from the tap units are summed with intermediate-frequency Gaussian noise, simulated atmospheric noise [Bolton, 1971], and/or CW interference whose levels are also adjustable. The CW interference (or externally supplied interference from other sources) can also be subjected to independent fading via one of the tap units. The summed double-sideband intermediate-frequency signals, noise, and/or interference can feed any one of three upper sideband filters with passbands of 0-3, 3-6 or 6-12 kHz relative to 525 kHz. The selected filter must correspond with the frequency band of the simulator input signal. A baseband output is obtained by heterodyning the filtered intermediate-frequency signal with a 525 kHz local oscillator.

6. Correlation with field tests

Tests on a digital selective calling system designed in accordance with Recommendation 493 were conducted with the HF channel simulator described in § 5 above [CCIR, 1974-78a] using the channel parameters given in Annex I of Recommendation 520. Subsequent operational tests by two Administrations [CCIR, 1974-78b and c] showed good correlation with the simulator tests, and confirmed the value of such a simulator in evaluating digital transmission systems.

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[1974-78]: **a.** 3/13 (United States of America); **b.** 3/11 (United States of America); **c.** 3/16 (Japan).

ANNEX I

PARAMETERS TO BE CONSIDERED IN SIMULATION

1. This Annex based on [CCIR, 1970-74a, b and c] deals with the question of parameters to be specified when using HF Ionospheric Channel Simulators to evaluate equipment intended for operation over HF radio circuits.

2. The Doc. [CCIR, 1970-74c] notes a relationship between distance, sunspot number and ionospheric modes, which may be of assistance in determining the parameters to be used in HF Ionospheric Channel Simulation.

3. The Doc. [CCIR, 1970-74a] recommends that HF Ionospheric Channel Simulators should be capable of simulating the following channel parameters:

	Parameter	*Range*
(1)	fading depths	2 to 40 dB (in steps of 2 dB)
(2)	* duration of fading (duration of a fade is defined as the time interval that the signal level is below a given reference level)	In the range from 0.05 to 1.5 s (in steps of 0.05 s)
(3)	* fading rate	5, 10, 20, 40 per minute
(4)	* delay time	0 to 5 ms
(5)	* spectral width of a single selective fade	0.1 to 1.2 kHz
(6)	* rate at which a selective fade moves through the spectrum	0.5 to 2 kHz/s
(7)	frequency drifts	0 to 7 Hz
(8)	signal-to-noise ratio using white Gaussian noise having a bandwidth of 2.7 kHz	0 to 40 dB

* These parameters are not all independent of each other.

To assess and test the following telegraphy and data transmission procedures:

- modulation methods
- diversity procedures
- error correction procedures

simulation of the HF medium should expediently be affected at audio frequencies ranging from 0.3 to 3 kHz, and from 3.3 to 6.0 kHz, respectively.

Due to the fact that the efficiency of the telegraphy and data transmission procedures on HF radio paths does not only depend on the properties of the transmission medium but also on the characteristics of the radio installations, it would also be possible to incorporate specific parameters of these radio systems into the simulator, for instance, frequency drifts, automatic volume control, sudden frequency and phase jumps such as sometimes occur due to frequency synthesizers in the radio-frequency equipment, etc.

Assessment of performance can be based on the character error rate, bit error rate or the rate of distortion.

4. Further information is needed for the determination of the parameter values to be used in the simulation of specific circuits of a given length and for a specific time period.

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REPORT 111 *

INFLUENCE ON LONG-DISTANCE HF COMMUNICATIONS USING FREQUENCY-SHIFT KEYING OF FREQUENCY DEVIATIONS ASSOCIATED WITH PASSAGE THROUGH THE IONOSPHERE

(Question 7/3)

(1959)

1. Introduction

This Report, based mainly on [CCIR, 1958a], deals with three aspects of the question. Firstly, the magnitude and time duration of the frequency changes to be expected are considered. Secondly, upper bounds of error rates for frequency-shift systems are calculated. Thirdly, experimental element-to-element phase changes are shown, relevant to phase-modulation techniques.

The present Report gives only partial information on the subject and a more complete study may be expected, to provide definitive information on the minimum frequency shift which is feasible in practical systems.

2. Characteristics of frequency changes over HF circuits

It is well known that the rapid fading observed on HF circuits is the result of interference between a number of different waves that have been reflected from different portions of the ionosphere. The ionosphere may be thought of as an irregular reflecting surface that is drifting across the sky. Because of this drift, waves that arrive at the receiving site are being reflected from elemental surfaces that are in motion; consequently, each reflected wave will have a small Doppler frequency change. The interference of these frequency-shifted waves gives rise to rapid fading. (This Report will be concerned only with rapid fading and not slow variations resulting from changes in absorption.) This being the case, a reasonable model describing the fading signal is to assume it has the character of very narrow-band Gaussian noise. This approach was probably first described by Ratcliffe [1948].

When the narrow-band noise representation is used, it is then possible to use the extensive work done by Rice [1948], in determining the nature of a fading HF signal.

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* This Report was adopted by correspondence without reservation.

Now the relationship between the fading rate N_G (defined as the mean number of times per second the signal envelope passes through the median signal level with positive slope), and the corresponding "equivalent noise bandwidth" of the fading signal is

$$N_G = 1.48\ \sigma$$

where σ is the standard deviation of an assumed Gaussian shaped band-pass filter. (This equivalent noise bandwidth refers to the received signal only and not the noise that may accompany it.) It is equivalent to the 2.17 dB half-bandwidth of the filter. If a rectangular filter is assumed then the fading rate N_R is

$$N_R = B/2.32$$

where B is the bandwidth of the filter. The Gaussian shaped filter seems to be a close approximation to the true fading bandwidth of an HF signal [Price, 1957]; however, for convenience, only a rectangular filter will be considered. Once we have a measure of the bandwidth of the fading signal, we may proceed to find the probability distribution of the instantaneous frequency along with several other statistics.

Fig. 1 shows the cumulative probability distribution of the instantaneous frequency. This curve has been normalized to the fading rate. For a fading rate of 1 Hz, the instantaneous frequency will be within about 20 Hz of the carrier frequency for 99.96% of the time.

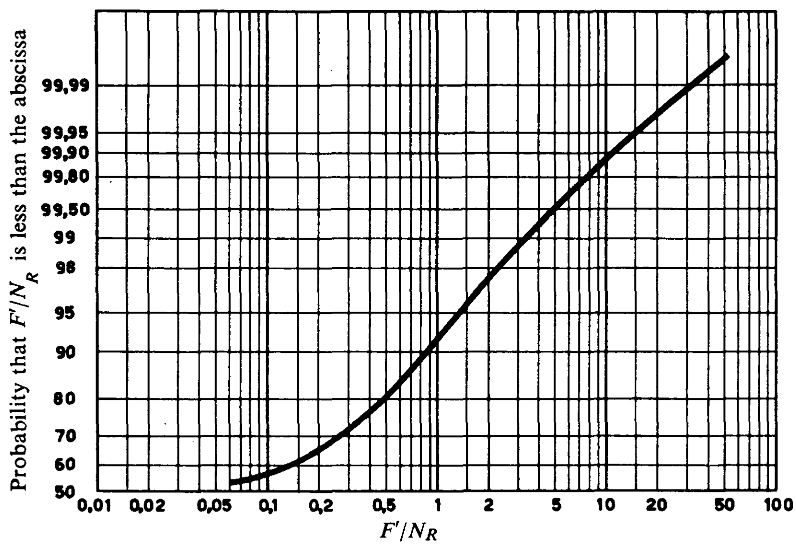

FIGURE 1 – *Cumulative probability distribution of instantaneous frequency change*

F' : Instantaneous departure from centre frequency (Hz)
N_R : Fading rate (fades per second)

Taking into account the fading rate indicated in Report 266, the values of excursion of instantaneous frequency are not inconsistent with the deviations of 3 parts in 10^6 for a few milliseconds duration reported in [CCIR, 1958b].

The mean duration of the instantaneous frequency deviation may also be found with the aid of results worked out by Rice. He derives the expression for the mean number of times per second that the instantaneous frequency exceeds or crosses a given instantaneous frequency, when the bandwidth of the filter is known. Taking the reciprocal of these crossings-per-second gives the mean time interval between them. And since we also know the percentage of the time the instantaneous frequency spends beyond the given crossings, we may compute the mean time duration it spends there. This is simply the product of the probability that it will be beyond the crossing and the mean time interval between the crossing. This mean time inverval, $\overline{\Delta t}$, versus frequency change from the centre frequency, is shown in Fig. 2. Fading rate is the parameter. If the fading rate is known, the mean duration of exceeding a given frequency change may be found. It is interesting to note that $\overline{\Delta t}$ is practically independent of the fading rate.

It should be noted that a more complete study is required to provide the cumulative distribution of the time durations for various specified frequency changes. This is beyond the scope of the present Report.

3. The effects on frequency-shift keying of frequency changes due to passage through the ionosphere

To determine the effect of frequency changes associated with passage through the ionosphere, we shall assume that no noise is present and that our detector is a frequency discriminator. Our system will make an error if the transmitted frequency is changed far enough to cross over into the wrong side of the discriminator and remains there for a period comparable to half the element length. We shall choose 20 ms as the element length.

If we assume a fading rate of one per second and a frequency shift of 40 Hz, we find, referring to Fig. 1, that the frequency of either the mark or space channel will change by 20 Hz and cross over into the wrong side of the discriminator for only 0.04% of the time. The 0.04% represents the upper limit of the binary error rate to be expected in the no noise case. If reference is made to Fig. 2, we find that $\overline{\Delta t}$ is only 6.2 ms; consequently, even when the instantaneous frequency does lie on the wrong side of the discriminator, its duration is so short that only rarely will an error be made.

Fig. 3 shows the maximum binary error rate to be expected versus the frequency-shift of the system with the fading rate as a parameter. It is assumed that errors occur with the probability that the instantaneous frequency has been displaced to the wrong side of the discriminator. This over-estimates the true error rate due to frequency changes, when the mean length of time of the change is small compared with the signal pulse length, since the discriminator (or post detection filter) time constant has been ignored. As an aid in estimating the region where this time-constant becomes effective, points on the curves, corresponding to $\overline{\Delta t}$ of 10 ms, have been located from the curves of Fig. 2.

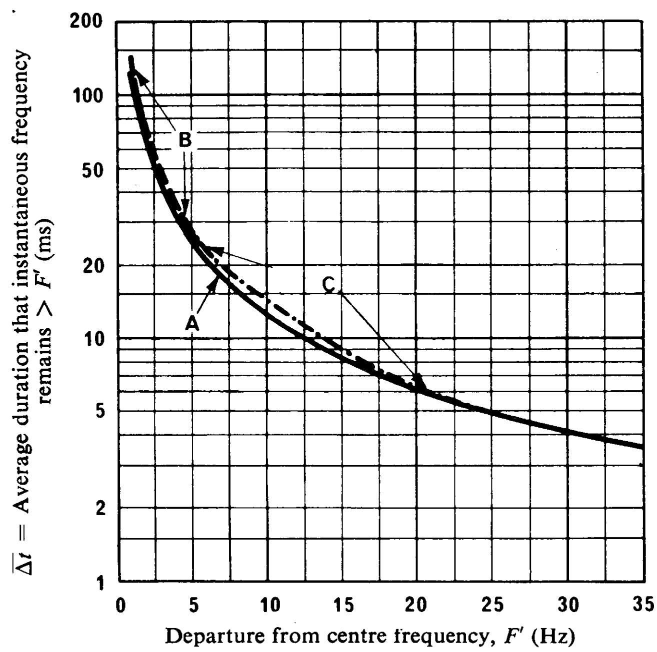

FIGURE 2 – *Average duration that instantaneous frequency change due to the ionosphere exceeds F′, with fading rates of 0·2, 1·0, and 5·0 fades per second (assuming a model of narrow-band Gaussian noise)*

Curves A: 0·2 fade/second
B: 1· fade/second
C: 5 fades/second

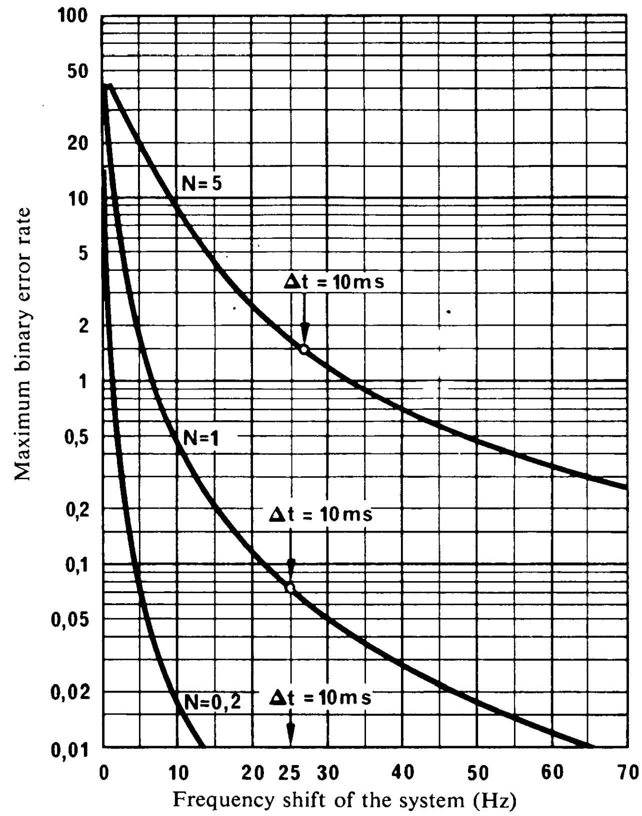

FIGURE 3 – *Relation between binary error rate and frequency shift of the system for fading rates, N, of 0·2, 1 and 5 fades per second. Element length = 20 ms (50 bauds)*

4. Experimental data relevant to phase modulation

Several experimental studies have been conducted, to determine the performance of the frequency-shift keying systems and phase-shift (synchronous) system over sky-wave transmission in the HF band. The phase-shift modulation system requires reasonable phase stability over an approximate period of 44 ms. Results of these studies are pertinent to this study of Doppler frequency changes.

A short study has been made of the phase stability of signals from WWV as received in Burbank, California [Doelz *et al.*, 1957]. Measurements were made at frequencies of 5, 10 and 15 MHz. A sequence of discrete phase comparisons were made at a rate of 50 Hz. Each measurement compared the phase of the incoming signals during a 20 ms period with that during the following such period.

Stability of receiving equipment for such measurements is of primary importance. For this test, all receiving gear was frequency controlled by a single high stability local standard oscillator (1 part in 10^8), thus ensuring that apparent phase shifts due to frequency error were insignificant compared to phase changes due to the propagation.

In general terms, the measuring technique consists of driving an extremely high *Q* resonator circuit with the received signal for 20 ms. The resonator was then allowed to ring while the second resonator was driven by the signal for another 20 ms. The relative phase between the two resonators was then measured in a phase detector. This resultant measurement was the phase difference between two integration-phase samples taken 20 ms apart. By a suitable connection between two quadrature phase detectors, a polar display of relative phase and amplitude was presented on an oscilloscope. The oscilloscope intensity level was blanked except at the end of each 20 ms integration period. The resulting display is a series of dots representing the tips of vectors, whose lengths from the origin are proportional to the amplitude of the applied signal, and having angles equal to the signal phase changes between samples. Photographs of these dot displays were made with exposure times of from 15 s to 5 min. The major results of the study were polar displays of signal phase shift and amplitude. Fig. 4 shows approximate probability contours drawn from these displays. These indicate a decrease in phase stability at higher frequencies, as expected, and give an indication of the degree of phase uncertainty, which cannot be attributed to additive noise.

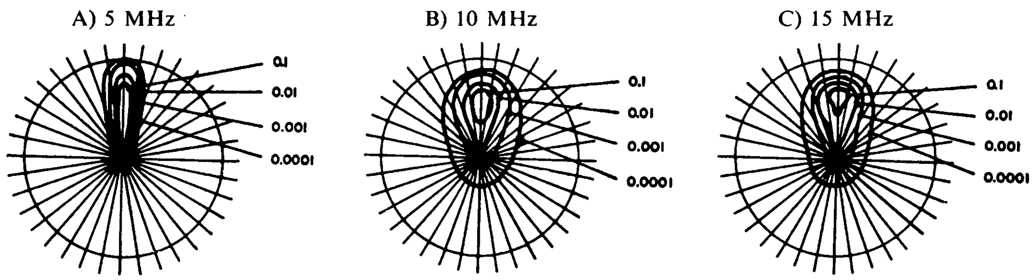

FIGURE 4 – *Polar probability contours of phase change and amplitude of WWV*

The numbers shown represent the probability that a measurement will fall outside the contours.

5. Conclusion

To the degree that the theoretical model describes the behaviour of an HF fading signal, it appears that frequency changes imposed by the propagation are small for typical fading rates. This conclusion is supported by some experimental evidence on phase uncertainty obtained over HF paths. Further studies, especially of the distribution of the duration of frequency changes, are needed to improve the estimates of errors imposed in frequency-shift keying systems.

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[1958] Geneva: **a.** III/34 (USA); **b.** III/3 (United Kingdom).

REPORT 357-1

OPERATIONAL IONOSPHERIC-SOUNDING SYSTEMS AT OBLIQUE INCIDENCE

(Study Programme 20A/3)

(1966-1974)

1. Introduction

Many ways are employed to improve the quality of HF communications. Most of these are concerned with upgrading the system elements, for example, increasing the antenna gain or the transmitter power. Although these usually result in some improvement, the performance of HF circuits is often still below the level that might be obtained, largely because the optimum working frequency has not been determined and used [Jelly, 1971].

Results of frequency sounding experiments have led a number of workers [Sandoz *et al.*, 1959; Doyle *et al.*, 1960; Hatton, 1961; Hunsucker *et al.*, 1969] to suggest that frequency sounding equipment could be used independently or as part of the communications system to determine optimum, short-term operating frequencies. A number of studies have been carried out [Jull *et al.*, 1962; Egan, 1963; Batts *et al.*, 1970; Page *et al.*, 1967; Stevens, 1968] which determine the improvements that can be achieved from the use of sounding information.

2. Types of sounding systems

There are a number of types of oblique incidence sounding systems but three in particular are described in this Report.

2.1 *The locally operated and controlled channel sampling system*

A particular service adopting a channel sampling system could use its complement of assigned frequencies for both frequency sounding and communications on a time- or frequency-shared basis. Such a system, named CHEC (Channel Evaluation and Calling) was developed for use on HF air-ground-air links [Stevens, 1968]. It is based on the assumption that the air-ground communications path is the one that could present difficulties, because of the inefficient antenna and low transmitter power usually inherent to an aircraft installation.

In the CHEC system, the sounding transmissions originate at the ground terminal and are received by the aircraft. The air-ground communications path efficiency is calculated based on the strength of sounding signals received, while assuming path-loss reciprocity. In addition, the sounding transmissions carry coded information concerning channel noise levels measured by a receiver at the ground terminal. This permits an estimate to be made at the aircraft of the probable signal-to-noise ratio for transmissions over the air-ground path, on channels that support communications.

The CHEC ground communications centre includes, besides the conventional transmit-receive facilities, a stepped-frequency ground-interference receiver for measuring ground interference levels, and a stepped-frequency sounding transmitter for the transmissions of the coded sounding signals. The aircraft, in addition to its communications transceiver, is equipped with a CHEC stepped-frequency receiver for reception and evaluation of the sounding transmissions. Both air and ground units are maintained in time and frequency synchronism by internal crystal-controlled clocks.

2.2 *The common-user system*

The CURTS concept [Probst, 1968] envisages the use of oblique synchronous ionospheric soundings, noise and interference measurements on the assigned communications frequencies, and current performance monitoring of the communications frequency in use, as inputs to a centralized computer. The computer memory contains all the necessary information on the available frequency resources. The computer logic then utilizes the inputs to predict the operational performance of assigned frequencies, to select the frequencies for use on all of the controlled trunks, and to provide, as output, directions for frequency changes to achieve continuity of the communications system being controlled.

A CURTS network comprising 6 paths has been tested in the Pacific. The sounders operated on 120 frequencies, transmitting four 1 ms pulses on each frequency at a rate of 20 pulses per second once every 10 minutes. The received sounder signal provided data on signal amplitude and on time and frequency dispersion for the computer. During the interval between sounding sequences, the output of the sounder receivers was sampled and digitized thus providing data on background noise and interference. The data from each sounder sequence were also compared with previous data and then retained for use on following days at the same time.

The computer memory contained the lists of the assigned frequencies for each of the HF paths being controlled. Of the sounder-signal amplitudes received, the two frequencies above and below each assigned frequency were utilized to provide a median figure from which a prediction could be made of the signal energy that would be received on the assigned frequency. The computer then evaluated each assigned frequency for possible interchannel interference. Ionospheric predictions and forecasts of disturbances programmed on the computer were also used to assess the adequacy of the assigned frequencies. A quality figure based on the binary error rate was determined for each assigned frequency by the computer which then ranked them in descending order of quality. This information was then transmitted by teletype to the technical controller for use in frequency change decisions.

2.3 *An idle-tone channel selection system*

A low level idle tone, or tones, transmitted on an HF radiotelephone terminal's frequency complement can provide a distant receiving terminal with a means of optimum frequency selection and circuit elevation, either manually or automatically.

Experiments are being carried out by a telephone operating agency in Canada to test the practicality and usefulness of idle-tone channel selection adapted to a conventional isolated region radiotelephone system. On this type of system one multi-frequency radiotelephone terminal serves many low power fixed and portable radiotelephone stations over distances of up to 1600 km. The terminal employs traffic operators; the small-user stations are operated by non-technical people. Conventionally, on a system of this type, a pre-arranged "calling" channel is used to establish the desired communication circuit. Using idle-tone channel selection on this same system, idle tones transmitted by the terminal on its frequency complement, at levels 10 to 20 dB below operational peak envelope power, permit the distant non-technical operator to select the best available channel by a simple listening test on each of the assigned frequencies.

The telephone operating agency studying this particular application of idle-tone channel selection suggests that it may have some usefulness on radiotelephone systems other than the one described, and summarizes its advantages as follows:

- No modification of the apparatus at the user radiotelephone is necessary.
- System costs are relatively low as compared to traditional sounding techniques.
- Non-technical personnel can operate the system.

3. Operational problems encountered using frequency sounding systems

Experiments carried out so far using ionospheric sounding at oblique incidence disclose a number of problems both when the sounding equipment is used in parallel with the communications equipment and when the communications equipment is used to perform the sounding. The following items must be considered:

3.1 any differences in operational sensitivity between communication and sounding equipment parameters;

3.2 inaccuracies in sounder predictions which result from sounding over an ionospheric path separated from the communication path and in the opposite direction of a non-reciprocal path. Studies [Jull, 1968] suggest that for a separation of 32 km these differences can be reduced to about 5 dB by averaging sounding information over eight minutes;

3.3 any difference of performance of the sounder and communication equipment in the presence of interference;

3.4 the difficulty in determining the sounding repetition rate required to ensure the validity of the information when ionospheric conditions begin to vary, as during disturbed periods;

3.5 the difficulty in determining a sounding signal that is representative of the modulation of the communications system.

4. Sounders as an aid to communication systems

Each system that has been tested has demonstrated that sounding is an effective aid to communications because uncertainties concerning the performance and operation of the communications systems are removed. This is particularly so in the higher latitudes where the ionosphere is very irregular.

Some of the improvements attained by sounding are as follows:

- time to establish contact is reduced;
- the quality of communications is improved;
- operations can be largely automated to reduce the requirements for skilled operators.

5. Interference

The use of the above techniques on a continuous basis may result in an undesirable increase in interference as radio frequency energy would be radiated on all assigned frequencies rather than only on the frequency in actual use.

It is therefore recommended that the channel probing be done on an intermittent basis, the probing rate being dependent on the variability of the communication channel quality. Additionally in some systems, probing may be confined to the assigned frequencies immediately above and below the operating frequency rather than on the full complement of assigned frequencies.

6. Further study

It is recommended that the operational and interference problems which may arise as a result of the widescale use of such systems be the subject of further study.

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REPORT 109-2

RADIO SYSTEMS EMPLOYING IONOSPHERIC-SCATTER PROPAGATION

(Question 4/3)

(1959–1966–1974)

A contribution, relating to Question 4/3, has been received from the United States of America [CCIR, 1958]; references are cited in which information on ionospheric-scatter propagation relevant to exploitation of systems has been published [Bailey *et al.*, 1955; IEE, 1958]. Basic propagation characteristics are given in Report 260.

1. Variation with frequency of propagation characteristics relevant to the use of systems

For estimation of the performance of fixed systems, it is important to know the variation with frequency of the mean signal intensity, the fading characteristics, such as short-term amplitude distribution and fading rate, and the background galactic noise level. For practical purposes, received power may be considered inversely proportional to approximately the 7th power of the frequency, using scaled antennas. The background galactic noise is inversely proportional to the 7/3 power of the frequency. The resulting signal-to-noise ratio, using scaled antennas, is proportional approximately to f^{-5}. Studies have shown that the frequency dependence during hours of weakest signal intensity is not significantly different from that observed for the mean signal intensity. The short-term amplitude distribution of signal intensity approximates a Rayleigh distribution at frequencies observed in the range of 30 to 74 MHz. The typical measured fading rate (median crossings), at 50 MHz, is approximately 1 Hz; the fading rate is proportional to operating frequency raised to a power of 0.7 to 1.2, depending on conditions.

Another important propagation characteristic which varies with frequency is the occurrence of long-distance F2 propagation giving rise to mutual interference and back-scatter, which represents a source of self-interference to a scatter system used for high-speed telegraph services. The occurrence of this type of propagation is dealt with in the following paragraphs, along with consideration of mutual interference.

2. The extent to which systems employing this mode of propagation and operating on the same or neighbouring frequencies are liable to interfere with each other and with other services

The propagation modes, most significant in long-distance interference between scatter services and other services, are sporadic E and F2. Adequate world-wide measurements of sporadic E are not yet available to permit a complete evaluation of the percentage of time that interference is likely to occur. A comprehensive study of world-wide occurrence of Es observed at HF by ionosphere recorders has been published [Smith, 1957; Smith *et al.*, 1959]. For practical purposes, ionospheric-scatter circuits, to avoid sporadic-E interference, should have their transmitting and receiving terminals geographically separated from other circuits or services by at least 2500 km. Figs. 1 to 3 of Report 259 represent contours of the F2-4000 km MUF exceeded for 1% of the hours for the December solstice, the June solstice and the Equinox, at sun-spot maximum. These are derived from standard CRPL F2-prediction data, using measured distributions of day-to-day values of F2 MUF about the median. A circle of 2000 km radius centred on the station gives the locus of frequencies at which propagation over 4000 km paths occurs 1% or 10% of the time during the season indicated. The percentage of the time is less for paths longer or shorter than 4000 km.

3. Radio-frequency and baseband characteristics of ionospheric-scatter systems

Ionospheric-scatter systems of high reliability are currently in operation and the number of such systems may be expected to increase. These systems employ highly directional antennas and transmitter output powers of the order of 40 kW.

In view of rapid technical advances, standardization is not practical at this time. Therefore, the modulation characteristics of typical systems in use or under consideration are presented for illustration:

- a single voice channel of responds from 300 to 3100 Hz using single-sideband, or narrow-band frequency modulation with a peak deviation of 3 kHz;
- four to sixteen channel, time-division multiplex, at a rate of 150 to 600 bauds with frequency-shift keying; a separation of 6 kHz is commonly used between mark and space frequencies, to minimize errors due to Doppler components;
- combinations of the above, using linear transmitters, such as a voice channel and a frequency-shift keying system or two independent frequency-shift keying systems; as an alternative, two transmitters may be used, one carrying voice intelligence and the other teleprinter;
- a system has been proposed with a single voice channel and four teleprinter channels, using error correction and detection techniques at 177 bauds. A typical channel arrangement for 20 kHz spectrum occupancy is shown in Fig. 1;
- a frequency-shift radioteleprinter system using heterodyne frequency-changing, the oscillator frequency being chosen between the frequencies representing the two significant conditions of modulation (see [CCIR, 1963-1966]) in such a manner that the upper beat frequency corresponding to one condition and the lower beat frequency corresponding to the other condition are both within a narrow band; among the advantages found for this method may be cited an increase in the signal-to-noise ratio and low cost.

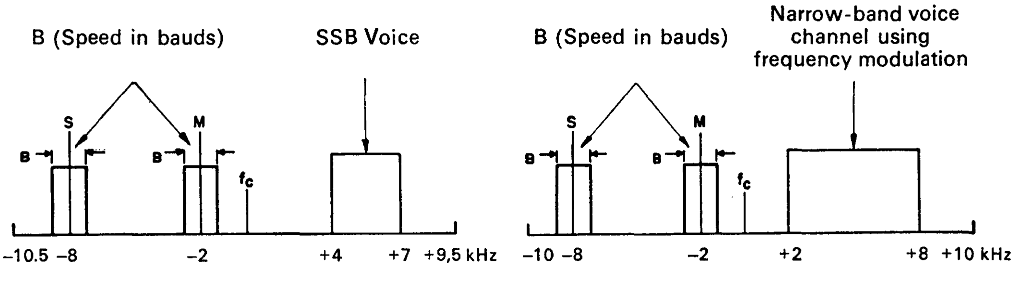

FIGURE 1 – *Typical 20 kHz channel arrangements for ionospheric-scatter transmission*
(B is the frequency in hertz corresponding to the telegraph speed in bauds)

Modulation characteristics of the propagation medium must be considered in system application. Some pertinent characteristics are:

- diversity reception is beneficial for voice teleprinter operation. Dual or triple diversity is commonly used;
- the coherence bandwidth, as determined by multipath considerations of the transmission medium, is limited to approximately 3 kHz;
- meteoric multipath will, in general, limit the maximum modulation rate;
- during periods where the MUF may be above the operating frequency, F2 propagation may be expected. The above conditions are frequently accompanied by long-delay multipath echoes, ranging up to 50 ms or more. The echo pulses may have amplitudes comparable to or even greater than the desired signal, thus resulting in a very high error rate. Long-delay multipath problems may find solution by the use of antennas having more desirable directivity characteristics, the use of a frequency above the MUF, or by the use of special modulation techniques;
- ionospheric-scatter systems characteristically employ high power and highly directional antennas; during periods of sporadic E or high MUF, they must be considered as potential sources of interference to other services sharing the same frequency band;
- current four-channel teleprinter systems, using dual-space diversity, typically require a signal-to-noise ratio of 24 dB (noise measured in a 250 Hz band), for a binary error rate of 1×10^{-4};
- voice systems currently in use will provide usable operator-to-operator quality over a single link with a radio-frequency signal-to-noise ratio of approximately 14 dB, as measured in a 3 kHz noise bandwidth.

The frequencies used for this mode of propagation are generally between 30 and 40 MHz. A few circuits currently being installed will use dual-frequency operation. Higher frequencies, perhaps as high as 60 MHz, will be useful as a means to avoid distance propagation during periods of high F2 MUF's at times of maximum solar activity.

The distances over which these circuits operate generally range from 1000 to 2000 km, and several of these circuits are now in operation in arctic regions.

4. Use of forward error-correction on ionospheric-scatter teletype circuits

The reliability of teletype operation over VHF scatter circuits can be improved through the use of error-correcting codes. Approximately 150 hours of test data were obtained on a 1300 km ionospheric-scatter path at moderate latitude, using a block code with 1/3-rate and interleaving over 8.4 seconds [Juroshek *et al.*, 1971]. The transmitter power was 500 W, the transmission rate was 108 bit/s, and the frequency-shift was 6 kHz.

Test results showed that for a channel bit error rate of less than 10^{-2} no character errors occurred in any of the 10 minute long samples (4032 characters per sample). Although the ratio of character error rate before decoding to character error rate after decoding was found to be somewhat dependent on the type of antenna and the use of diversity or non-diversity, the overall performance was close to theoretical predictions. Other coding techniques, for example, convolutional codes, given comparable coding rates and constraint lengths, may be expected to provide a comparable performance.

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3A d: Operational questions

Reports

REPORT 551

AUTOMATICALLY CONTROLLED HF RADIO SYSTEMS

(Question 14/3)

(1974)

[CCIR, 1970-74] describes a method of programming an HF receiving system to operate at pre-arranged times during a 24-hour period on any one of three frequencies in a prescribed sequence based on propagation forecasts and experience.

The method completes the frequency change in two stages. Firstly, time periods during which a frequency change is expected are identified by prior agreement with the transmitting station. A 24-hour timing clock fitted with three cams, each of which is arranged to actuate a switch contact in the control line and is associated with a specific tuned frequency, brings the receiver to a prepared state for a frequency change. This prepared state is set for a period of 15 minutes before to 30 minutes after the scheduled time of frequency change. Secondly, the control circuit is completed by a switch contact operated by a telegraph distortion (short element) monitor (as mentioned in Report 351, § 3, Geneva, 1974) which detects persistent distortion or the disappearance of the received signal. If this should happen during a pre-arranged time period, the receiver changes to the appropriate new frequency.

The telegraph distortion monitor actuates when 12.5% of incoming signal elements exceeds 30% distortion or in the complete absence of keying. If excessive distortion or circuit failure occurs outside the prescribed frequency-change time periods, the receiver automatic frequency control is inhibited, thus preventing correction on a poor quality signal or on noise. Antenna selection is programmed with the frequency change so that the appropriate antenna is selected for the frequency in use.

To date four routes have been equipped since which 90% of the changes have been made automatically.

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REPORT 857

CHARACTERISTICS OF REMOTE CONTROL SYSTEMS FOR HF RECEIVING AND TRANSMITTING STATIONS

(Question 24/3)

(1982)

1. Introduction

Remote control of receiving or transmitting equipment should be considered with respect to firstly, the type and form of each controlled function and, secondly, the connection medium and mode of operation. This Report contains considerations concerning the second category.

In general, control units will be designed and manufactured as part of the controlled equipment and, as such, do not require to be compatible with those of other manufacturers. However, there would be advantages to the user if basic design features were standardized and some optional facilities specified.

2. Considerations

2.1 Remote control can involve either a local extended operating panel or, alternatively, a remotely sited panel.

2.2 A remote control unit might control radio equipment of the same differing type.

2.3 Control action might be initiated by manual selection at the control unit or by demand of a separate computer system.

2.4 The connecting medium might be a switched network or a direct link.

2.5 A control system might require a memory system which is organized on a group control basis.

2.6 The most favoured method of control is by a digital system.

2.7 Dependent on the response time required and length of interconnecting link, a serial or parallel transmission of data may be used.

2.8 Account should be taken of parallel work, particularly development in the field of computer interfacing to instrumentation and other peripherals.

2.9 Account should be taken of parallel work in the field of error detection and correction and the use of efficient modulation systems.

3. Conclusions

3.1 Standardization should be confined to:

- a definition of modulation mode, using existing standards;
- a preference for serial data streams;
- a list of preferred speeds of data transmission;
- a list of preferred word lengths and format.

3.2 Control system performance to be expected under specified minimum quality interconnecting link conditions, and optional error detection and correction codes, should be specified.

3.3 Provision for the range of facilities referred to in §§ 2.1 to 2.4 would allow operating agencies to adopt control arrangements to suit changing needs. These range from single manual control panels for each item of equipment to computer supervised multi-role stations operating remotely and automatically via public or private networks.

REPORT 329-3 *

REMOTELY CONTROLLED HF RECEIVING STATIONS

(Question 24/3)

(1966-1970-1978-1982)

1. The CCIR has recognized the increasing importance of remote control of unattended HF receiving stations. This Report contains information relating to experience with respect to the evolution and operation of remotely controlled HF receiving stations. Particular attention is given to:

- problems relating to stations arrangement;
- special characteristics of HF receivers intended for use in remotely controlled stations;
- characteristics of the remote control system.

2. An example of an early unattended remotely controlled HF receiving station for the fixed service employed receivers having preset HF amplifiers with crystal filters to improve selectivity. Fine tuning was performed by motor-driven potentiometers connected in the second local-oscillator circuits. The control system accommodated up to 10 receivers, using both analogue and digital control signals to obtain command and monitoring via voice frequency telegraph channels.

* This Report has been transferred from Study Group 1.

3. Some aspects of remotely controlled HF receiving stations

3.1 Because of the different operational requirements of various services it would be expedient either to control several receivers by one common control panel in succession, or to control each receiver by its own control panel. Neither the performance of the receiving system, e.g. fine tuning, frequency stability, and so on, nor the operating convenience should be impaired by remote control.

3.2 The special characteristics of an HF receiver designed to be remotely controlled should be: use of a frequency synthesis equipment; storage of the receiver's control state so that it will remain unchanged in case of control circuit breaks or mains failure; and substitution of the analogue controls and control-replies by digital ones, with incremental steps as small as necessary.

3.3 The control system should obtain improved reliability by avoiding all mechanical methods should process the control data – both the command signals and the control state information – into a suitable format to be transmitted over one switched channel for telephony or voice-frequency telegraphy.

4. Report 705 shows an example of a minicomputer-controlled HF receiving station which has been in operation since 1972.

5. Special characteristics required in remotely controlled receivers

If the radio-frequency gain of the receiver is not remotely controlled it is extremely important that the automatic gain control characteristic of the receiver is effective.

Good AGC action results in much better audio at the operating position, compared with that from a receiver with poor AGC but processed through a compressor amplifier at the output of the receiver.

It is especially important that measures be adopted to prevent received atmospheric noise or interference from being retransmitted. One effective way to accomplish this is to use a very long decay-time-constant on the receiver AGC. This also prevents the noise from surging up between words or sentences of an SSB or CW transmission. This is equivalent in effect to setting a remotely-controlled radio-frequency gain control to the threshold of atmospheric noise for the duration of the conversation.

6. Annex I identifies some possible characteristics of remote control systems.

7. Annex II describes remotely controlled HF receiving stations particularly suitable for small systems and mixtures of fixed and mobile services.

8. Annex III describes the outline of a new remotely controlled HF receiving station for the fixed and mobile services.

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ANNEX I

POSSIBLE CHARACTERISTICS FOR REMOTE CONTROL SYSTEMS FOR HF RECEIVING STATIONS

1. All information concerned with the operational control of the receiver conveyed between the local control position and the receiver should be in binary form and may conveniently take the form of binary coded decimal. This information will consist of forward control data, revertive data and all necessary timing signals and should be transmitted serially.

2. Data transmission speeds should be within the range 50 to 9600 bit/s with speeds of at least 1200 bit/s for fast operating functions, e.g. tuning.

3. With the implicit use of modems to facilitate long distance control, the data interchange will probably be by way of a four-wire public telephone circuit and CCITT standard data modems.

Conformity with the following CCITT Recommendations is required:

CCITT Fascicle VIII.1	Recommendation V.28	Electrical characteristics for unbalanced double-current inter-change circuits.
	Recommendation V.24	(Appropriate sections) List of definitions for interchange circuits between data terminal equipment and data circuit-terminating equipment.
	Recommendation V.23 *	600/1200-baud modem standardized for use in the general switched telephone network.
	Recommendation V.26 *	2400 bits per second modem standardized for use on 4-wire leased telephone-type circuits.
	Recommendation V.27 *	4800 bits per second modem with manual equalizer standardized for use on leased telephone-type circuits.

4. Complete control functions

The following, as shown in Table I, is a list of control functions which are necessary to give an operator essentially the same degree of control and revertive information that he would have if he were operating a receiver directly.

TABLE I

Function No.	Functions	Facilities	Control positions
1	AGC	Fast, slow, off	3
2	RF/IF gain	5 dB steps over a range of at least 100 dB	21
3	Receive mode	A1A, A1B, A3E, R3E, H3E, J3E, F1B	6
4	Frequency tuning	1.6 to 28 MHz in 10 Hz increments	2.64×10^6
5	BFO tuning range	3000 Hz in 10 Hz increments	301
6	High stability BFO	On, off	2
7	IF filter selection	Maximum of 5 bandwidths	5
8	Antenna selection	According to operational requirements for bearing and frequency	256 (max.)
9	Revertive RF/AF level	Meter indications in 10 dB steps	11
10	AF output		Analogue

5. Limited receiver control functions

There are many situations where the full range of control facilities listed above are not required and consquently the number of controlled functions can be substantially reduced. Economy of control functions may in any case be exercised for the following reasons:

- to reduce the complexity and cost of the control system;
- to reduce the degree of skill required by the operator;
- where signalling capacity of the control link is limited such that sending the complete information listed above would take too much time; for example when a number of receivers are to be controlled over a link having limited bandwidth.

* As applicable.

Economy of control functions can be achieved by the following means:

- Where the number of operating frequencies is limited these can be stored in a memory system connected to or forming part of the receiver. The tuning control function then has only to select a "channel number" and the number of control positions required is the same as the number of channels available. This function (No. 4 in the Table) would then be suitable for controlling function 8 at the same time.
- Where the signal characteristics for each mode will be identical then selection of a mode can automatically determine the setting of other functions. For example, whenever the F1B mode is selected the high stability BFO would be switched on, an appropriate IF brought into use and the AGC set to fast. The number of control positions for functions 1, 3, 6 and 7 combined is then equal to the number of different operating modes required.

The above examples could be combined; the number of control positions for functions 1, 3, 4, 6, 7 and 8 would then equal the number of channels available.

6. Bit allocation

Data bits should be allocated to each function according to the range of control required. The form of allocation must not prejudice the uniqueness of any synchronization signals (see § 8).

The allocated bits should be grouped for transmission into omni-function or specific-function data words.

7. Message formats

7.1 *Omni-function data word*

The word length should be sufficient to order the state of all the receiver controls in the forward direction and sufficient in the return direction to update all the revertive check information at the remote control panel.

The word may incorporate the following features:

- synchronization,
- receiver control,
- antenna control,
- parity check (see § 8),
- address (see § 7.3),
- spare facility.

Cessation of control signals should leave each receiver's control functions in their most recently updated position.

7.2 *Specific-function data word*

Short data words should represent either specific control functions or small groups of control functions and should be transmitted when only specific control changes are required.

7.3 *Addressing*

If the destination of control or revertive data is ambiguous, for example, when several receivers are controlled from a single remote point, then addressing bits should be transmitted. These may be part of the control or revertive data words or may make up separate addressing words.

8. Error protection and synchronization

The risk of errors arising in the transmission of control data should be reduced by either the duplicated transmission of each data word or by the inclusion of parity check bits in each word, or both.

The date code adopted should include means of establishing synchronism between the receiving decoder and the transmitted data. Sufficient bits should be allocated to synchronization to make the synchronizing signals uniquely recognizable.

9. Response time

The response time of the remote control system may be assessed as the sum of:

- the time to transmit a word at the chosen bit rate, i.e. w/b where w is the word length in bits and b is the bit rate in bit/s;
- the delay time of the remote control channel;
- the processing time of the remote control system, which should not exceed 1% of the time to transmit a word.

For example, at a bit rate of 100 bit/s, the response time could be 0.24 + 0.02 + 0.0024 = 0.2624 s.

10. Re-establishment of control after restoration of a control channel or power failure

Where the central control point has a separate control panel for each remote receiver, the control panel should have access to a memory which will enable quick restoration of the correct receiver settings.

Where one central control panel may be switched to control one of a number of remote receivers, restoration of the correct receiver settings may be expedited by an associated computer memory.

11. Computer control

The remote control system may be designed so that it may be readily interfaced with a computer which could be arranged, for example, to carry out automatic surveillance of a number of radio frequencies or to effect station programming.

ANNEX II

1. Introduction

The present Report deals with remotely controlled HF receiving stations in the fixed service, which is generally understood to mean the international service. A description is given below of remotely controlled stations which can be used in a wider range of HF services, such as small domestic systems and mixed mobile and fixed systems, where the problems are often quite different from those in the international service.

In the paragraphs that follow, the term "remotely controlled HF receiving station" is taken to mean the control of a receiving station located some distance from the operating centre.

2. Basic requirements

A remotely controlled receiving system for the HF services should meet the following requirements:

- all control and monitoring facilities required operationally should be available to the remote operator;
- overall performance should be as good as that achieved with manual control at the receiving site;
- there should be no operationally discernible delay in the response of the remote equipment to instructions from the operator;
- remote control should not cause any increase in the amount of circuit time needed for setting up and maintaining the circuit.

There are disadvantages as well as advantages to the use of remote control. The ultimate performance of a remotely controlled system can never be better than that of a locally controlled one. Remote control should only be adopted where local control is not practical for one reason or another.

3. Remote control facilities

The control facility requirements may vary from those of a very simple system with merely on/off control and selection of pre-set frequencies, to systems with control of all receiver and antenna functions and providing the operator with revertive information. This description is concerned with this more complex type.

Facilities required by an operator can be grouped under two main headings:

– receiver and antenna controls;
– revertive information.

The various function controls will require different response rates according to their particular characteristics, but in general they can be divided into two groups:

– fast response;
– slow response.

Fast response controls:

These may include tuning, beat oscillator frequency, radio frequency gain and antenna direction selection. All these controls are used dynamically by the operator.

Slow response controls:

These include pre-set controls – band selection, mode selection, and the other facilities that are not operated dynamically.

4. Revertive information

The amount of revertive information required will be dependent upon the particular receiving complex. In general, the types of revertive information required include:

– confirmation that commands have been obeyed;
– indication of signal strength;
– indication of the degree of tuning error;
– indication of automatic frequency control status.

5. The control system

The performance of the receiving system should not be compromised by false economies which may result in inefficient and unreliable utilization of the radio channels. Particular attention should be paid to this point if it is proposed to control a number of receiving systems by means of a common control system using, for example, a sequential transmission system.

Care must be taken that hum and noise picked up on the control link does not modulate the remotely controlled oscillators or a radio frequency amplifier stage.

6. Remote control of sensitivity

It is desirable to be able to adjust sensitivity in either direction of a control knob's rotation rather than have to go full rotation in one direction only. The operation is more likely to be performed correctly when it is rapid and convenient.

There are a number of techniques that provide a satisfactory solution to this problem. One very satisfactory system in use has the following features:

– the control at the operating position is similar to the one normally found on a local receiver;
– the receiver circuit is isolated from induced hum and noise on the control link;
– the attenuator is external to the receiver, connected in the antenna feed;
– control is by means of a light-sensitive resistor in series with the antenna, and responsive to light from a lamp which is controlled by a transistor. The transistor conductivity is varied by adjustment of the sensitivity control at the operating position. The time constant of the lamp system is long enough to remove the effect of any hum or noise present on the remote control link; day to day variations are of no consequence because the operator adjusts the gain control according to the audible (or visual scan) conditions on the channel.

Light-sensitive resistors are especially suitable for this purpose as they have linear voltage/current characteristics. They are therefore not likely to cause intermodulation effects.

7. Remote testing of frequency and sensitivity

Three methods of remote testing which have been used are:

7.1 *Method 1*

A transmitter-receiver is installed at the radio service centre, which is equipped for other purposes with precise frequency measuring equipment.

After checking the radio frequency of this transmitter-receiver, a call is placed through the coast station to a telephone in the maintenance centre. The transmitter-receiver is modulated with a precise 1000 Hz tone, and the frequency of the audio received over the telephone pair is compared with that of the tone source. There are no carrier facilities in the circuit, so this measurement consitutes an accurate and reliable frequency check of the remote receiver, providing that a propagation path exists at the channel frequency being tested.

This arrangement is used for quick operating checks of the entire system (including a frequency check of the coast station transmitter by applying 1000 Hz to the telephone line and measuring the frequency of the audio output from the test receiver). Also, this facility is used for measuring the frequency of ships working into the coast station, by measuring the audio frequency of the re-transmitted signal, the ship sending a precise 1000 Hz tone as mentioned in Recommendation 477 (New Delhi, 1970).

7.2 *Method 2* (illustrated in Fig. 1)

There is often a more stable propagation path between the transmitter and receiver sites than that which exists between the transmitter site and the operating centre. Also, the receiver site is chosen for low electrical noise characteristics whereas the operating location is normally chosen without regard to the local noise.

It is therefore sometimes advantageous to locate at the receiving location, remotely controlled interrogation equipment to monitor emissions from the transmitter site. Fig. 1 includes this feature of the interrogation system.

A low power and very stable remotely controlled interrogation transmitter is located at the receiver site, coupled through an attenuator to the antenna multicoupler which feeds all the receivers.

A precise 1000 Hz tone is fed over a line from the radio service centre to modulate the interrogation transmitter, the level being set to produce a signal into the receiver of a value which does not activate the automatic gain control; the audio output is then proportional to the radio frequency input. The audio signal arriving at the radio service centre via the radio switchboard is then measured for frequency and amplitude, the attenuation of the telephone line being taken into account. Sensitivity is read from a calibrated graph which has been prepared for each receiver.

It is necessary to make the test at a time of day when atmospheric noise on the channel being tested is at a low level. It would be preferable to disconnect the antenna feed automatically from the receiver being tested, and replace it during the test with a feed from the interrogation transmitter, but this adds complexity and cost.

7.3 *Method 3* (illustrated in Fig. 2)

The signal generator is a remotely controlled low power transmitter at the remote receiving station, feeding a radio frequency signal to the antenna multicoupler through a remotely controlled variable attenuator.

The transmitter monitor is a remotely selected fixed gain receiver also located at the remote receiving station. The gain of this receiver is set to produce a reference level of audio output when the transmitter is operating at its rated output power and modulating fully. The signal for the monitor is picked up on a short vertical whip antenna. This minimizes reception of very high angle sky wave; the ground-wave signals from the transmitters, normally strong and stable over the distance involved, are used to indicate the transmitter performance.

7.3.1 *Remote functions*

Remote control is used so that tests may be carried out from either one of two central locations; normally routine periodic tests are made from a radio service centre, and on-demand tests from a location near the operating room.

The remote control unit has provisions for:

- turning the signal generator on and off;
- changing the signal generator frequency to the appropriate channel;
- setting the signal generator to the proper mode of emission;
- modulating the signal generator with a tone, or audio from a microphone;
- adjusting the remotely controlled attenuator;
- setting the transmitter monitor to the channel to be tested;
- access by means of jacks, to measure the level and frequency of the tones sent to and received from the signal generator and transmitter monitor.

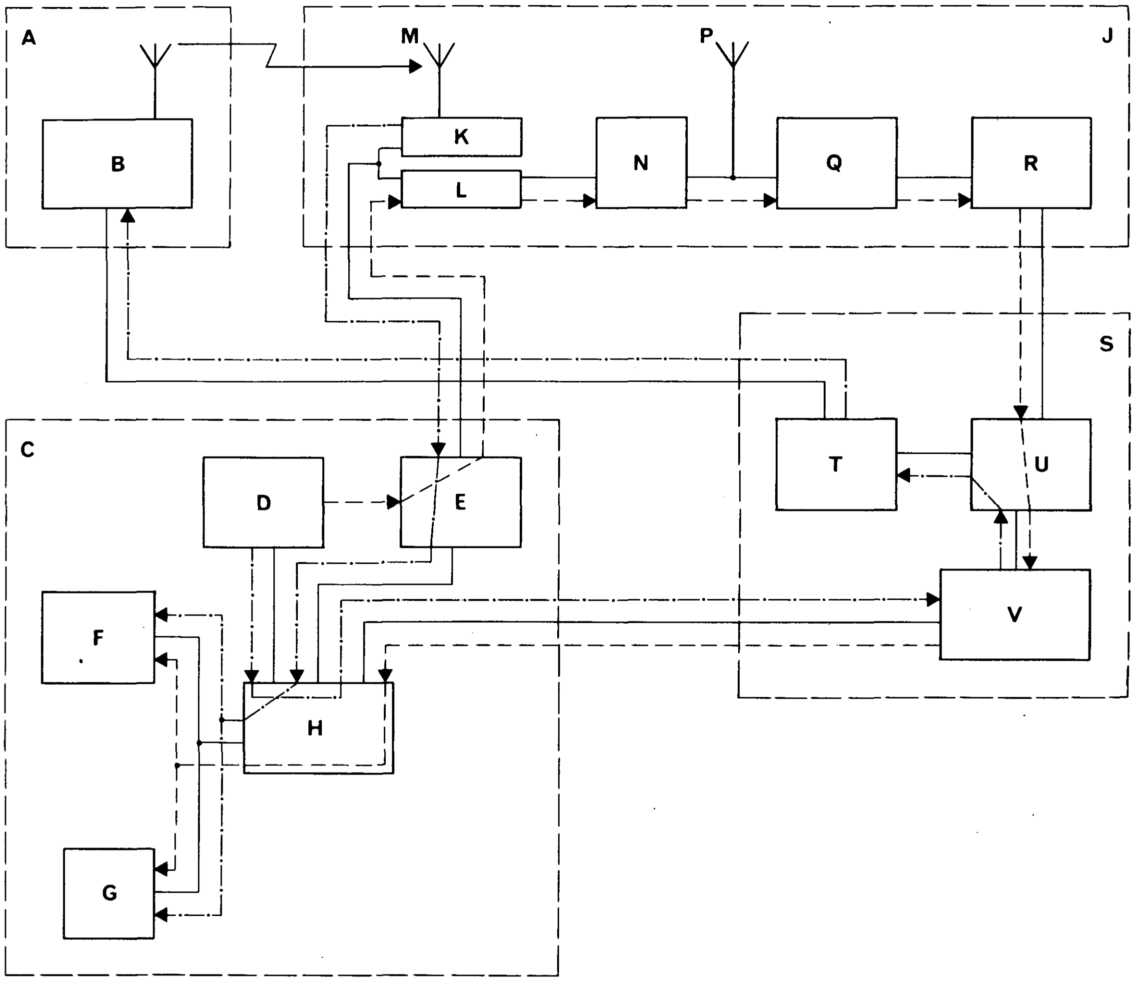


FIGURE 1 – *Method 2 – Test signal routes*
(Circuit layout schematic showing interrogation signal routes)

—·—·— Transmitter test
– – – – – – Receiver test

A: Transmitter site
B: Transmitter
C: Radio service centre
D: 1000 Hz tone generator
E: Remote control unit
F: Frequency counter
G: Audio voltmeter
H: Control panel
J: Receiving station
K: Receiver
L: Transmitter
M: Short vertical antenna (40 in or 1 m)
N: Attenuator
P: Station antenna
Q: Antenna multicoupler
R: Channel receiver
S: Operating room
T: Compressor amplifier
U: Hybrid
V: Switchboard

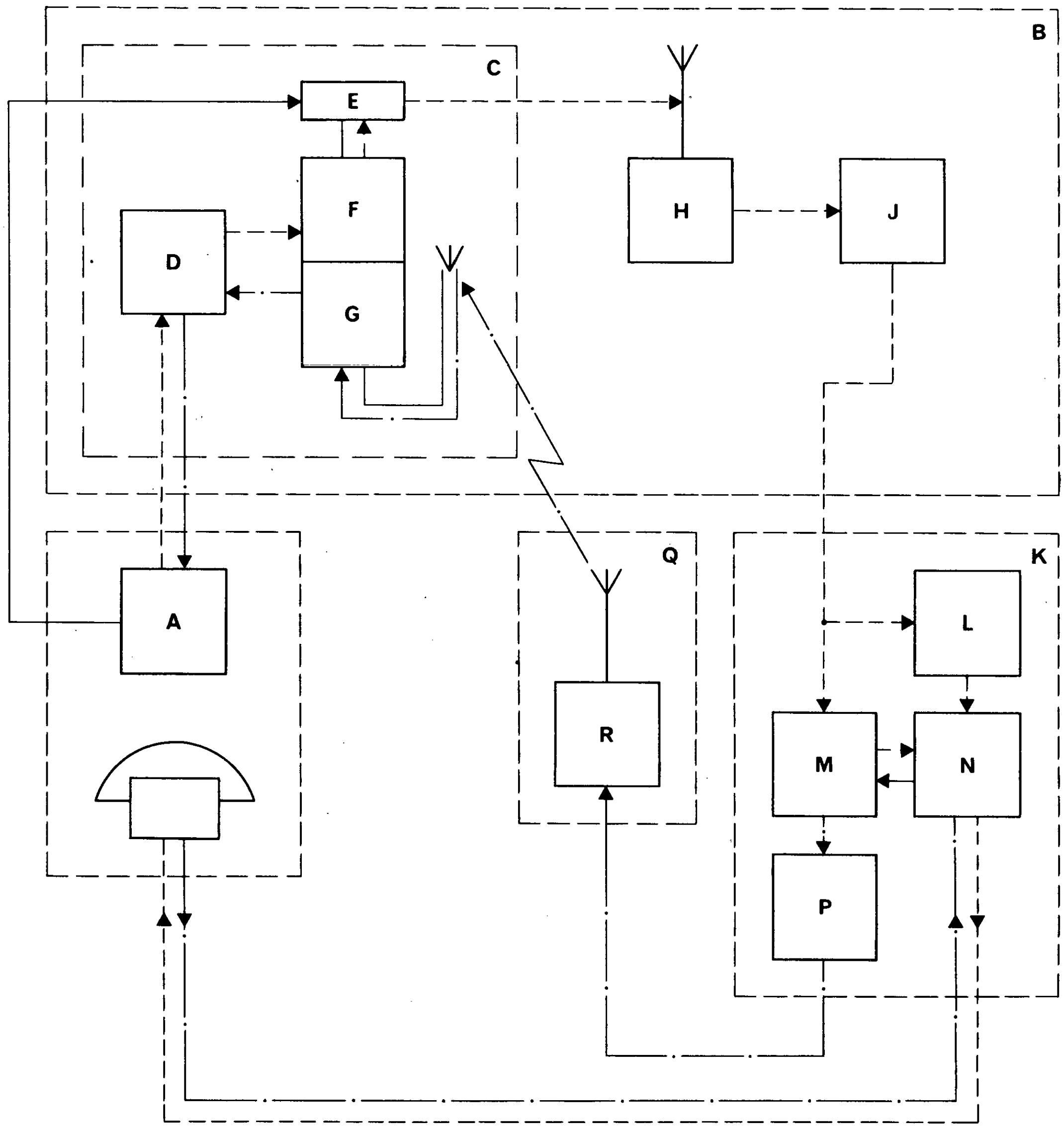


FIGURE 2 – *Method 3 – Test signal routes*

—·—·—·— Transmitter test

– – – – – – – Receiver test

A:	Remote control unit	K:	Operating room
B:	Receiver station	L:	Signalling system
C:	Interrogation system	M:	Hybrid
D:	Remote control unit	N:	Radio operator
E:	Attenuator	P:	Compressor amplifier
F:	Signal generator	Q:	Transmitter station
G:	Monitor receiver	R:	Transmitter
H:	Antenna multicoupler		
J:	Receiver		

7.3.2 *Receiver testing*

The routine receiver test consists of placing a call through the operator to a telephone in the radio service centre, and making the appropriate measurements by remotely adjusting the variable attenuator and observing the audio signal received over the telephone line.

A periodic measurement is made of the attenuation of the lines to the remote receiving site and very little variation is found to exist. In situations where line variation is likely to be a problem, a measurement of the amplitude of the output of the signal generator and the monitor could be relayed back to the service centre by means of analogue-digital converters, as integrated circuit chips for this purpose are now becoming available at reasonable cost.

It is convenient to locate the 1000 Hz source of tone at the service centre, as the outgoing and incoming tone can then be directly compared for frequency. A SINAD test coupled with analogue-digital converter read-out would remove the variable of possible changes in line attenuation.

Another advantage of applying the modulation from the service centre is that other tones can be applied (for example for a check of receiver passband) and at varying levels (for example for a check of AGC action).

7.4 *Comparison of the three methods*

Method 1 is simple and relatively inexpensive, but it depends on a propagation path existing between the two locations. When this path exists, and the landline facilities are such that no frequency error is introduced, radio frequency checks can be made using the equipment normally in use in the service centre for other purposes. But there are obvious limitations in the number of different characteristics that can be checked.

Methods 2 and 3 have the advantage that both frequency and sensitivity of receivers can be checked on one test. Provided the noise level on the channel under test is low at the time of the test, several other functions of the receivers can be tested remotely. The cost is much greater because of the special equipment necessary, the switching arrangements that have to be engineered, and the need for a dedicated line between the service centre(s) and the remote receiver site. Despite the addition of relatively complex monitoring and control equipment, use of Method 3 has resulted in a drastic reduction in the number of maintenance visits to the remote site.

ANNEX III

1. Introduction

At the Final Meeting 1981 Japan described the outline of new remotely controlled HF receiving systems for radiocommunication circuits in the fixed service and the maritime mobile service.

2. Outline of systems

The systems consist of 24 HF receivers and 9 remote control systems.

A circular antenna array is used to obtain many directional beams in this remotely controlled HF receiving station.

The circular antenna array is used for the fixed service and the maritime mobile service.

For the fixed service, a common control system is used as shown in Fig. 3 for up to 10 receivers. Three control systems have been applied for the time being to 18 receivers for the fixed service as follows.

System A	8 ISB receivers	(Telephony)
System B	4 dual-diversity FSK receivers with PIX adaptor	(Phototelegraphy)
System C	6 ISB receivers	(Telephony & Phototelegraphy)

For the maritime mobile service, one remote control position is required to control only one receiver at any one time, although it is necessary for any one of six operators to be able to control any one of six receivers. Six control positions have therefore been provided for six receivers, as shown in Fig. 4.

3. Antenna system

The circular antenna array consists of 36 horizontal log periodic antennas, 36 power dividers and 37 beam formers. This array is installed in a circular land space, and the diameter is 300 metres as shown in Fig. 5.

Each directional beam is formed by combining the outputs of 11 adjacent antennas, weighted by attenuators in amplitude, and phase-adjusted by delay lines, before combining them.

This array provides 36 directional beams with 10° spacing in azimuth, and omni-directional coverage.

The main specifications at 15 MHz are as follows.

Directional

Gain	18 dBi
Beamwidth	17° (−3 dB)

Omni-directional

Gain	7.5 dBi

The outputs of beam formers are fed into antenna multicouplers and supplied to antenna switchers controlled by a remote control system. Each selected beam is connected to a specific receiver.

For diversity reception, seven rhombic antennas are provided to be used in combination with the circular array.

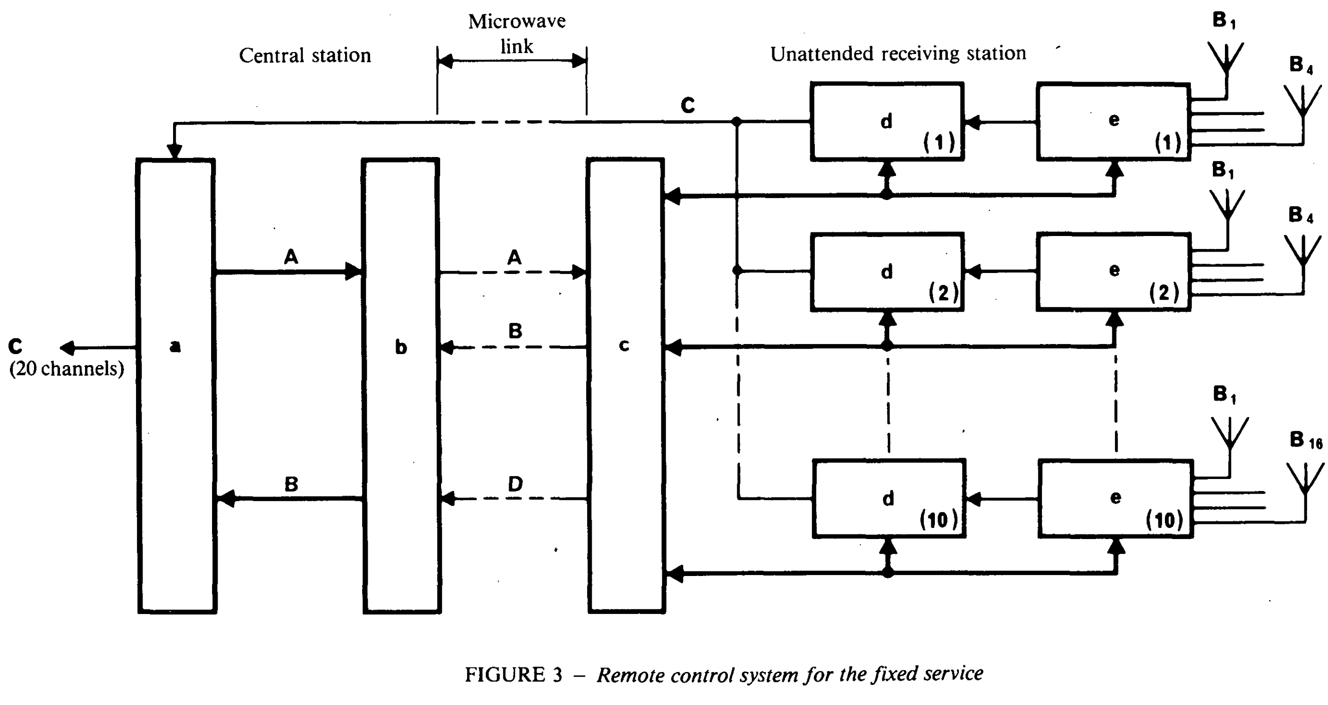


FIGURE 3 – *Remote control system for the fixed service*

a: Control rack
b: Control equipment for central station
c: Control equipment for receiving station
d: HF receiver
e: Antenna switcher (4:1 or 16:1)

A: Control signal, FSK 1200 bauds
B: Monitoring signal, FSK 1200 bauds
C: Output of receiver (Channel A and channel B)
D: Telemetering signals and carrier or IF signal
B_n: Beam number

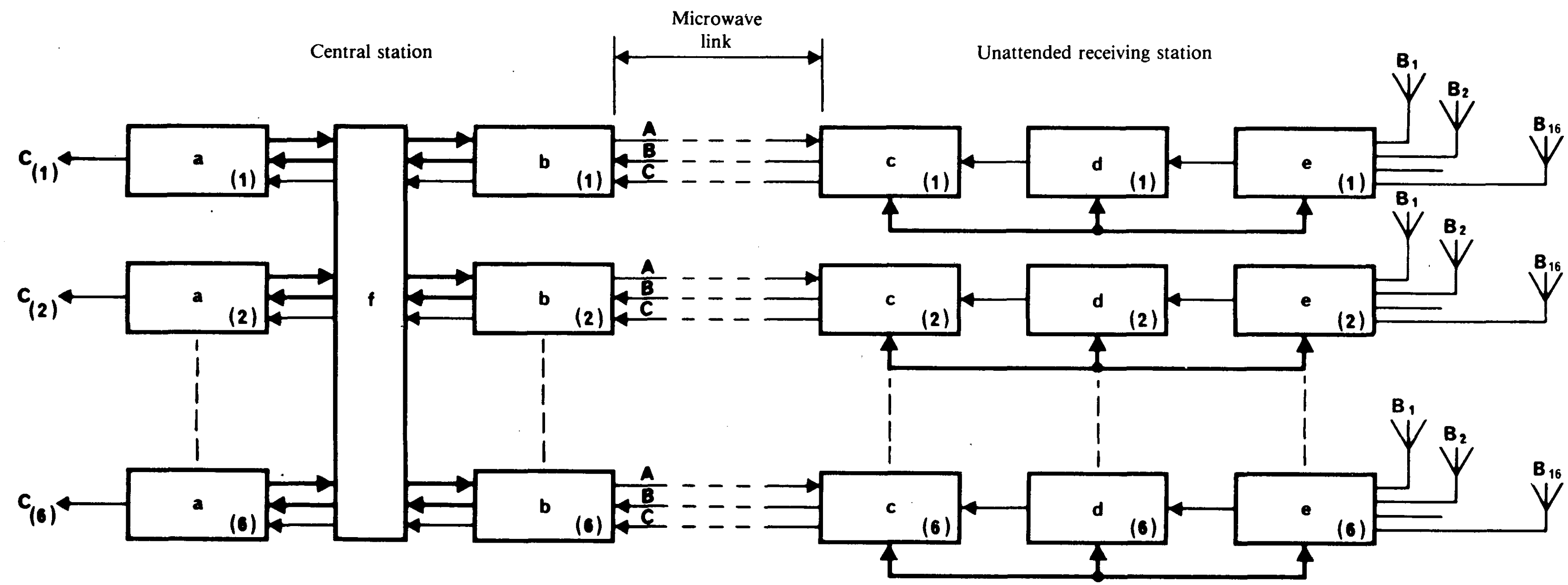


FIGURE 4 – *Remote control system for the maritime mobile service*

a: Control desk
b: Remote control equipment for central station
c: Remote control equipment for receiving station
d: HF receiver
e: Antenna switcher
f: Circuit selection switch

A: Control signal, 1200 bauds
B: Monitoring signal, 1200 bauds
C: Output of receiver
B_n: Beam number

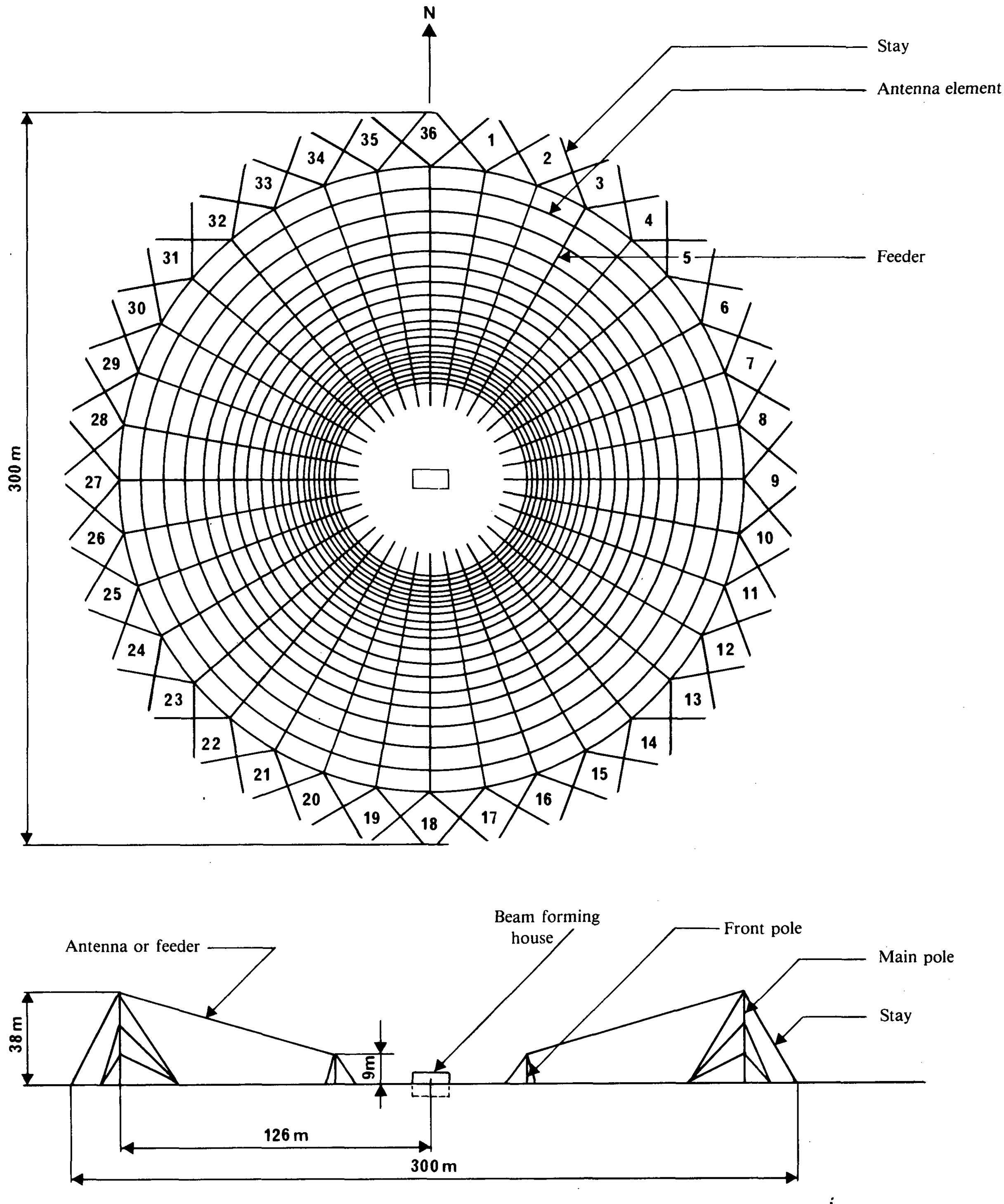


FIGURE 5 – *Circular antenna array*

4. Remote control system

4.1 *Fixed service*

4.1.1 *Outline*

Remote control is achieved by transmission of a code word consisting of 44 bits. The message is initially coded by using a sequence of 22 bits the polarity of which is then reversed, resulting in a word consisting of 44 bits. The word is preceded by a 44-bit phasing sequence as shown in Fig. 6. The received word is checked for error by comparing the normal and reversed portions of transmissions, and by parity bits in each portion.

Digital transmission at 1200 bauds is fast enough even for controlling the local oscillator of the receiver, where the shortest response time is required.

Operation of the control equipment is performed by a 1-bit processor with program stored in Read Only Memory.

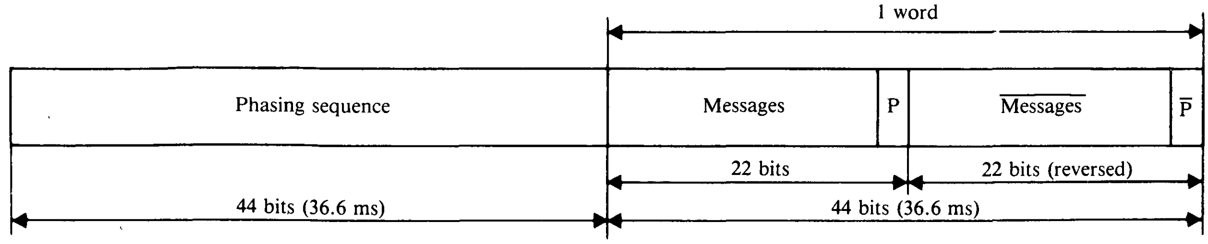


FIGURE 6 – *Word configuration of the remote control system for the fixed service*

4.1.2 *Functions*

The control and monitoring functions are shown in Tables II and III.

The ten-key switch and command key switches are used for selecting a receiver and an antenna beam and for setting a receiving frequency. The frequency and antenna are set by selecting a present number from 1 to 8.

In operation for the fixed service it is not necessary for the operator to monitor receiving conditions at all times, so the control panel is mounted in a control rack.

TABLE II – *Control functions for the fixed service*
(These items are also included in monitoring functions)

Functions	Facilities	Control positions
Receiver selection	1 to 10, and free	11
Power	On, off	2
Frequency setting	4 to 28 MHz in 100 Hz steps	24×10^4
Clarifier	Fast/slow, right/left	4
AFC	On, off	2
Receiving mode	DSB, ISB	2
IF bandwidth selection	Narrow, wide	2
Antenna selection	1 to 16	16
Alarm reset	On, off	2

TABLE III – *Monitoring functions for the fixed service other than those shown in Table II*

Functions	Facilities	Control positions
Alarm	ZCS or AFC, power	4
Local operation	Local, remote	2
Sound monitor	CH A, CH B, carrier, off (A side, B side, IF)	4
(AFC Gate)	(Open, close)	(2)
S meter	0 to 100 dB(μV)	A/D → D/A
Tuning indicator	± 100 Hz	
Tuning dial	± 1.5 kHz	

( ): only for the dual-space diversity FSK receivers.

4.2 *Maritime mobile service*

4.2.1 *Outline*

Remote control is achieved by the cyclic transmission of frames containing a 10-bit phasing sequence, and control messages as shown in Fig. 7. The message section is divided into 14 blocks each consisting of 4 information bits and one parity bit for detecting error at the receiving end.

Digital transmission at 1200 bauds is fast enough for operation in the maritime mobile service.

Since one remote control system controls only one receiver at any one time, simple control units are adequate.

4.2.2 *Functions*

The control and monitoring functions are shown in Tables IV and V, respectively.

Thirty push switches are used for selecting one of the thirty preset frequencies, and 16 push switches are provided on the control panel for antenna beam selection.

5. Conclusion

These remotely controlled HF receiving systems for the fixed and maritime mobile services have been proven in operation.

It has been demonstrated that the work load of operators has been reduced with the improvement of operational features, stability and reliability of these systems.

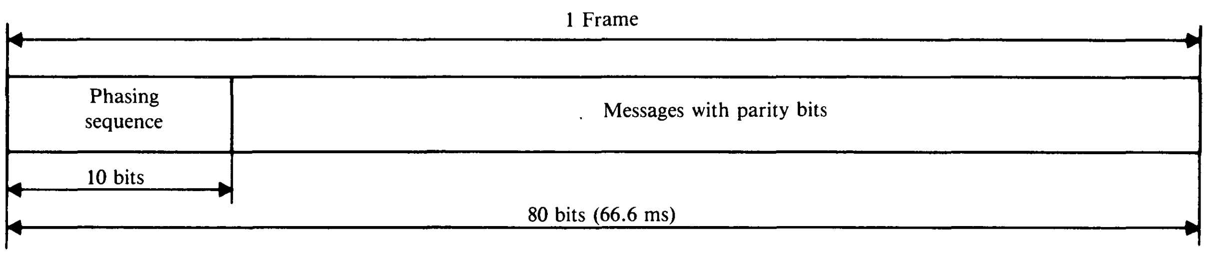


FIGURE 7 – *Frame configuration of the remote control system for the maritime mobile service*

TABLE IV – *Control functions for the maritime mobile service*
(These items are also included in monitoring functions)

Functions	Facilities	Control positions
AGC	Slow, fast	2
RF/IF gain	10 steps	10
RF Attenuator	On, off (20 dB)	2
Power	On, off	2
Frequency setting	4 to 28 MHz in 100 Hz steps	24×10^4
Clarifier	±300 Hz	2^9
Antenna selection	1 to 16	16

TABLE V – *Monitoring functions for the maritime mobile service other than those shown in Table IV*

Functions	Facilities	Control positions
Alarm	APC, power	4
Local control	Local, remote	2
S meter	0 to 100 dB(μV)	A/D → D/A

REPORT 858

REMOTELY CONTROLLED HF TRANSMITTING STATIONS

(Question 24/3)

(1982)

During the CCIR study period, 1978-1982, two administrations described HF transmitting stations for the fixed and maritime services, in which the transmission facilities are remotely controlled.

Annexes I and II show the outline of these systems.

ANNEX I

(ITALY)

1. Introduction

This Annex describes an HF transmitting station for point-to-point telecommunications, in which the transmission facilities are entirely controlled by a remote control console through a microwave link.

2. System layout

2.1 *Transmitting system*

The described remote operation system controls:

– 21 pre-tuned fixed-frequency transmitters, assigned to more frequent transmissions. These transmitters are arranged in groups of 3; of each group 2 transmitters can be operated simultaneously;
– 6 automatic self-tuning transmitters, available for less frequent transmissions and as spare transmitters for use during maintenance operations;
– 3 steerable antennas, operating with automatic transmitters, each covering the entire 360° azimuthal plane;
– 27 antennas, connected to the fixed-frequency transmitter groups by means of 3 × 2 matrixes at each group in such a way that each operating transmitter has a choice of one of two available antennas (ANT 1 or ANT 2) by remote switching.

2.2 *Remote control system*

2.2.1 *Basic requirements*

The remote control system of the transmitting station was designed to meet the following requirements:

– to enable remote operation of the transmission installation while maintaining station flexibility and with acceptable performance as compared to local control operation;
– to ensure that any delays introduced by the remote control and return verification are operationally acceptable;
– to maintain the possibility of locally controlling the transmitters for maintenance operations.

The above aims have been attained by performing the following remote controls:

Functions	*Facilities*
Transmitter remote control operation	Off/Stand-by/On
Transmitting mode	ISB/FSK
Carrier attenuation	0% 16% 100%
Frequency range (for automatic transmitters)	3.5 MHz to 28 MHz in steps of 100 Hz
Incident power measurement	Up to 30 kW ± 10%
Choice of antenna for the pre-tuned fixed frequency transmitters	ANT 1/ANT 2
Steerable antenna control operation	Azimuth 360°; counter-clockwise/clockwise rotation
Incorrect operation or alarm indication	Reset
Control	Remote/Local

Every state of the transmitting equipment is indicated by appropriate telesignals. Other kinds of telesignals are:

- Alarm due to no radio frequency signal at the transmitter output;
- Smoke alarm.

2.2.2 *The control system*

The basic diagram of the remote control system is shown in Figs. 1 and 2.

Modulation rates of sub-carriers are in accordance with CCITT Recommendation R.70 *bis* (Fascicle VII.1);

- 50 bauds for remote control and telesignals;
- 100 bauds for frequency synthesizer remote control of the automatic self-tuning transmitters;
- 200 bauds for telemetering.

2.2.2.1 *Remote control equipment*

The remote control message information is contained in a 12 bit code word having a constant ratio property of equal number of ones and zeros. The 12 bit code word is furthermore automatically repeated in inverted form for added error protection. Each control message is preceded by a start bit.

The received message is submitted to a threefold check of:

- the equal ratio property of the code word;
- the equal ratio property of the inverted code word;
- the complementary status of the first and second code words.

The above checks have to be all successful before the control information is passed to the appropriate transmitter remote control interface.

2.2.2.2 *Telesignalling equipment*

This is based on a cyclical system, at a scanning rate of 6 s per cycle.

The status of the incoming binary information is read (tested) by the transmitter through a sequential scanning operation. A correspondent 10-bit message, having odd parity, is forwarded to the receiver.

A synchronism word is inserted at the beginning of each cycle.

The receiver sequentially checks the various messages consisting of 10 bits and the output is accepted only after checking the parity status (presence of an odd number of ones) in the resulting word of the information group.

2.2.2.3 *Telemetering equipment*

This is based on a cyclical system with words consisting of 8 information bits plus 1 synchronism but plus 1 redundancy bit whose absence in reception bars the output. Moreover the cycle synchronization information is always provided at the beginning of the message.

The analogue power values and azimuthal position of an antenna to be transmitted are sampled at a continuous rate and converted into 10-bit frames. Since 8 bits are usable, 256 quantization levels will be obtained.

In reception, a digital/analogue conversion will give back the original analogue form to the power value or azimuthal angle of antenna.

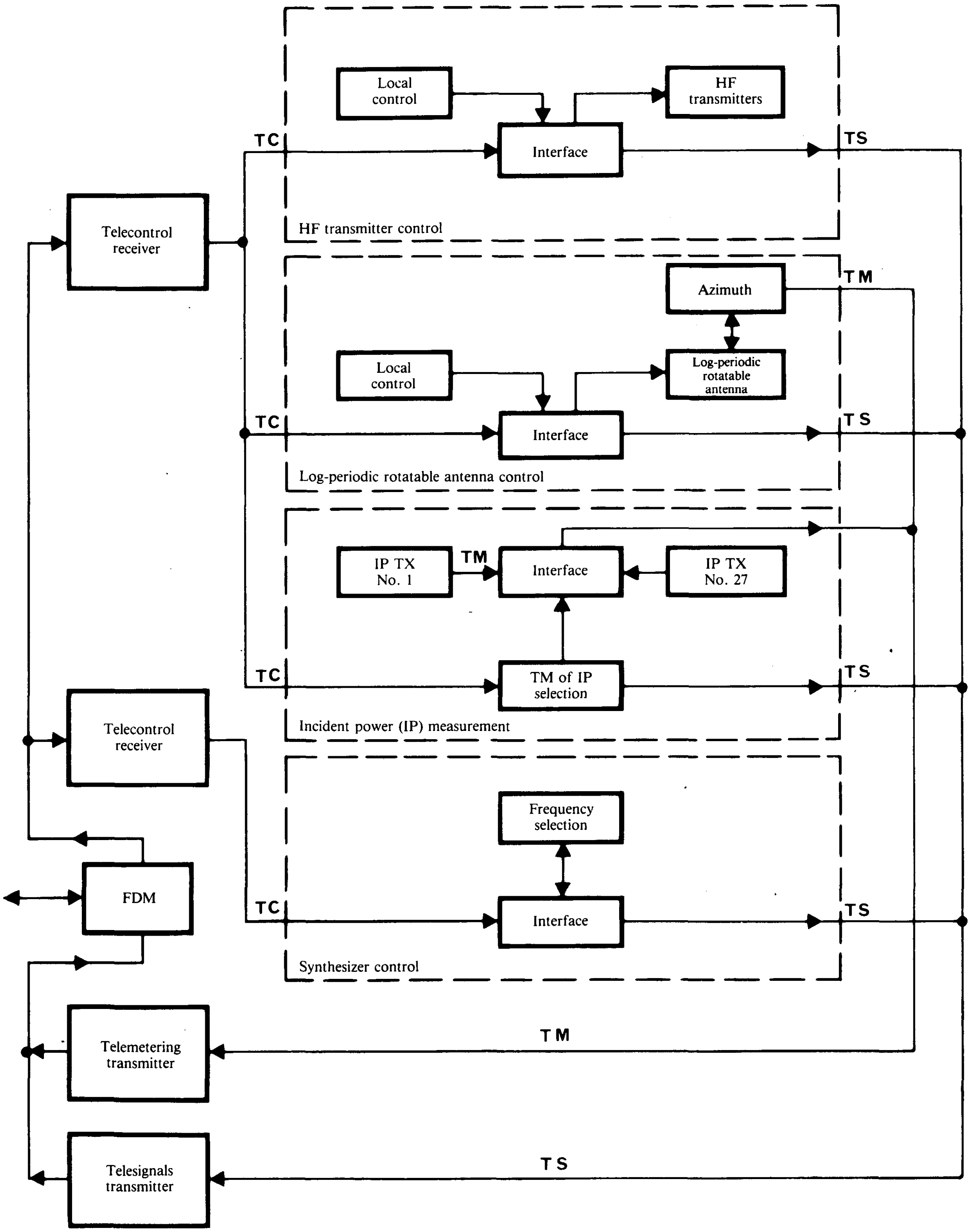


FIGURE 1 – *Radiotransmitting station*

TC: Telecontrol
TM: Telemetering
TS: Telesignals

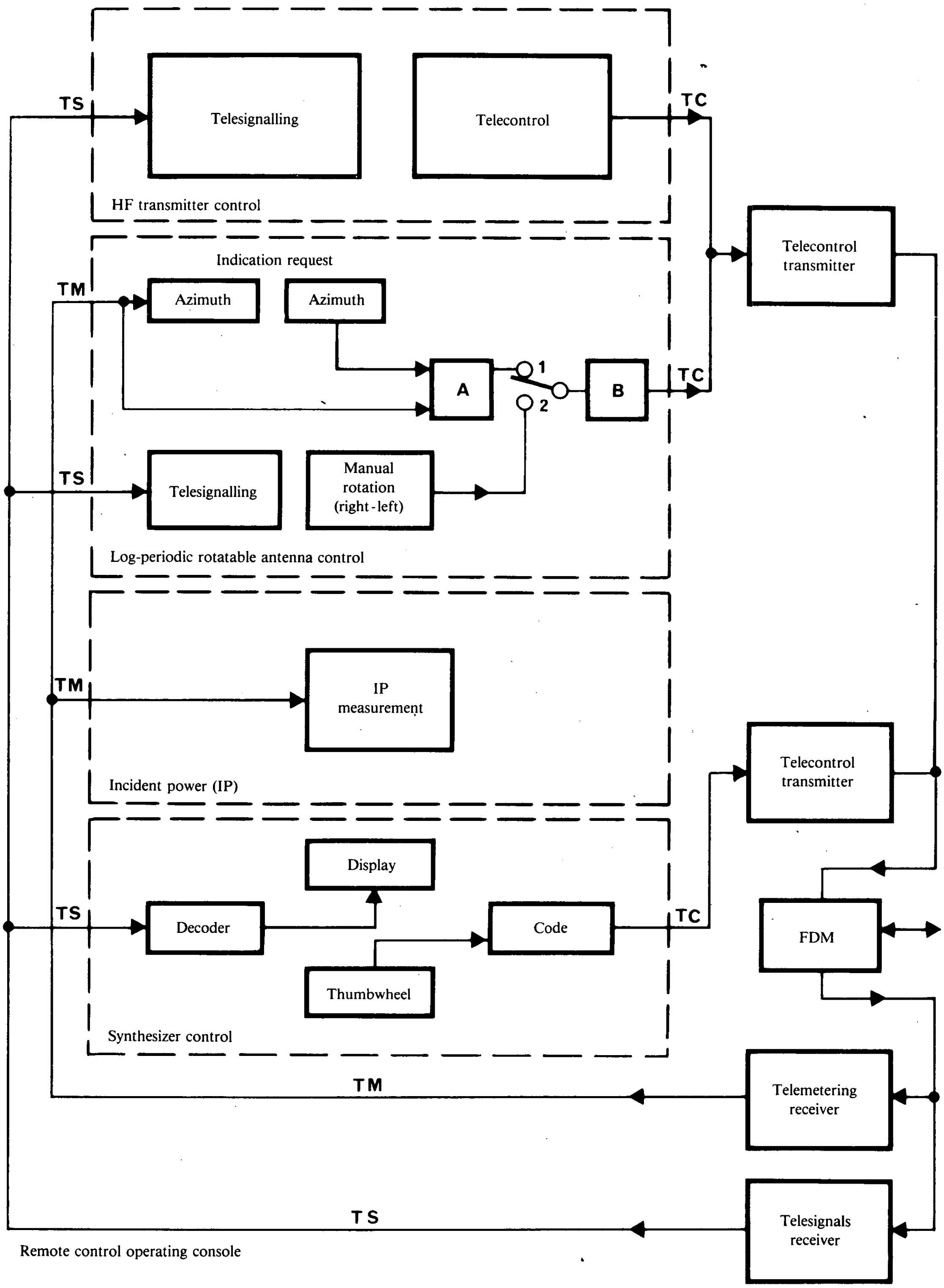


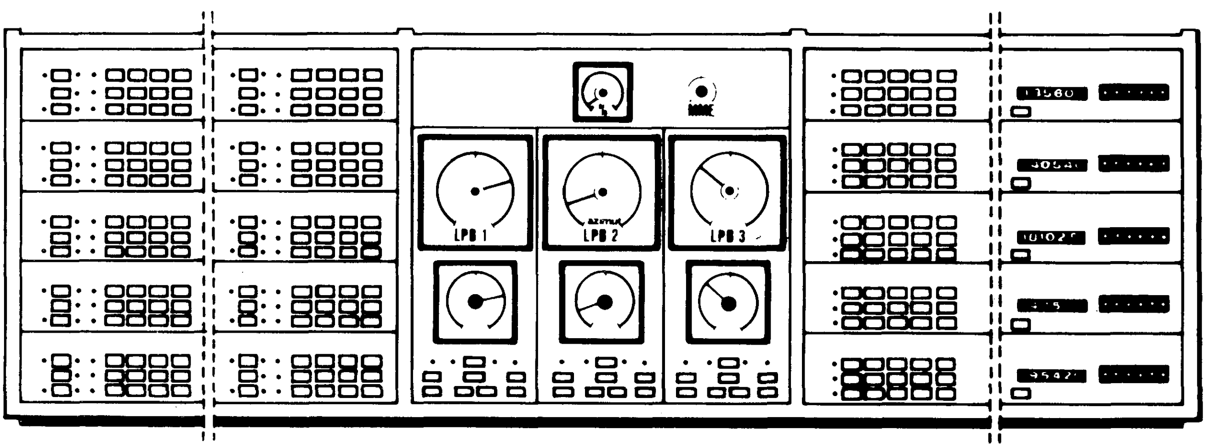
FIGURE 2 – *Operating centre*

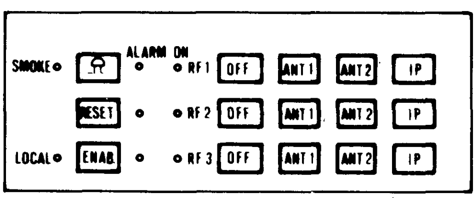
A: Voltage comparator
B: Rotator control
1. Automatic
2. Manual

TC: Telecontrol
TM: Telemetering
TS: Telesignals

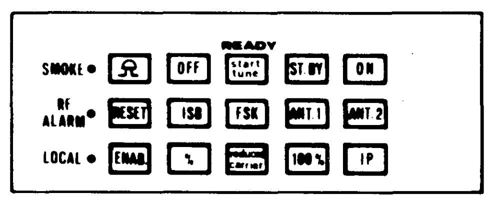
2.2.2.4 *Operating console* (See Fig. 3)

The operating centre console enables control and monitoring of the transmitters and display of all backward information from the transmitting station.

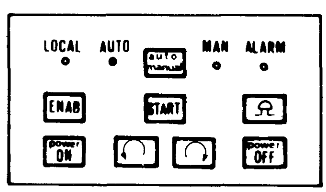




Channelized transmitter



Self tuning transmitter



Rotatable antenna

FIGURE 3 – *Operating console*

3. Operating experiences and conclusions

The high reliability of the remote control system has been clearly demonstrated in almost two years of operation.

This is due to the advanced technological level of the remote control system and to a maintenance policy aiming at maximum availability of the transmitting equipment.

The operating redundancy system is based on the use of automatic transmitters associated with steerable antennas, as hot stand-by reserve for the entire set of transmitters.

ANNEX II

(JAPAN)

1. Introduction

This Annex describes the remote control and supervisory system used in the LF, MF and HF bands. The systems are used at the coast station for HF maritime communication and at the station which broadcasts weather news for ships and standard time signals. The systems have shown satisfactory results in reliability and availability since they came into operation.

2. System outline

The main functions of the system are to control and supervise the unattended transmitting station from the system control station. It is composed of three subsystems, which are control/supervisory, channel switching and recording. Subsystems are connected with each other by data bus and operate as one system.

The configuration of the system is shown in Fig. 4, and the outline of each subsystem is as follows.

2.1 *Control and supervisory subsystem*

The system control station is able to control and supervise a maximum of five unattended transmitting stations.

It provides remote control functions, such as transmitter on/off, frequency and antenna selection, and selection of equipment for monitoring. It also has two kinds of telemetry functions. One is transmission of measured data and the other is continuous meter indication of the voltage and current of power supplies.

All signals are transmitted in digital form at 1200 bit/s for the control, alarm and telemetry signals, and in 200 bit/s for the voltage and current telemetry signals.

2.2 *Channel switching subsystem*

This subsystem has the function of channel monitoring and switching, and in case a working channel failure is detected, the channel can be switched over to the standby channel automatically.

In addition, manual operating functions such as "switch over", "reset", and "inhibit" are provided.

14 channels, 12 working and 2 standby, are switched.

2.3 *Recording subsystem*

This subsystem is able to record and compile all the data concerning equipment and channels, including the measurement of data.

Any changes of status in the transmitting station, such as equipment trouble and channel switching, are detected and printed out in order of occurrence. The recording control equipment has a memory unit, and data are stored in it temporarily, and compiled into up to five formats.

3. System characteristics

The characteristics of the system are:

- Large capacity for control, supervisory and other functions, as shown in Table 1.
- Scheduled transmitter on/off control facility.
- Graphical display of the status of channels.
- Transmitter output power/frequency measuring and recording function at a prearranged time by automatic scanning.

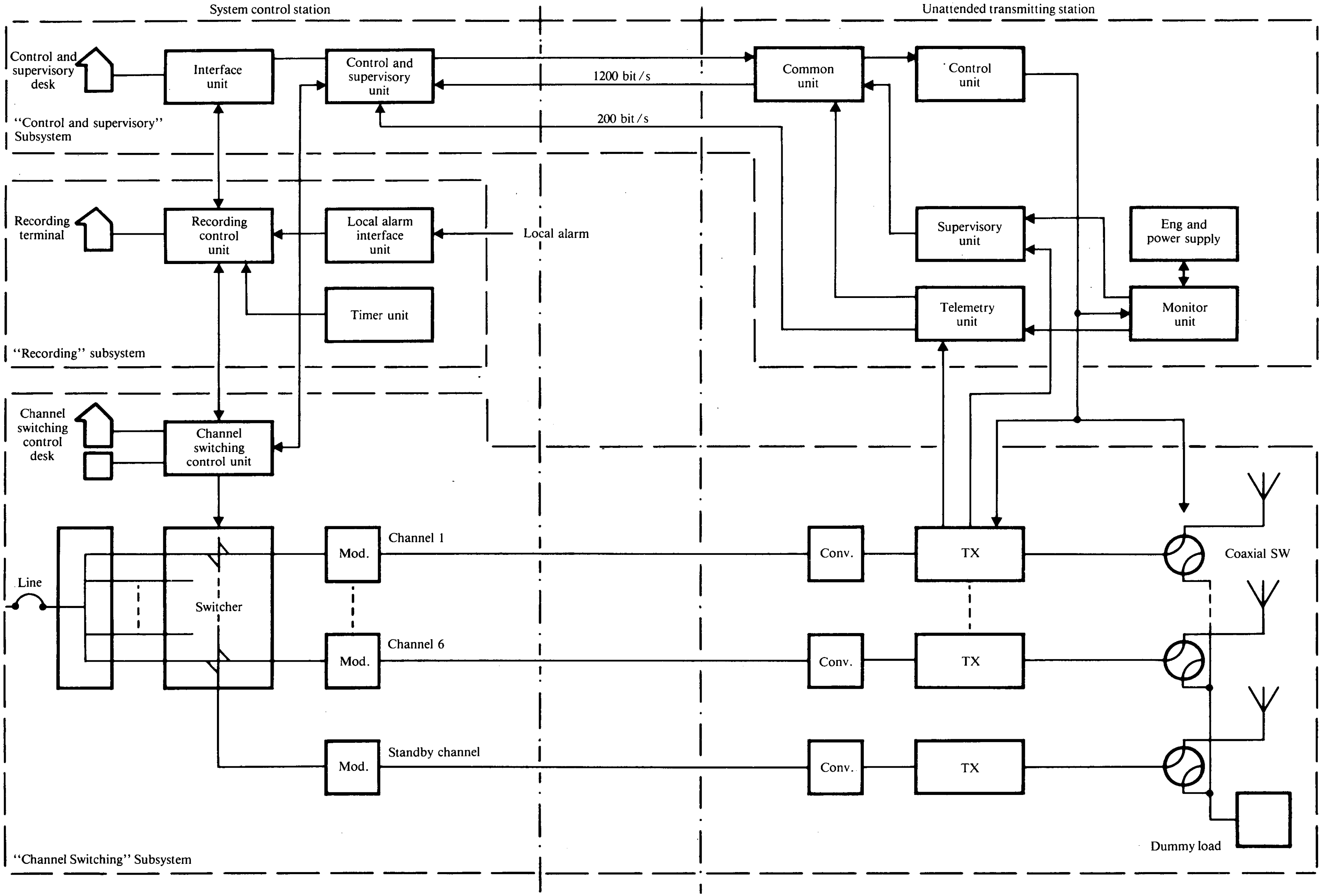


FIGURE 4 – *Configuration of the control and supervisory system*

TABLE I – *Capacity of system*

Functions	Items	Capacity.	Notes
Control and Supervisory	Supervisory	1200 items maximum	per station
	Control	960 items maximum	per station
	Telemetry (transmitter)	70 units maximum	
	Telemetry (voltage, current)	6 items maximum	
Channel Switching	Protection rate	12:2	Working channel: 12 Stand by channel: 2
	Channel groups	40 groups maximum	One group is made up of 7 channels
Recording	Memory	40 kbit maximum	

REPORT 705

COMPUTER-DIRECTED REMOTELY CONTROLLED HF RECEIVING STATION

(Question 24/3)

(1978)

1. Introduction

[CCIR, 1974-78] describes a remote controlled HF receiving station which serves all HF long distance point-to-point communications circuits. The station contains 27 HF receivers with the possibility of extending this number to 40 receivers and is fully controlled from a remote terminal control site via a microwave link.

Antenna selection, receiver selection and receiver functional control is affected by means of a Central Processor Unit (CPU) and Modular Input-Output Systems (MIOS) located at the receiving site. 1200 bit/s data modems connect the CPU with 3 Video Display Units (VDU) equipped with keyboard entry which are located at the remote control site. The CPU and MIOS are duplicated with automatic changeover in case of failures. Operational and functional status of the receivers, antenna's selected and auxiliary station information is displayed on the VDU. To make full use of the capabilities of the CPU, 300 routine-control programmes are included which can be selected either manually or automatically in accordance with a predetermined time-schedule. In addition, each receiver can be manually controlled via direct entry on the VDU keyboard. Overall performance of the radio receivers can be checked from the remote control site by means of a test-routine programme under CPU control.

2. System layout

2.1 *Receiving systems* (Fig. 1)

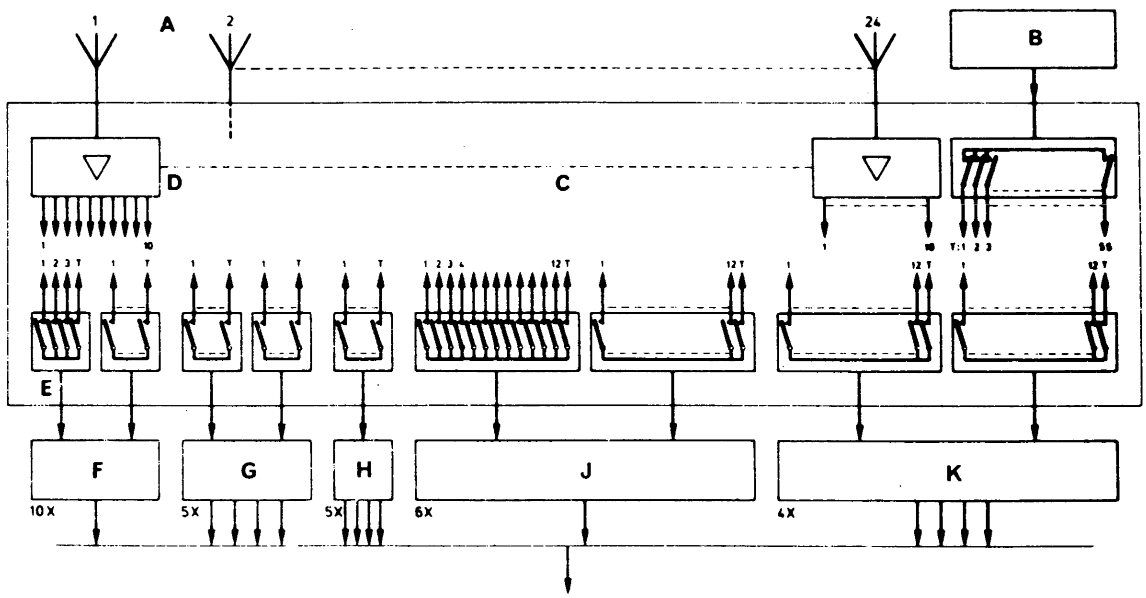
The signals coming from each antenna are distributed via active Antenna Multicoupler Units (MCU), each with ten outputs. Each receiver has its own Antenna Selector Unit (SLU). Primary receivers are dedicated to predetermined links and can select 1 out of 3 antennas. Spare receivers can select any one of all available (24) antennas.

The receiving system consists of the following groups (number between brackets indicates quantity of spare receivers)

–	10 + (2)	dual diversity FSK receivers	(F1B)
–	1 + (2)	dual diversity FSK receivers	(F1B/F7B)
–	5	non-diversity ISB receivers	(telephony)
–	3	dual diversity ISB receivers	(telegraphy)
–	(8/4)	single/dual diversity ISB receivers	(telephony/telegraphy)

Diversity selection for voice frequency multichannel telegraphy is performed in the terminal equipment.

In principle all functions which can be controlled and metered from the front panel can be performed also remotely and all controlled functions are signalled back to the remote control terminal. All functions, such as frequency shift, telegraph speed, IF bandwidth, pilot level, etc. are performed with reed relay switching. The ISB receivers have a built-in frequency search mode to bring the receiver within the AFC capture range.



Audio channels to terminal station (via microwave link)

FIGURE 1 – *HF receiving system 48 rhombic antennas offer 24 diversity outputs to the signal distribution system. This consists of antenna multicouplers (MCU) and antenna selectors (SLU), which distribute the antenna signals over the various receivers*

A: Antennas
B: Test signal generator
C: Signal distribution system
D: Antenna multicoupler units (MCU)
E: Antenna selector units (SLU)
F: FSK main receiver
G: ISB - dual main receiver
H: ISB single main receiver
J: FSK spare receiver
K: ISB - dual spare receiver

2.2 *Central Processor Unit (CPU) and Modular Input-Output System (MIOS)* (Fig. 2)

The output of the MIOS controls the different functions of the receiver. The receiver delivers to the input of the MIOS both digital and analogue information for back-signalling purposes via the CPU to the VDU.

The automatic change-over of the CPU and MIOS is controlled by internal test programmes in each CPU and between the CPU's. The spare CPU is used as hot-stand-by, so that normally all information is available in both CPU's simultaneously.

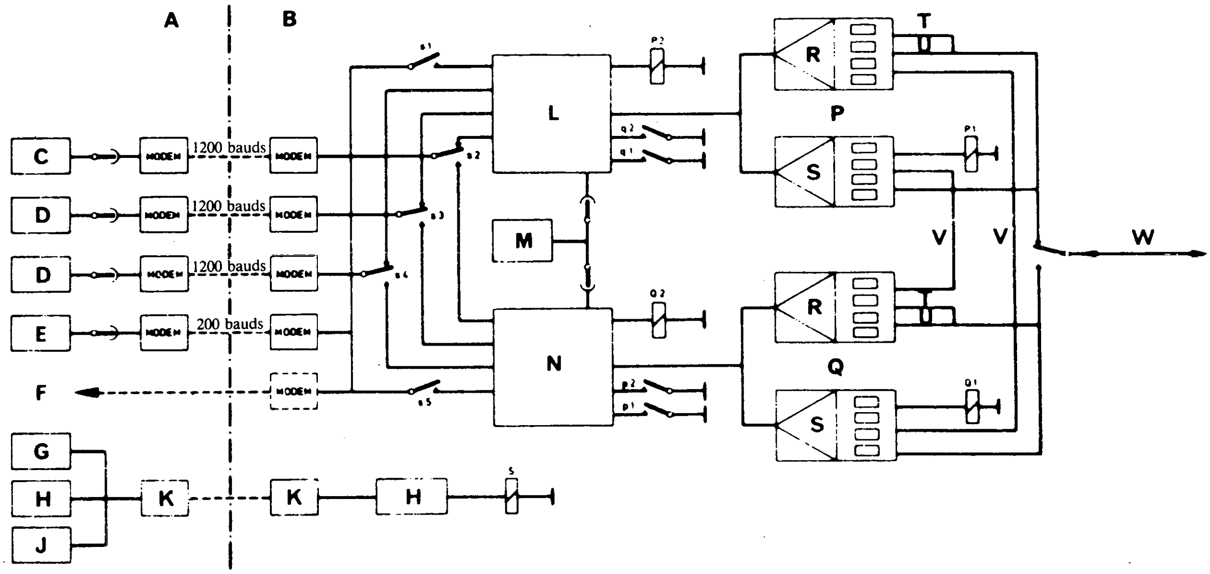


FIGURE 2 – *General unit configuration, consisting of one unit control and up to 19 group controls. Each group control can handle up to 16 modules with 16 channels per module*

A: Terminal station
B: Receiving station
C: Stand-by VDU
D: VDU
E: Hard-copy device
F: Monitoring computer
G: Alarm A
H: Manual switching
J: Alarm B
K: FDM
L: Central processor unit A
M: ASR teletype
N: Central processor unit B
P: MIOS A
Q: MIOS B
R: Input
S: Output
T: Analogue
U: Digital
V: Data link
W: To and from receiver

2.3 *Control units (Video Display Units)* (Fig. 3)

The video display units available in the terminal station are used to control the receivers and to display all the information arriving from the receiving station. The control procedure can be seen on the display layout (Fig. 3) typical for a group of ISB receivers. This information is automatically written on the VDU within 1.5 seconds. The lines direct under the heading (fixed data field) are used for telesignalling the status of the different receivers. The variable data field is on the last line and is used for manual control of a selected receiver. An explanation of the different abbreviations can be found in the same Fig. 3. To facilitate the work of the operator most of the routine procedures are present as software in the CPU. The operator types his instructions on the keyboard. The text appears on the screen and can be checked. By pressing the "transmit" key the information is sent to the CPU. After the message is accepted by the CPU the message content is returned to the VDU and displayed. After checking by the operator, the keys "execute" and "transmit" are pressed to execute the command. The new status of the receiver including the metered values are then displayed on the screen. In case of alarm condition, e.g. end of AFC range, too low S/N, etc. or failure in the CPU, an appropriate alarm message is printed on the screen together with the time. A hard copy device provides a permanent record of instructions, station logging and alarm messages.

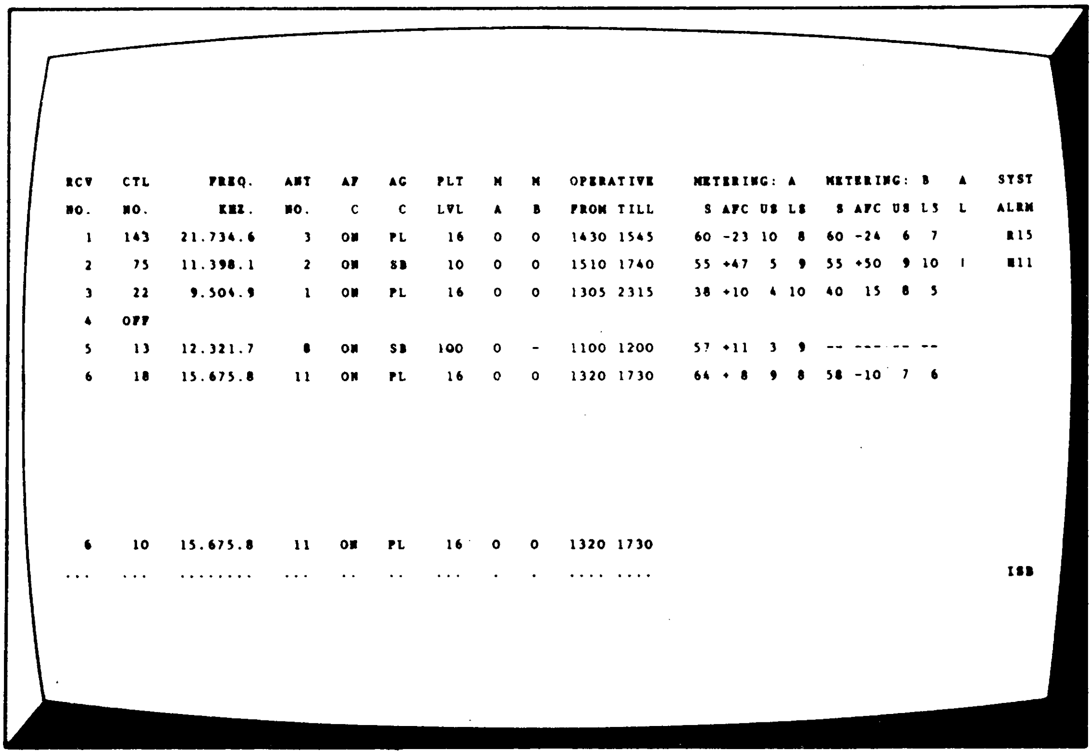


FIGURE 3 – *Screen layout of video display unit for ISB type of receivers*

Explanation of abbreviations:

heading	contents	description
RCV NO	8 EA DA	Receiver number 1 to 99 Enter automatic control Display automatic control
CTL NO	TST 193 D M OFF	Receiver under test Control number 1 to 300 Direct control Monitoring Receiver in off status
FREQ kHz	21 785.3	Antenna frequency 1600 to 28 000.0 kHz
ANT NO	2	Antenna number 1 to 12
AF C	ON OFF	Automatic frequency Control 'on' or 'off'
AG C	PL SB	Automatic gain control on pilot or side band
PLT LVL	5 10 16 100	Pilot carrier level in percentage

heading	contents	description
M A	+ – 0	Frequency deviation with manual frequency control of receiver A
M B		See M A
OPERATIVE FROM TILL	1430 1510	Time during which receiver is operative
METER-ING: A		Telemetering values of A
S	32	Signal strength dB (μ V)
AFC	+47	AFC position —50 to +50
US	5	USB output level 0 to 10 dBm
LS	9	LSB output level 0 to 10 dBm
METER-ING: B		See METERING A
A L	1	Common alarm for: end of AFC range; *S/N* ratio too high; synchronisation of synthesizer
SYST ALRM	R15 H4 RC3	System alarm for: receiver number; station household; remote control system

2.4 *Monitoring*

The VDU is also used for monitoring the panel meter readings of the receivers. In addition the audio frequency output of ISB receivers and the IF output of FSK receivers can be displayed on an oscilloscope via a separate voice frequency channel in the microwave link. Together with information obtained from different terminal equipment such as ARQ, Lincompex, etc., the complete circuit can thus be continuously supervised.

2.5 *Conclusions*

The operational reliability of the radio-receiving station is very high and the service quality significantly superior to the old one.

The high rate of updating of the VDU for the control parameters, e.g. signal-strength, automatic frequency control (CAF), output levels etc., provides for improved operational efficiency.

Operational cost has decreased because the receiving station is unattended and no additional technical staff is required at the remote control terminal.

REFERENCES

CCIR Documents

[1974-78]: 3/21 (Italy).

REPORT 859

FREQUENCY SHARING BETWEEN SERVICES BELOW 30 MHz

(Question 32/3)

(1982)

1. Introduction

The World Administrative Radio Conference, Geneva, 1979 (WARC-79) allocated several frequency bands below 30 MHz to the fixed and other services on a shared basis. Question 32/3 was adopted by CCIR Study Group 3 at its Interim Meeting, 20-29 October 1980. This Report identifies the diverse factors that must be taken into account when studying frequency sharing between the fixed and other services below about 30 MHz.

2. Factors involved

The basic factors to be taken into account when preparing studies relating to sharing between the fixed and other services at frequencies below about 30 MHz include: radiated power, type and bandwidth of emission, antenna characteristics, link configuration, path length variability, circuit usage and circuit predictability. A comparison of these factors is contained in Report 911. Preliminary comparison of the factors to be studied indicates that frequency sharing between the fixed and other services may, in certain circumstances, be feasible. Sharing is based, in part, on the concept of maximum flexibility of other services, such as the mobile service, to select frequencies which are usable. A preliminary technical assessment of fixed and mobile service sharing frequencies, including some of the factors to be studied, is contained in Report 658.

3. Conclusions

3.1 Sharing could be initiated on a provisional basis. Data for use in further analysis should be collected as far as practicable for all cases of shared frequencies below 30 MHz between the fixed service and other services.

3.2 Further analysis on a case-by-case basis is required in order to develop sharing criteria between the fixed service and other services using the band below about 30 MHz.

REPORT 860

CRITERIA TO BE USED IN DIFFERENTIATING BETWEEN CLASSES OF OPERATION

(Question 33/3)

(1982)

1. Introduction

Interim Working Party 3/2 was established shortly after the Interim Meeting of Study Group 3 to respond to Question 33/3 which was drafted at that meeting.

The terms of reference were to determine:

(1) the criteria that should be taken into account in differentiating between classes of operation A and B;

(2) the protection ratios and other technical parameters that are required for these classes of operation, taking into account the work of IWP 3/1,

This Report is for information only and further study is required. *

2. Review of the work

In the period leading up to the Study Group Final Meeting there were no contributions to the work other than a number of introductory and information documents prepared by the Chairman. During the period of the Final Meeting three meetings were held which were attended by the majority of delegates participating in the working groups of Study Group 3, in addition to the established membership.

The first meeting resulted in agreement to the response to be made to the first term of reference. The second meeting resulted in four proposals for dealing with the second term of reference. The third meeting, convened as a working group in order to enable more effective discussion, resulted in agreement of a response to the second term of reference reflecting the four proposals.

3. Response to the first term of reference

This was interpreted as meaning 'what are the fundamental differences between the classes of operation'. The other interpretation 'that relative parameters should be identified' is covered in the consideration of the second term of reference.

The conclusion was that the criteria to be taken into account in differentiating between classes of operation A and B was provided in the Final Acts of the WARC-79 under 1222 of the Radio Regulations. The criteria are defined as:

Class A: Assignment for regular operational use which is not provided by another satisfactory means of telecommunication.

Class B: Assignment for use as a standby to some other means of telecommunication.

4. Considerations for second term of reference

Note. – In these considerations the term 'notification' refers to a Notice of Assignment which is undergoing technical examination according to the provisions of the Radio Regulations, and the term 'registration' refers to any entry in the IFRB Master Register which has to be afforded protection against that Notice.

There are three factors in a protection ratio:

Firstly, a ratio of wanted-to-unwanted signal levels under steady-state (non-fading) conditions which will allow the wanted signal to achieve the desired grade of service. Recommendation 240 which is under study by IWP 3/1 is the source of this information in Study Group 3. There is a general lack of information in this area and it is noted that IWP 3/1 has proposed a programme for obtaining data. One approach to deriving values, is to estimate the effect of the unwanted signal on the characteristics of the noise on which the required signal-to-noise ratio is based. The latter are given in Recommendation 339 and noise data is given in Report 322, published separately.

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* Study Group 6 is requested to pursue further study on this matter.

Secondly, a fading allowance to guard against instant-to-instant variations of the signal levels about their hourly median values. Information on this factor is given in the Notes of Recommendation 339 and details of the statistics involved are in Report 266. This allowance varies according to the type and grade of service. For telegraphy it can be derived from the allowable element error rate, for example : less than 1 per 1000 errors corresponds to 99.9% protection. For telephony the values might be derived from the required articulation index, (see Report 526), the normal range of protection being 80 to 95%.

Thirdly, an intensity fluctuation factor to guard against day-to-day variations of signal levels about the monthly medians of their hourly medians. Information on this factor is given in Report 252-2 + supplement (published separately). It has the same value for all types and grades of service. A difficulty is that correlation between the day-to-day variations of two signal levels at a common reception site varies considerably and consequently so does the standard deviation of the associated distribution. The 90% value, the protection generally applied, ranges from 0 to 14 dB and a compromise has to be chosen. A value of 7 dB has been found to give satisfactory results. Fading allowance and intensity fluctuation factor are taken to have the same value for all months and years mainly because the number of calculations, even by computer, becomes prohibitive and in any case the accuracy of the data and the compromises involved are such that a limited improvement would be obtained.

With the introduction of Classes of Operation there are four operational situations which can arise:

TABLE I

Case No.	Notification Class	Registration Class
1	A	A
2	A	B
3	B	A
4	B	B

Clearly for case 1 any currently used protection ratios which have been proven in practice should be applied.

For case 2 the notification will be active whenever the registration is active and therefore it will require the same protection as an A since it is effectively class A when in use. However we note that the Radio Regulations dictate that protection for class B shall be less than class A so an insignificant reduction of class A protection by 1 dB can be used.

For case 3 the registration will be active whenever the notification is active and thus treatment will be the same as case 1.

For case 4, whenever the registration is active the notification may or may not be active and this effectively modifies the statistics of day-to-day variations of signal level and hence the intensity fluctuation factor. The probability of the notification being active, on an annual basis, should not be greater than 0.5 and could be down to about 0.1. Applying protection for 50% of the days (i.e. 0 dB) the effect would be:

For probability 0.1, protection at least 90% tending to 95%
For probability 0.2, protection at least 80% tending to 90%
For probability 0.3, protection at least 70% tending to 85%
For probability 0.4, protection at least 60% tending to 80%
For probability 0.5, protection at least 50% tending to 75%

The lower figure arises because the period in question may be too short for the statistical distribution of signal levels to be the same as the annual distribution. The higher figure is when the annual distribution is valid.

An intensity fluctuation factor of 0 dB would, so far as can be estimated at present, give 90% protection for the case 4 situation.

5. Response to second term of reference

Summary of the above considerations in a form suitable for algorithmic determination of X, where X is the amount by which the protection to be afforded is reduced and F is the intensity fluctuation factor results in:

if registration is A then X = 0

else

if notification is B then X = F

else

X = 1.

Noting that the examination procedure has different values for F for favourable and qualified favourable findings it is confirmed that the above can be applied for any value of F.

6. Other conclusions

The IWP concluded that further studies and reports of operational experience were required before a Recommendation could be made and therefore definitive advice could not, at this time, be provided.

REPORT 861

PROTECTION OF RADIO STATIONS AGAINST LIGHTNING AND OTHER ELECTROMAGNETIC DISTURBANCES

(Question 31/3)

(1982)

1. Introduction

The general theory of lightning discharge is set out in Chapters 1 to 3 of the CCITT manual on the protection of telecommunication lines and equipment against lightning discharges (ITU, 1974). Chapter 7 of the manual includes statistical data on the frequency of earth flashes based on a special extensive study made by the World Meteorological Organization at the request of the ITU.

Radiocommunication systems may be affected by lightning discharge at a number of points in an installation, e.g.:

- antennas, since they are generally outdoors and may be of considerable height above ground level;
- cables, feeding from antennas to multi-couplers, transmitters and receivers, where the dielectric strength may be exceeded.
- the active input and output devices of receivers, transmitters and antenna multi-couplers, may well be semi-conductor devices with a relatively low dielectric strength.

Surges induced by lightning, occurring in uninsulated overhead wires, can be summarized as being less than 50 kV in peak value, less than 1 μs in wave front duration, les than 2 kV/μs in wave front steepness and less than 150 A in current flowing in lightning arresters. These values represent 90% of the observed values.

Special precautions may also be necessary to protect personnel from danger due to lightning. In particular in high danger areas provision of an earth connection is recommended and arrangements should be made to dissipate electrical charges to it. These arrangements may consist, for example, of a suitable choice of material of appropriate dielectric strength or the use of lightning protectors with the interconnection of all the earth electrodes (electricity mains, radiocommunication system, water pipes, etc.).

2. Receiving stations

The surge voltage applied to semi-conducor devices, commonly used as the active components in antenna multi-couplers and the signal frequency stages of receivers, should be reduced to as low a level as is practicable because of the lower dielectric strength of these components.

Systems designed to achieve this aim are described in Annex I and Annex II.

3. Transmitting stations

Lightning induced surge voltages on antennas and transmission lines can cause additional problems for transmitter systems.

It has been found that damage to transmitters is rarely the direct result of lightning discharges themselves. The damage is usually caused by ionization of the air in the spark gap protectors (initially caused by the lightning discharge) being maintained by the transmitter output r.f. power. This can result in a severe mismatch of the transmitter output circuits and consequent damage.

Examples of systems for transmitter lightning protection are shown in Annex III and Annex IV.

ANNEX I

LIGHTNING PROTECTION FOR RECEIVING SYSTEMS IN JAPAN

1. Introduction

This Annex gives both a method for, and test results of, a lightning protection system for HF receiving stations. Fig. 1 shows the characteristics of the waveform used for the tests. This was defined by the IEE (Institute of Electrical Engineers) in Japan as representing a typical voltage surge induced by lightning in a communication cable.

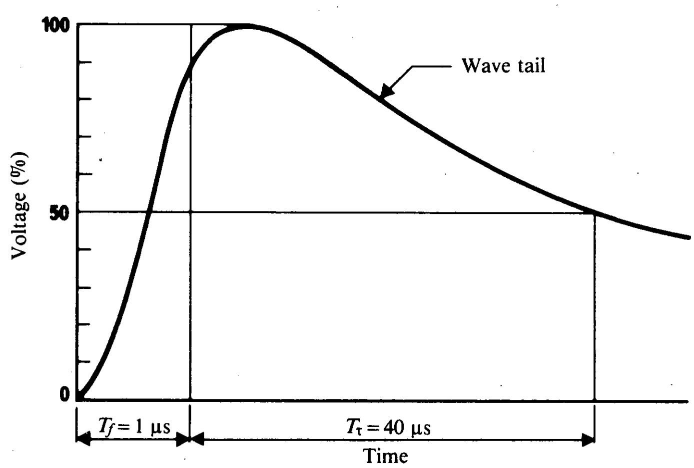


FIGURE 1 – *Characteristics of test waveform*

T_f: wave front duration
T_t: wave tail duration

Figure 2 shows the HF receiving system. Lightning protection was installed for both outdoor and indoor sections of the receiving station.

2. Lightning protection system

2.1 *Outdoor section*

In the outdoor section, an air-gap lightning arrester (see Fig. 3) was installed to discharge the lightning energy. Sometimes, the air-gaps g_1 and g_2 may have different discharge voltages and discharge times. Therefore, it may be assumed that different impulse voltages will appear at L_1 and L_2. It follows that the air-gap lightning arrester (called the primary lightning arrester) should have equal and stable discharge characteristics in the two gaps.

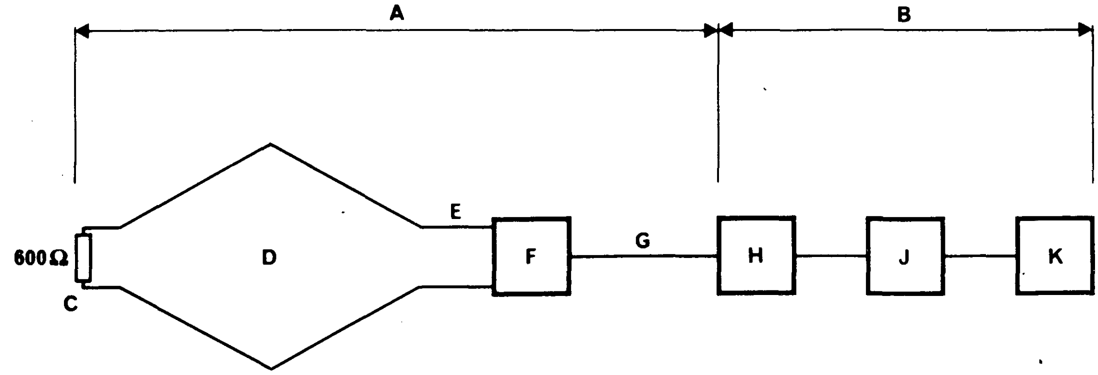


FIGURE 2 – *Schematic diagram of receiving system*

A: outdoor section
B: indoor section
C: terminating resistance
D: antenna
E: parallel 2-wire feeder
F: matching unit
G: 75 Ω coaxial cable
H: high-pass filter
J: multi-coupler
K: receiver

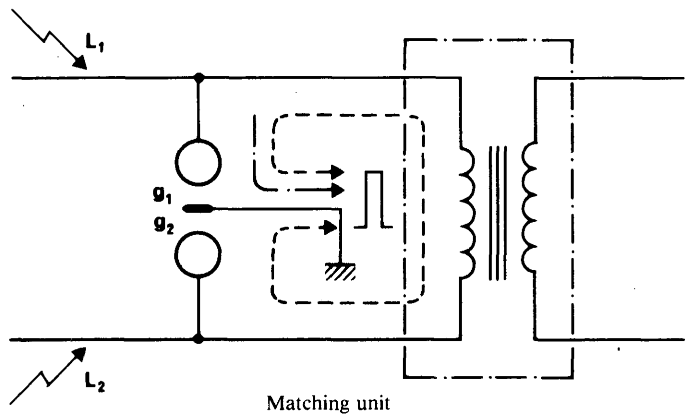


FIGURE 3 – *Operation of an air-gap lightning arrester*

Even when the primary lightning arrester operates, a surge voltage will appear between L_1 and L_2. In these cases, a gas-filled lightning tube (called the secondary lighting arrester) should be installed to suppress this voltage. The characteristics of primary and secondary arresters are shown in Fig. 4.

The outdoor section was tested with an impulse waveform as indicated in Fig. 1. The voltage which remained at the output of the matching unit was about 50 V peak. However, this value is still far too high as compared with the break-down voltage of semi-conductors in the multi-coupler. Further protection must therefore be provided in the indoor section.

2.2 *Indoor section*

In the indoor section a high-pass filter with a cut-off frequency of approximately 3 MHz was installed to improve the intermodulation characteristic of the multi-coupler. This high-pass filter also blocks a lightning surge as the major components in the spectrum of the lightning surge are less than 10 kHz.

When tested with the high-pass filter installed, the voltage at the output of the filter was reduced to approximately one-third of the input voltage. Satisfactory results could not be achieved by this high-pass filter alone, however, and a diode surge protection circuit was inserted in the output side of the high-pass filter.

3. Resistance to earth

The resistance between the lightning arrester and earth should be minimized to obtain effective protection against lightning for semi-conductor circuits. Assuming the peak value of a lightning surge appearing on an antenna to be 100 kV, the resistance to earth which satisfied the conditions for complete protection of the matching unit, coaxial cable, and multi-coupler was calculated for the severest conditions (when only one gap of the primary lightning arrester operates while the other gap fails). This calculation shows that the resistance to earth should be less than 13 ohms.

After testing a few practical methods, the one shown in Fig. 6 was finally employed.

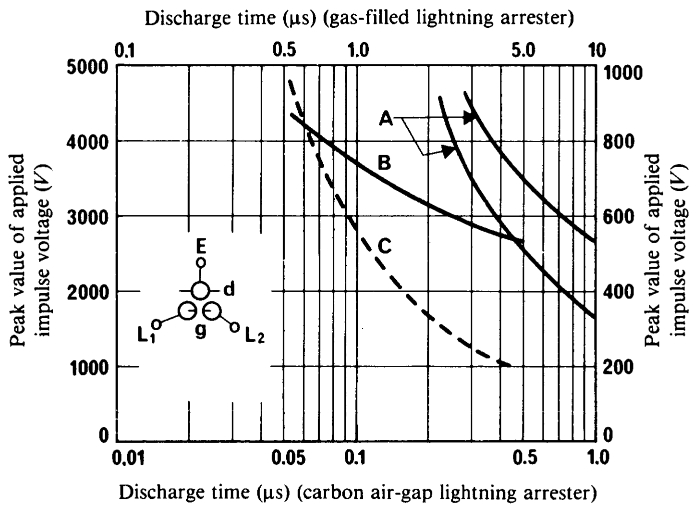


FIGURE 4 – *V(t) curves of primary (carbon air-gap) and secondary (gas-filled) lightning arresters. The discharge start voltages of the primary and secondary lightning arresters are 1100 V ± 200 V and 75 V ± 10 V, respectively*

d = 15 mm
g = 0.4 mm
A: carbon air-gap lightning arrester
B: discharge time difference
C: gas-filled lightning arrester

4. Protection system

Based on the foregoing considerations, the circuit configuration shown in Fig. 5 was produced, on a trial basis, for protection of a semi-conductor multi-coupler.

In this circuit, coils were inserted in the outdoor lightning arrester to improve the impedance characteristics. The overall VSWR of the lightning arrester system is less than 1.3 from 4 to 28 MHz referenced to 75 ohms. As voltage is likely to be induced in the coaxial cable when lightning strikes close by, a compact gas-filled lightning tube was installed in the indoor lightning arrester. Its characteristics are nearly the same as those of the gas-filled tube used in the outdoor section.

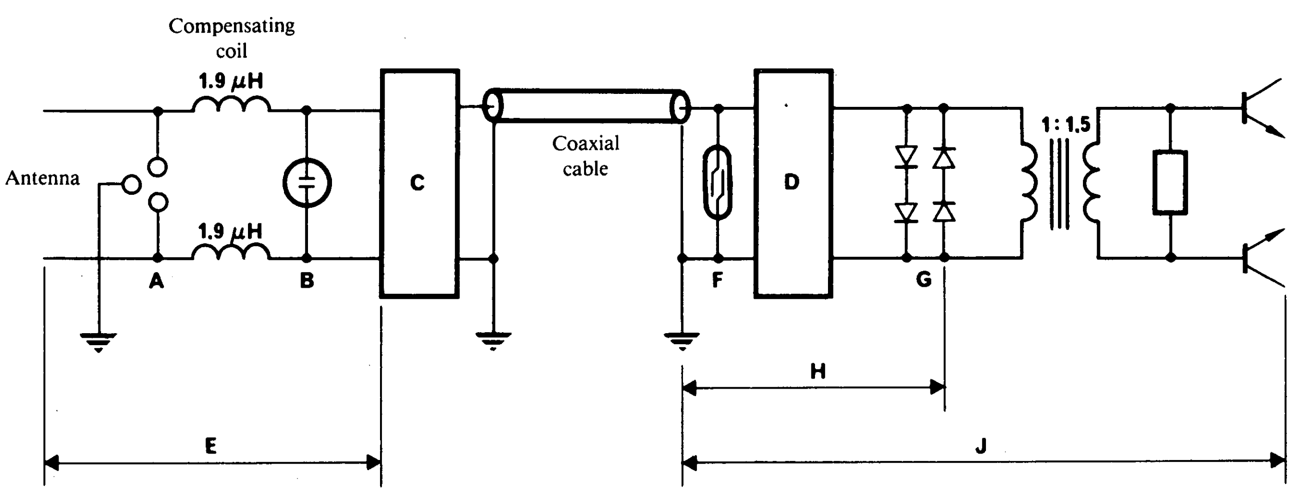


FIGURE 5 – *Configuration of protection system against lightning*

A: carbon air-gap lightning arrester
B: gas-filled lightning arrester
C: matching unit
D: high-pass filter
E: outdoor lightning arrester
F: gas-filled lightning arrester
G: diode surge protection circuit
H: indoor lightning arrester
J: transistorised multi-coupler

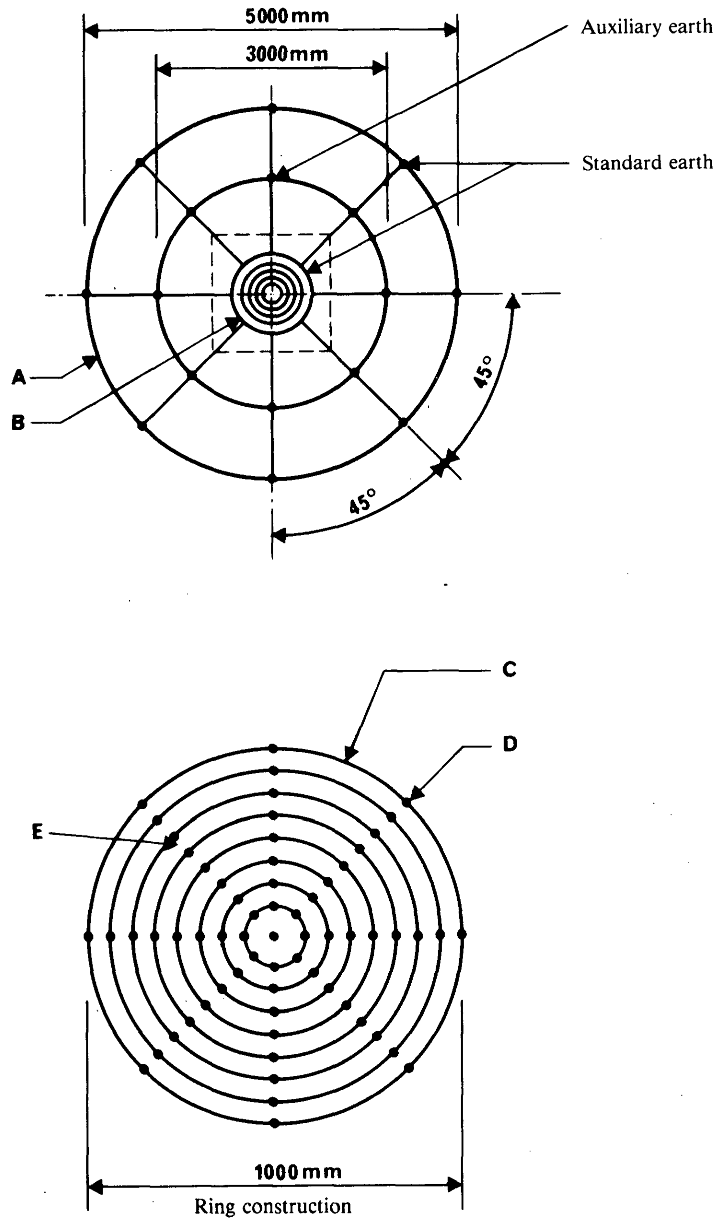


FIGURE 6 – *Diagram for earthing connection*

A: earthing rod
B: ring
C: 2.9 mm hard copper wire
D: soldering
E: 5 mm mild copper wire

5. Test results

Final testing showed that the voltage at the diode surge protection circuit was less than 2 V.

Tests of performance with an operational system were made during the summer, when lightning was frequent. The antenna lightning arrester sparked violently from close, strong lightning discharges which struck nearby during the test period. However, the multi-coupler was not damaged. Measurements of 2 V were obtained at both ends of the diode surge protection circuit during the lightning activity.

6. Conclusion

This lightning protection system has been used in remotely controlled receiving stations since 1966 and there has been no breakdown due to lightning discharges.

ANNEX II

PROTECTION OF RADIO-RECEIVING EQUIPMENT AGAINST DAMAGE CAUSED BY LIGHTNING IN ITALY

1. Introduction

Radio receiving equipment for telecommunications may be affected by harmful voltage surges usually generated in the antennas and in lines conveying RF signals.

These surges are mainly caused by:

- electrostatic charges in the atmosphere;
- electromagnetic induction caused by atmospheric discharges.

A description follows of a system for protection against voltage surges used at a radio receiving station located in an area with averge atmospheric discharge production (25-30 strikes per year per km^2) and a ground conductivity of 2 x 10^{-14} e.m.u.

2. System description

Lightning protection is provided for both the receiving terminal and the antenna feeder system.

Three pairs of earthed voltage discharger (EVD) with decreasing striking voltage are inserted in the output of each rhombic antenna, connected to the balun transformer (Fig. 7a).

An important consideration in the design of this system is that the coils and capacitors at the antenna side of the balun must be large to withstand the energy created by the lightning strike.

The first pair of EVD (gap = 1.55 mm, striking voltage = 5000 to 6000 V) are directly connected to the antenna terminals and are shown in Fig. 7b.

The second pair (Fig. 7c) (gap = 0.5 mm, striking voltage = 2500 to 3000 V) and third pair of dischargers (Fig. 7a) are housed in the balun transformer which includes a 3.3 to 32.5 MHz pass-band filter whose electrical diagram is indicated in Fig. 8. The third pair consists of metal ceramic surge voltage protectors with a 600 V striking voltage.

Coaxial cables between the antennas and the receivers (buried at a depth of 90 cm and average length 500 m) are protected by a lightning conductor consisting of a galvanized iron rod, 8 mm in diameter housed 30 cm above the cables (see Fig. 9 and 10a).

Protection for more than three cables is provided by two rods as indicated in Fig. 10b. These rods are interconnected every 20 m. The rods are then connected to the station general earth system. The resistance of the protection system to earth is approximately 1.5 ohms.

The two types of protection (dischargers and lightning rod) complement one another. The lightning rod reduces the voltage transient level and the dischargers reduce it to safe values for the radio receiving equipment.

Additional terminal protection is provided through voltage dischargers inserted at the terminals of the RF cable in the equipment room (cable terminating cabinet) and at the multi-coupler inputs. They have a striking voltage of 90 V.

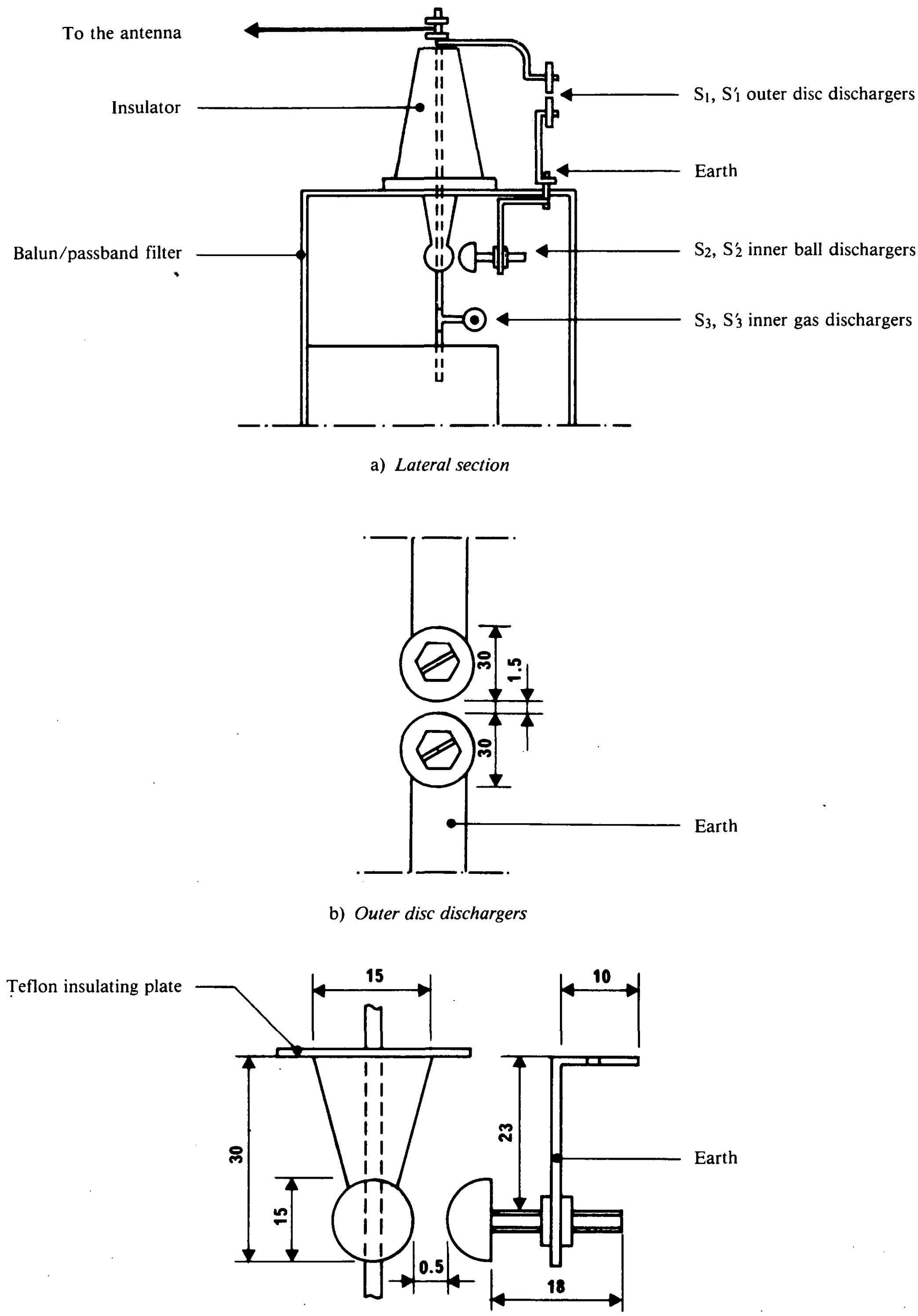
3. Conclusions

The system has proved to be very efficient, both against induced surges and direct lightning.

During seven years of operation, the radio receiving equipment and the coaxial cable lines, which span an area of more than 1 km^2 with a total spanned distance of about 14 km have never suffered damage.

In most cases, surges were absorbed by the three pairs of dischargers housed in the baluns.

The average incidence of repairs (dischargers and components, if any) was 0.16 repairs per year/balun.



a) *Lateral section*

b) *Outer disc dischargers*

c) *Air dischargers*

FIGURE 7 – *Details of outer and inner dischargers*

— Arbitrary scale
— All measurements are in millimetres

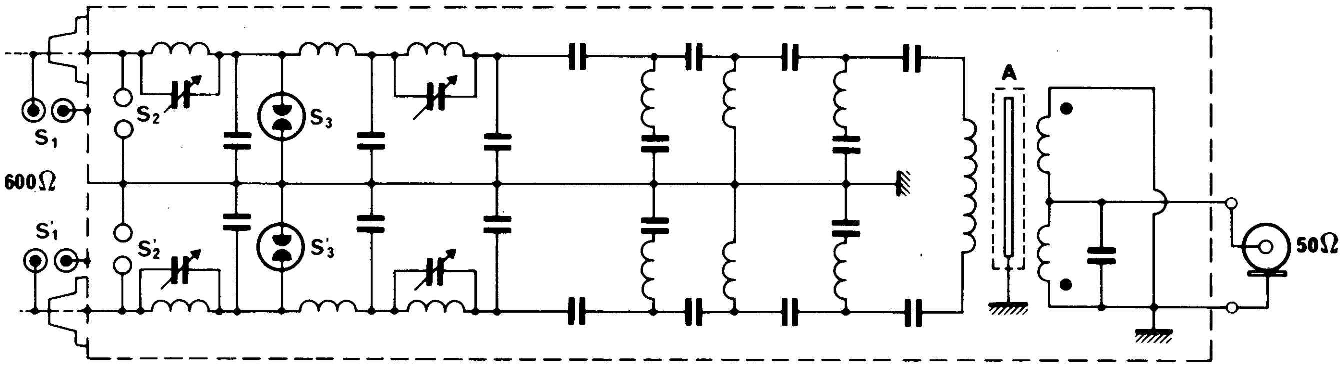


FIGURE 8 – *Balun and pass-band filter transformer diagram*

A: balun
S_1-S'_1: outer disc dischargers
S_2-S'_2: inner ball dischargers
S_3-S'_3: inner gas dischargers

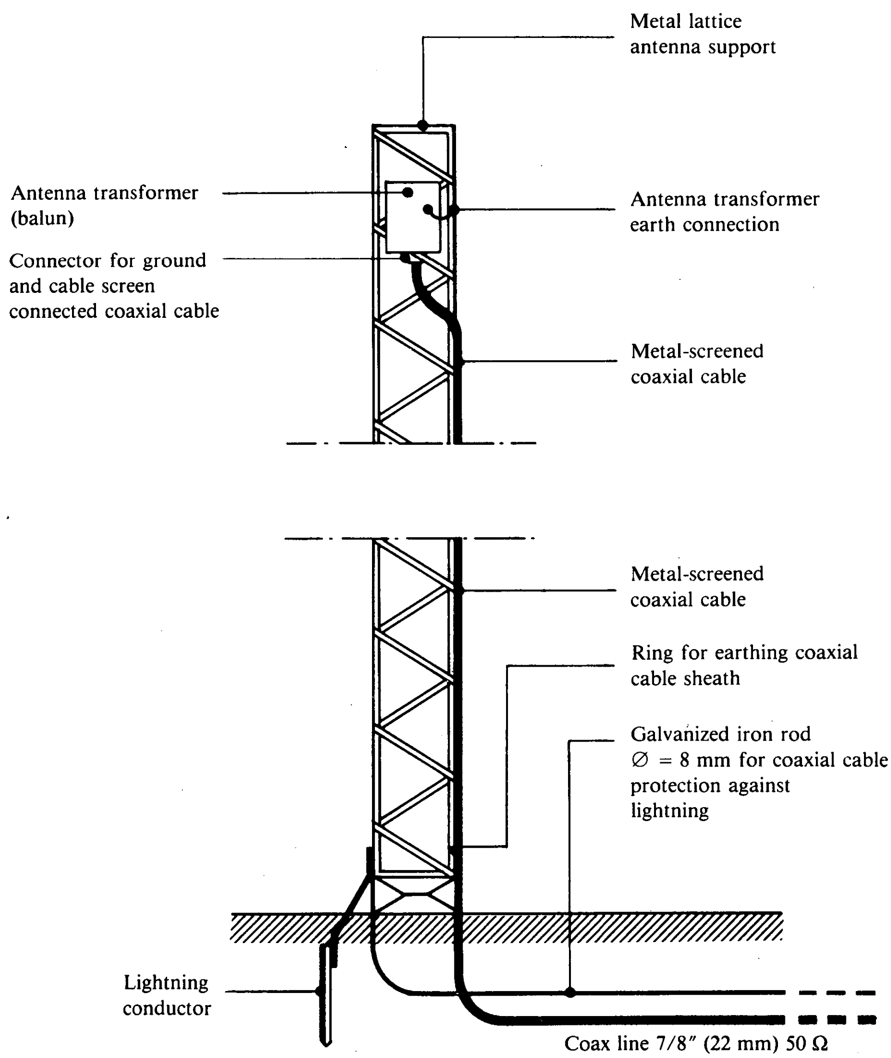


FIGURE 9 – *Details of grounding and protection of coaxial cable at the antenna tower*

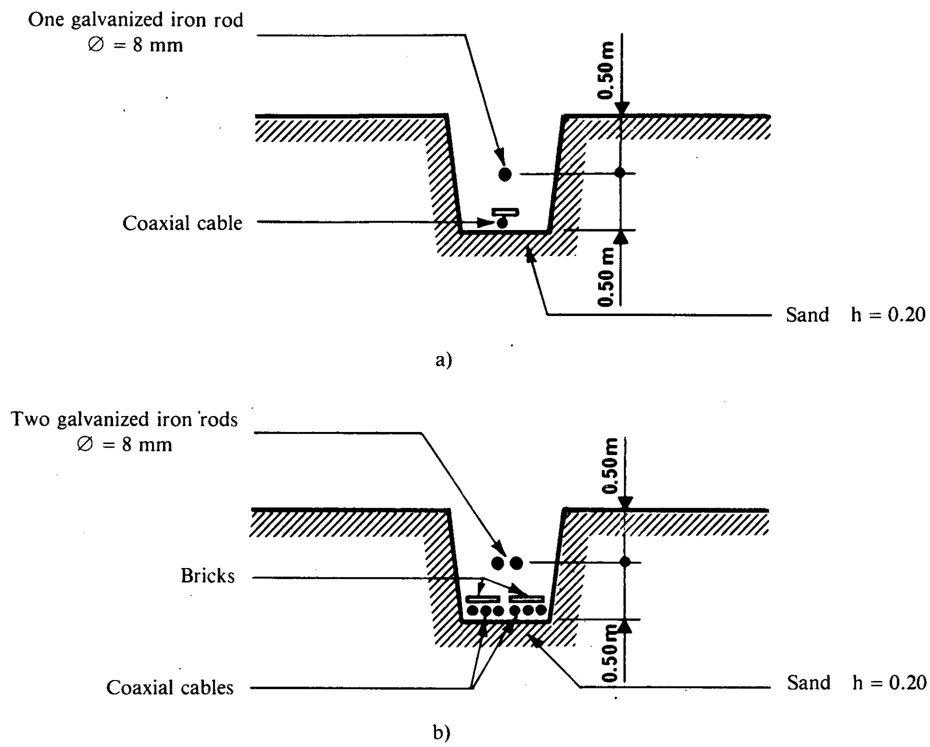


FIGURE 10 – *Typical cable protection systems*

ANNEX III

LIGHTNING PROTECTION FOR TRANSMITTING STATIONS OF THE FIXED SERVICE IN THE NETHERLANDS

Protection method

In the Netherlands, a simple protection method for transmitters employing balanced feeder lines to the antenna has been developed which has been used successfully for many years. This method, illustrated in Fig. 11, consists of two parallel earthing rods (which are part of a dual horn spark-gap protector for the two sides of the balanced feeder line), a coil situated between the two rods and associated circuitry which removes the transmitter excitation.

During lightning discharge current in the two rods flows in the same direction, and thus no voltage is induced in the coil. However, if subsequent ionization of the gaps is maintained by the transmitter power, alternating current will flow in the rods in opposite directions and a voltage will be induced in the coil. This voltage is rectified and used to energize a relay which removes the transmitter drive until ionization of the air in the spark gaps has disappeared. For most effective protection, the dual horn spark gap and pick-up coil are mounted on top of the transmitter between the feeder line terminals.

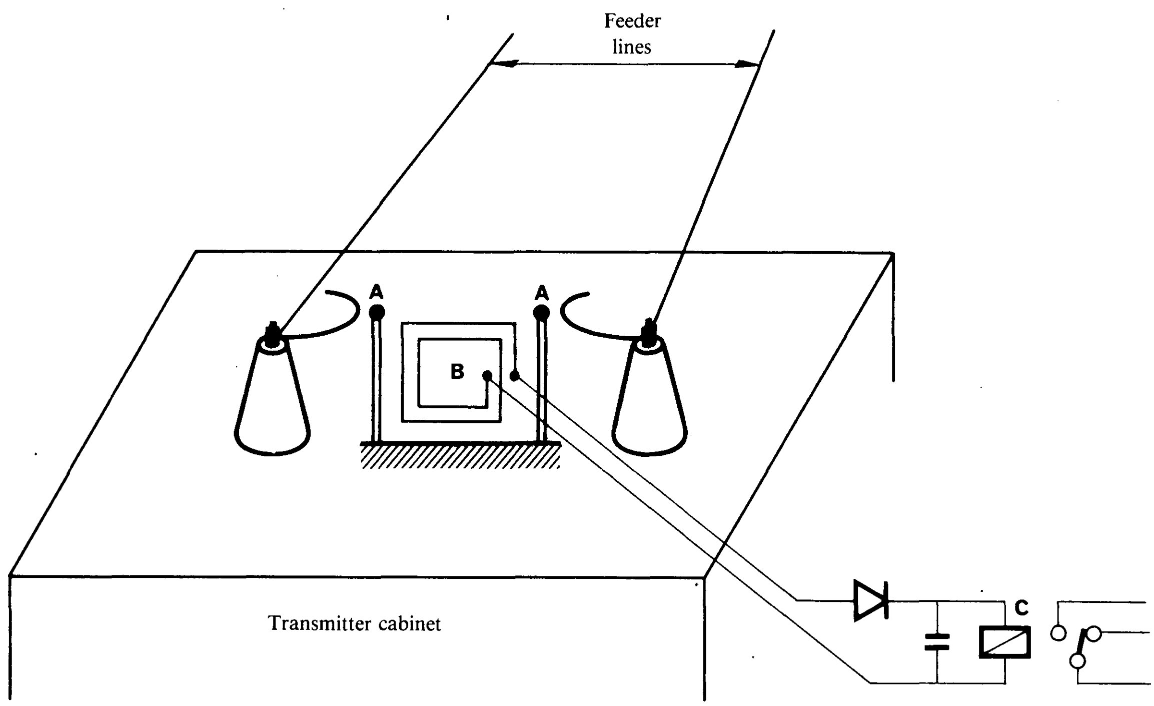


FIGURE 11

A: parallel earthing rods and horn spark gaps
B: pick-up coil mounted on insulating board
C: relay used to remove RF drive in a lower power stage

ANNEX IV

LIGHTNING PROTECTION FOR HF TRANSMITTERS
IN JAPAN

1. Introduction

Radiocommunication equipment is always exposed to the danger of lightning damage because its antenna systems are installed outdoors. Repair of a transmitting system can be a time consuming and costly operation. For this reason it is necessary to take steps to minimize lightning damage. A variety of auxiliary circuits are therefore included in transmitter antenna systems.

After analyzing the causes of heavy damage by lightning at HF transmitting stations, the horn-type gap discharge lightning arrester, which had been in use for some time, was found to be of little value. A high-pass filter type lightning arrester (HP-type lightning arrester) was therefore developed, and its performance tested during the summer with good results. This new type of lightning arrester is outlined below. The HP-type lightning arrester has been in use for a long time and has been confirmed to be very effective.

2. Horn-gap lightning arrester

Horn-gap lightning arresters have been commonly used in HF receiving and transmitting stations. They discharge the lightning voltage as a spark when this voltage is generated at the arrester terminals.

From the standpoint of arresting, lightning can roughly be classified into direct lightning and induced lightning. Most direct lightning has a momentary discharge current of 20 to 40 kA. Sometimes, instantaneous currents of about 100 kA are registered. When such direct lightning hits, most of the lightning energy is discharged into the ground through the horn gap. However, because the current is very large, a surge voltage in the order of tens of kV remains at its discharge terminal due to the low resistance to earth. This induces a current in the radio equipment that destroys its components. Even when most of the energy, from induced lightning with a relatively low instantaneous discharge current, is absorbed by the lightning arrester, a discharge arc is often sustained by the output power of the transmitter. When this happens, the load of the transmitter is virtually short-circuited and the tuning condition of the transmitter is disturbed. An extraordinary voltage is thus generated which may destroy the harmonic rejection filter, etc. Therefore, the discharge gap of a lightning arrester should be one that does not allow an arc to remain under any circumstances. Because the firing voltage of the horn gap lightning arrester nearly approaches the break-down voltage of the transmitter output circuit, it is difficult to achieve sufficient lightning protection using only a horn gap lightning arrester.

The firing voltage of a gap-discharge type lightning arrester is normally selected midway between the operating voltage and the break-down voltage of the equipment. For an abnormal voltage, in which residual surges are of no problem equipment can be fully protected by setting it as described above. For a lighting voltage with a very large amount of energy, the equipment will always be in danger of being destroyed by a residual surge unless it can be suppressed.

As stated, a gap-discharge type lightning arrester does not fully protect communications equipment against lightning. Even if the equipment is protected by its spark discharge, communications are temporarily disrupted during this time.

3. HP-type lightning arrester

3.1 *Basic concept*

The spectral components of lightning energy range from audio frequencies to frequencies higher than the VHF band, but most of the spectral energy is in the band below 10 kHz. Taking into consideration the relationship between this property of the energy distribution and the transmitting frequencies of HF transmitters, it is considered that a high-pass filter can discharge lightning energy to earth without affecting operation of the transmitter.

A particularly steep attenuation characteristic is not needed since the frequencies of the lightning energy are sufficiently remote from the HF band. Therefore, a very simple circuit of a constant K-type can be used. This is shown in Fig. 12.

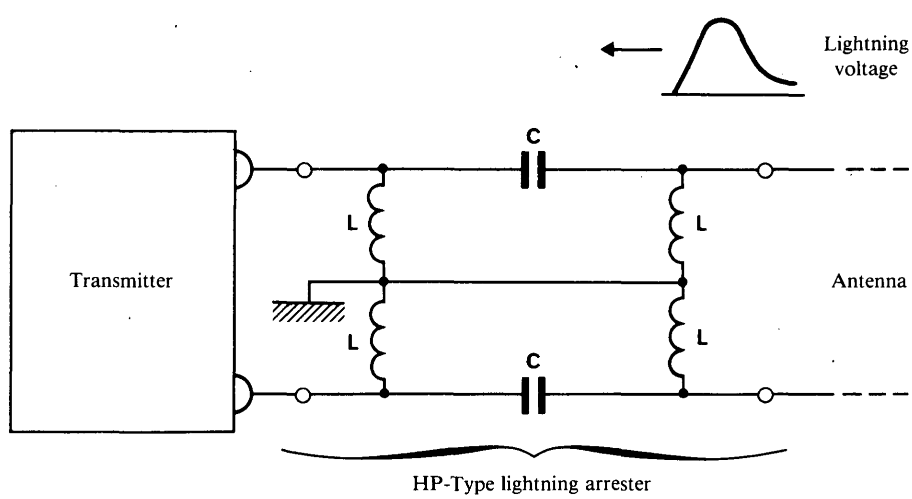


FIGURE 12

3.2 *Design of constant K-type high-pass filter*

In designing a constant K-type high-pass filter (see Fig. 13), parameters can be obtained from the equation shown below. However, the cut-off frequency is not uniformly determined, and various combinations have been studied by considering the input impedance characteristic of a filter in an HF band.

$$C = \frac{1}{4\pi f_c R}$$

f_c : Cut-off frequency

R : Characteristic resistance

$$L = \frac{2R}{4\pi f_c}$$

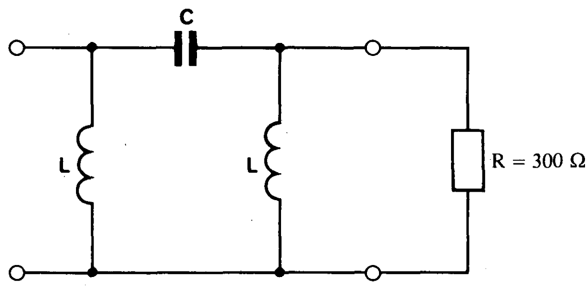


FIGURE 13 – *Equivalent circuit of one-half of the high-pass filter*

As a result, the parameters shown in Table I below have been selected to be optimal for a 600 ohms balanced transmission line.

TABLE I

Cut-off frequency	2650 kHz
C	100 pF
L	18 μH

3.3 *Capability of attenuating lightning energy*

The ability of this type of arrester to attenuate lightning energy is estimated to be as in Table II.

TABLE II

Frequency (kHz)	Output to input voltage
100	6.3×10^{-4}
10	6.3×10^{-6}
1	6.3×10^{-8}

When seen from the transmitter side, this HP-type lightning arrester is approximately terminated with the transmitter characteristic impedance in all bands and has characteristics inherent to such filters. Therefore, it affects the adjustment condition of the transmitter very little. When seen from the antenna side, its termination is nearly the characteristic impedance only at the operating frequency of the transmitter. At other frequencies, the load is determined by the output circuit constants of the transmitter and is capacitive. The output impedance of a HF transmitter is determined by the capacity of its harmonic rejection filter, and its value is from 100 to 500 pF. Such a load is very close to a state of no load relative to lightning energy below 10 kHz.

Consequently, the voltage transmission ratio of this high-pass filter will be as described above, and sufficient attenuation can be obtained regarding components below 10 kHz. The residual surge voltage will be very small.

3.4 *Method of earthing*

The characteristics of the HP type lightning arrester, against a lightning surge voltage, have been described. Nevertheless, an earthing method to obtain improved performance cannot be neglected.

The methods of earthing shown in Figs. 14 and 15 can be considered.

When a lightning arrester and load (transmitter) are earthed independently (see Fig. 14), a residual surge generated at both ends of the lightning arrester earth resistance is applied to the load, and full attenuation by the lightning arrester cannot be expected.

When both the load and arrester have a common earth, (see Fig. 15), only a reduced surge voltage is fed into the load. Therefore, the characteristic of the high-pass filter is not affected by the resistance to earth.

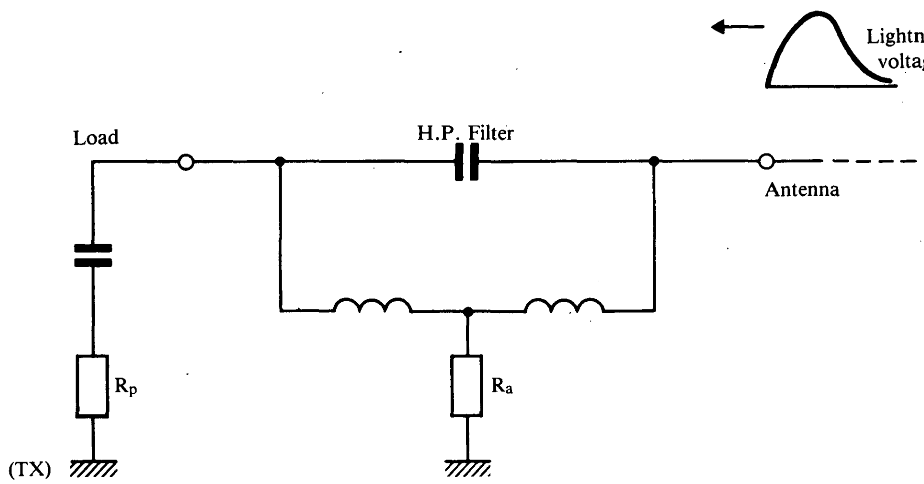


FIGURE 14

R_a: Earth resistance of HP filter
R_p: Earth resistance of load

3.5 *Capacitors and coils of the HP type lightning arrester*

Serially connected capacitors may be destroyed when direct lightning strikes the antenna system. Ceramic capacitors would be short-circuited when broken down, and the impedance would be slightly mismatched, but communications can continue. With balanced feeders, if only one capacitor is destroyed, the phase characteristics on both sides of the feeder are disturbed. Therefore, the remaining capacitor would also be short-circuited and communications should be rapidly resumed by using them temporarily as a drain coil.

When short-circuiting serial capacitors and using them as a drain coil, a switching method to maintain the impedance characteristics in good condition can also be considered.

As a result, the circuit shown in Fig. 16, which proved to be the simplest, was employed.

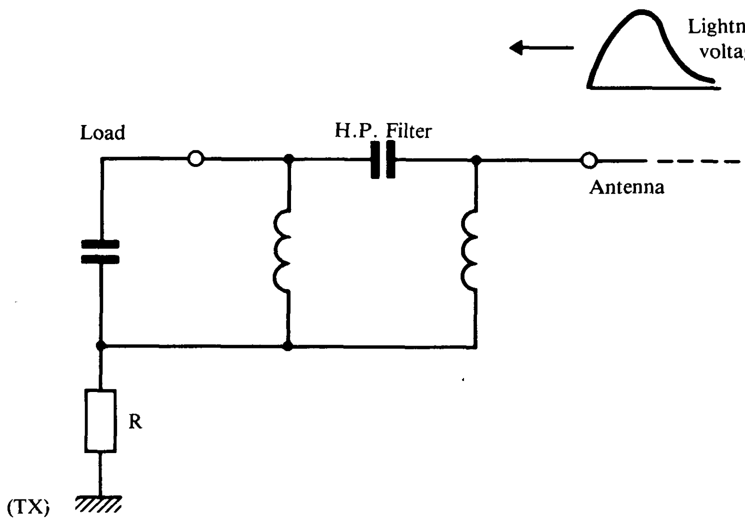


FIGURE 15

R: Common earth resistance

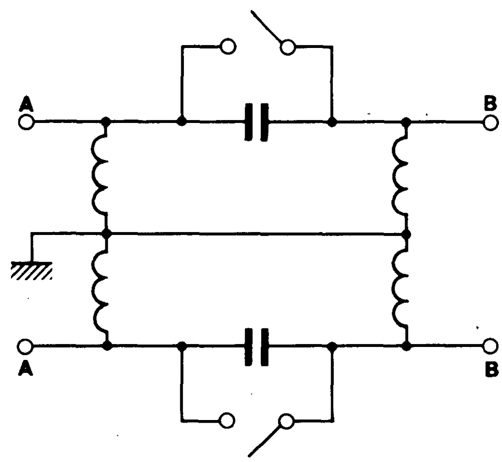


FIGURE 16

4. Test results

4.1 *Characteristics of lightning arrester mounted with transmitter*

The lightning arrester was connected directly to the output of a transmitter, and the VSWR was measured. As shown in Fig. 17, the VSWR changed very little, regardless of whether the transmitter was provided with a lightning arrester or not.

4.2 *Characteristic as drain coil*

Figure 18 compares the VSWRs calculated between those values when the HP arrester operated as a drain coil, and those values measured using an impedance bridge when the arrester was terminated in a resistor, and also with those values of VSWR measured when connected to a 575 ohms transmitter. All three curves nearly coincide, showing that a circuit configuration according to the design had been obtained. In a test with a transmitter, a dummy load was used instead of an antenna, and the matching trap was adjusted for each frequency so that the load of the lightning arrester would always indicate the value of 575 ohms.

The impedance of the HP type lightning arrester when the series capacitors are shorted (drain coil) could effect the transmitter load impedance. However, since the usual daytime summer operating frequencies are above 10 MHz, the drain coil impedance does not affect the operation.

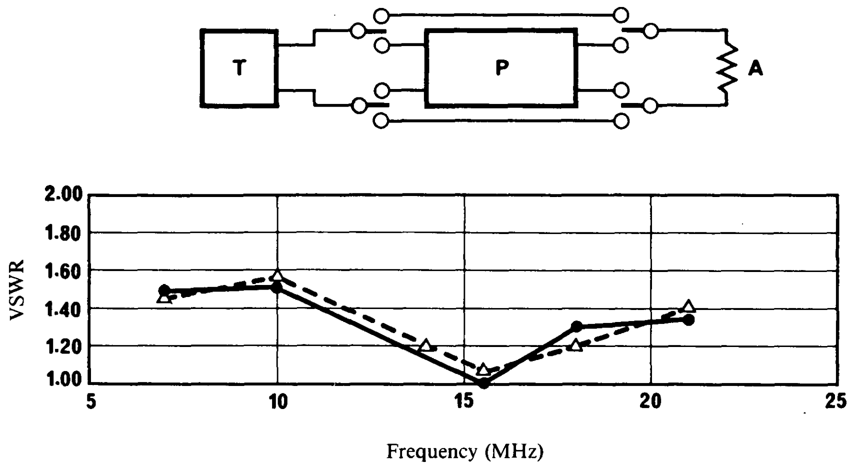


FIGURE 17 – *Comparison of VSWR with and without lightning arrester*

●——● : with lightning arrester
△– – –△ : without lightning arrester
A : antenna
P : lightning arrester
T : transmitter

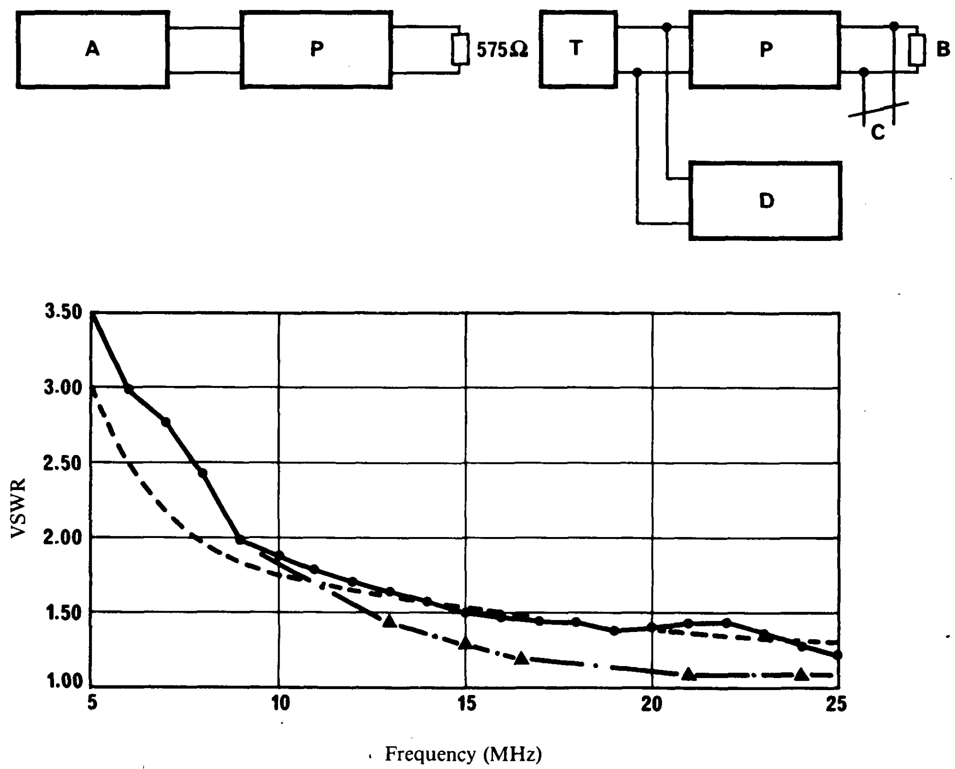


FIGURE 18 – *Comparison of VSWR when using the coils as drain coil*

●——● : measured values by bridge HP-arrester input VSWR
— — — : calculated values
▲—·—▲ : input VSWR measured HP-arrester when connected to the transmitter
A : bridge
B : dummy
C : trap
D : VSWR meter
P : lightning arrester
T : transmitter

4.3 *Effects on lightning protection*

A test was made during the summer to validate the performance of this lightning arrester by mounting HP type lightning arresters on 20 transmitters. Spark discharges were frequently observed on horn-type lightning arresters at the output of transmitters that had no lightning arresters of this type. Transmitters with HP type lightning arresters installed were free of spark discharges, indicating that the lightning voltage was completely suppressed.

5. Lightning protection by antenna configuration

In the case of two-layer (stacked) rhombic antennas, use can be made of the configuration to obtain lightning protection. The upper antenna is usually used at night, and the lower in daytime. Since in Japan lightning usually occurs only in the daytime, a selector switch was installed so that a discharge gap between the upper antenna and earth was inserted when the transmitter was connected to the lower antenna only.

The lightning energy has been shown to be by-passed by the upper antenna which is not connected to the transmitter, through the discharge gap, thus having almost no effect on the operating condition of the transmitter.

6. Conclusion

The HP type lightning arrester has the advantage of being able to allow safe operation of communications equipment without even momentary disruption when lightning strikes.

Almost all HF transmitters used for international communications (including coast station transmitters) have now been equipped with HP type lightning arresters. Their effect has been significant, and the number of transmitter failures due to lightning has been greatly reduced. In fact, transmitter failures due to lightning have not occurred since 1967.

The HP type lightning arresters can also be used with MF transmitters and radio equipment, and for receiving and mobile stations.

The antenna configuration method of lightning protection has been used effectively with an HP type lightning arrester for remote-controlled transmitting stations.

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SECTION 3B: RADIOTELEPHONY

Recommendations and Reports

RECOMMENDATION 335-2

USE OF RADIO LINKS IN INTERNATIONAL TELEPHONE CIRCUITS

(Question 13/3)

(1951-1963-1966-1970)

The CCIR,

CONSIDERING

(a) that, at the present time, radiotelephone systems connecting the various countries often employ carrier-frequencies below about 30 MHz (further reference to 30 MHz in this Recommendation means "about 30 MHz");

(b) that the use of such a radio link, in a long-distance telephone circuit, implies certain special conditions, which introduce particular difficulties not encountered when purely metallic connections are used;

(c) that such a radiotelephone circuit differs from a metallic circuit in the following ways:

c.a such a radiotelephone circuit is subject to attenuation variation with the special difficulty of fading;

c.b such a radiotelephone circuit suffers from noise caused by atmospherics, the intensity of which may reach, or even exceed, a value comparable with that of the signal which it is desired to receive;

c.c special precautions are necessary in the setting up and maintenance of such a radiotelephone circuit, to avoid disturbance of the radio receiver by any radio transmitter and especially by its own radio transmitter;

c.d to maintain the radiotelephone link in the best condition from the point of view of transmission performance, it is necessary to take special measures to ensure that the radio transmitter always operates, as far as possible, under conditions of full loading, whatever may be the nature and the attenuation of the telephone system connected to the radiotelephone circuit;

c.e it is necessary to take measures to avoid or correct conditions of abnormal oscillation or cross-talk;

c.f although the recommended frequency band, to be effectively transmitted by international landline circuits, has been determined by a study of the requirements of the human ear, this band (for a radiotelephone circuit operating at a frequency below 30 MHz) may be limited by the necessity of obtaining the maximum number of telephone channels in this part of the radio-frequency spectrum and so that each telephone channel does not occupy a radio-frequency band larger than necessary;

c.g in general, such a radiotelephone circuit is a long-distance international circuit giving telephone service between two extended networks, and this fact is of great importance from two points of view:

> *c.g.a* on the one hand, international conversations, in general, are of great importance to the subscribers and, on the other hand, they are made in languages which are not always their mother tongue, so that high quality reception is particularly important;
>
> *c.g.b* the public should not be deprived of a very useful service under the pretext that it does not always satisfy the degree of excellence desirable for long-distance communication,

UNANIMOUSLY RECOMMENDS

1. Circuits above 30 MHz

that between fixed points, telephone communications should be effected wherever possible by means of metallic conductors, or radio links using frequencies above 30 MHz to make the allocation of radio frequencies less difficult; where this can be realized, the objective should be to attain the transmission performance recommended by the CCITT for international telephone circuits on metallic conductors;

2. Circuits below 30 MHz

2.1 that since it becomes necessary to economize in the use of the frequency spectrum, when considering international circuits which consist mainly of single long-distance radio links operating at frequencies less than 30 MHz, it is desirable to use single-sideband transmission to the maximum extent possible, to employ a speech band less than the 300 to 3400 Hz recommended by the CCITT for landline circuits and, preferably, to reduce the upper frequency of the speech band to 3000 Hz or less, but not below 2600 Hz, except in special circumstances;

2.2 that, although it will be necessary to tolerate large variations in noise level on such a radiotelephone circuit, every possible effort should be made to obtain minimum disturbance to the circuit from noise and fading by the use of such techniques as full transmitter modulation, directional antennas and single-sideband operation;

2.3 that, during the time that such a radiotelephone circuit is connected to an extension circuit equipped with echo suppressors (voice-operated switching device), the intensity of disturbing currents should not be sufficient to operate the echo suppressor frequently;

2.4 that such a radiotelephone circuit should be provided with an echo suppressor to avoid singing or echo disturbance on the complete circuit, or, preferably, with terminals using the principles of constant overall transmission loss, as set forth in Recommendation 455;

2.5 that such a radiotelephone circuit should be equipped with automatic gain control to compensate automatically, as far as possible, for the phenomenon of fading;

2.6 that the terminal equipment of such a radiotelephone circuit should be such that it may be connected, in the same way as any other circuit, with any other type of circuit;

2.7 that, where privacy equipment is used, this equipment should not appreciably affect the quality of telephone transmission;

2.8 that, when suitable automatic devices are not provided, the circuit controls should be adjusted, as often as necessary, by an operator to ensure optimum adjustment of transmitter loading, received volume and the operating conditions of the echo suppressor.

Note. – Although the requirements contained in § 2 of this Recommendation are much less severe than those imposed on international landline circuits, the objective remains to attain the same standards of telephone transmission in all cases. In view of this, it is desirable that the telephone systems connected to a radiotelephone circuit should conform to CCITT Recommendations covering the general conditions to be met by international circuits used for landline telephony, especially in respect of equivalent, distortion, noise, echoes and transient phenomena.

Bearing in mind the recommendations contained in §§ 1 and 2, it is desirable that in each particular case, Administrations and private operating agencies concerned should first reach agreement on how far the standards usually employed for international landline circuits may be attained in the case considered. If the technique of § 1 of this Recommendation can be used, the objective should be to obtain, as far as possible, the characteristics recommended by the CCITT for international landline circuits. Otherwise the Administrations and private operating agencies concerned should study the best solution from the point of view of both technique and economy.

RECOMMENDATION 336-2

PRINCIPLES OF THE DEVICES USED TO ACHIEVE PRIVACY IN RADIOTELEPHONE CONVERSATIONS

(Question 13/3)

(1951-1963-1966-1970)

The CCIR,

CONSIDERING

(a) that the devices referred to are intented to achieve privacy rather than secrecy in radiotelephone conversations;

(b) that, in the interest of maximum privacy, the details of the systems employed and of their performance, should be agreed upon between the Administrations and private operating agencies concerned,

UNANIMOUSLY RECOMMENDS

1. that the following statement of principles and characteristics of the devices concludes the study of Question 30 (Stockholm, 1948), for radio circuits operating at frequencies less than about 30 MHz;

1.1 *Principles of the devices*

Two general types of system are used to achieve privacy in radiotelephone circuits operating at frequencies less than about 30 MHz;

1.1.1 *For double-sideband systems* (see Note)

inverter systems, the speech band being inverted about a fixed frequency.

1.1.2 *For single-sideband and independent-sideband systems*

band-splitting systems, in which the speech band is subdivided into equal frequency bands, the speech components in the sub-bands being interchanged, with or without frequency inversion, and, according to a prearranged sequence, to give "scrambled" speech. The process is reversed at the receiving terminal to reform the speech signals. Accurate synchronization of the switching processes at the two terminals is required.

1.2 *Characteristics of the devices*

1.2.1 the band-splitting system provides privacy superior to that obtained with the inverter system, but for satisfactory operation it can tolerate less distortion;

1.2.2 the apparatus is designed to reduce attenuation distortion and the levels of unwanted products of modulation and of carrier signals to a minimum. The extent of the permissible distortion due to the presence of the privacy devices is, in general, dependent on the type of privacy and is usually agreed between the Administrations or private operating agencies concerned;

2. that, for frequencies above about 30 MHz, the details of the systems to be employed and of their performance should be agreed upon between the Administrations or private operating agencies concerned.

Note. – The attention of Administrations is drawn to No. 2700 of the Radio Regulations, which states:

"**2700** § 1. (1) Administrations are urged to discontinue, in the fixed service, the use of double-sideband radiotelephone (class A3E) transmissions."

RECOMMENDATION 348-2

ARRANGEMENT OF CHANNELS IN MULTI-CHANNEL SINGLE-SIDEBAND AND INDEPENDENT-SIDEBAND TRANSMITTERS FOR LONG-RANGE CIRCUITS OPERATING AT FREQUENCIES BELOW ABOUT 30 MHz

(Question 2/3)

(1953-1956-1959-1963-1966-1974)

The CCIR,

CONSIDERING

(a) that the lack of uniformity, in the arrangement and designation of the channels in multi-channel transmitters for long-range circuits operating on frequencies below about 30 MHz, may give rise to certain difficulties when one transmitting station has to work with several receiving stations;

(b) that, since it is necessary to economize in the use of the radio-frequency spectrum, when considering international circuits consisting mainly of single long-distance radio links, operating on frequencies below 30 MHz, it is desirable:

- to use independent-sideband transmissions to the maximum extent possible;
- to transmit a band less than the 300 to 3400 Hz recommended by the CCITT for landline circuits;
- to reduce the upper frequency to 3000 Hz, or less in special circumstances, but never below 2600 Hz;

(c) that there are already in operation international multi-channel radiotelephone circuits, in which the bandwidth allocated to each channel is 3000 Hz, but which are actually transmitting a speech band of 250 to 3000 Hz;

(d) that, in general, the outer channels are liable to cause and receive more interference to and from stations operating on adjacent assigned frequencies, the outer channels being those located furthest from the assigned frequency;

(e) that there are advantages in adopting channel arrangements which are the same in all parts of the HF (decametric) range,

UNANIMOUSLY RECOMMENDS

1. that standard channel arrangements should be adopted for multi-channel radiotelephone systems;

2. that the effective speech channel allocation should be 3000 Hz;

3. that the transmitted band in each speech channel should be from 250 Hz with an upper frequency of 3000 Hz, or lower in special circumstances, but never below 2600 Hz;

4. that in four-channel systems the channel arrangement should be as shown in Fig. 1a;

5. that, when less than four channels are used, the channels nearest to the carrier should be selected according to the arrangements shown in Figs. 1b, 1c, 1d, 1e or 1f;

6. that the effective date of these arrangements be fixed by the next Administrative Radio Conference.

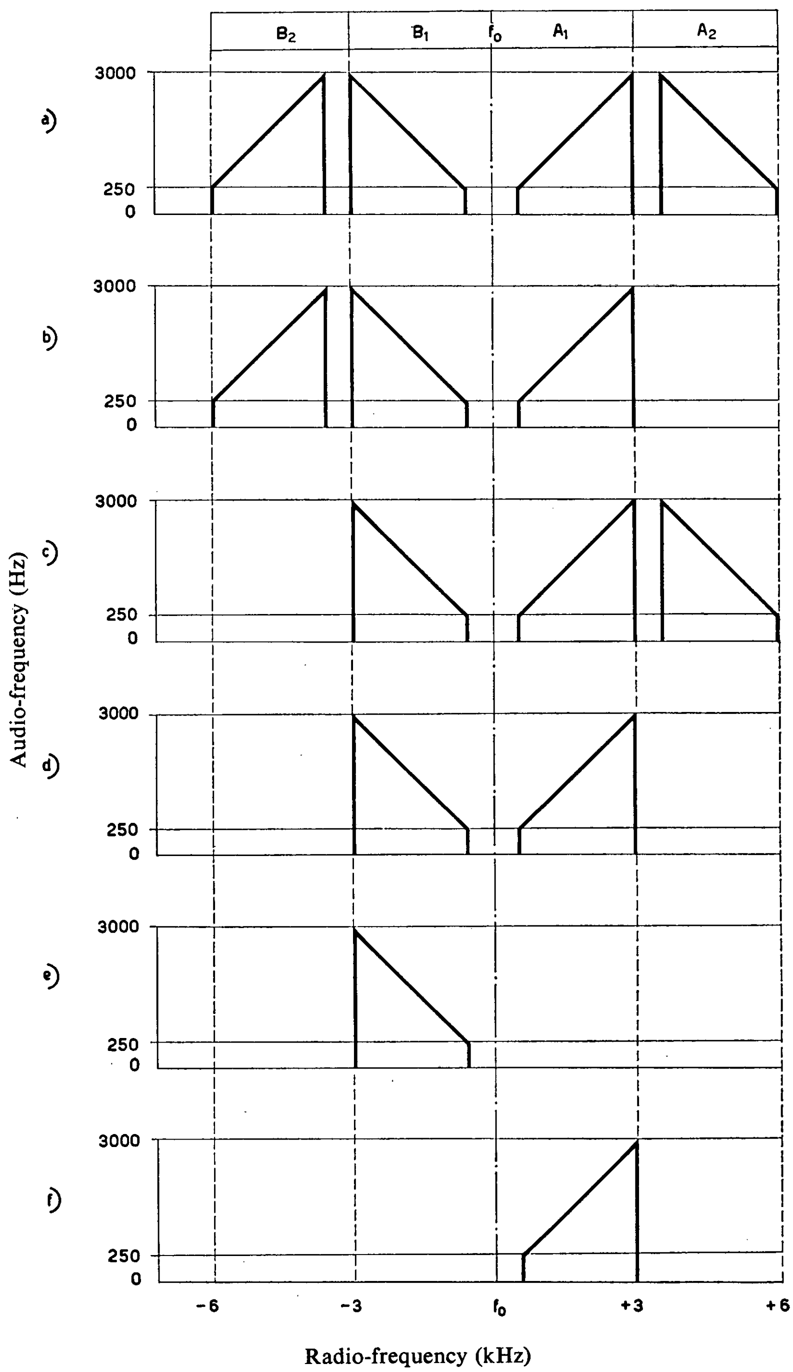

FIGURE 1 – *Relationship between audio-frequencies and radio-frequencies for the various channel arrangements*

RECOMMENDATION 480

SEMI-AUTOMATIC OPERATION ON HF RADIOTELEPHONE CIRCUITS

Devices for remote connection to an automatic exchange by radiotelephone circuits

(Question 13/3)

(1974)

The CCIR,

CONSIDERING

(a) that telephone circuit operation is substantially improved by the use of semi-automatic instead of manual working;

(b) that HF radiotelephone circuits will continue to be used for many years to come in the international fixed service;

(c) that employment of CCITT signalling codes on such circuits, even when they are equipped with systems of the type described in Recommendation 455, is difficult owing to the loss probabilities prescribed for the use of these codes in the international service;

(d) that, on the other hand, the use of signalling methods specially intended for radiotelephone channels makes it possible to transmit the information required for remote connection of an operator in one country to an automatic exchange in another country;

(e) that the FSK signalling system now in use on HF radiotelegraph circuits meets the requirements of *(d)* above;

(f) that Report 434 contains precise details on the use of, and tests made by certain countries with devices using the signals mentioned in *(e)* above and that the results are very satisfactory,

UNANIMOUSLY RECOMMENDS

that, when it is desired to provide remote dialling facilities into an automatic exchange via an HF radiotelephone circuit, the system parameters used should preferably conform to those described in Annex I to this Recommendation.

ANNEX I

The following specifications concern two devices, a "TRANSMITTING device" in OUTGOING country A and a "RECEIVING device" in INCOMING country B. The TRANSMITTING device is connected to the operating centre of country A (operators) and the RECEIVING device is connected to the automatic switching equipment of incoming country B by a dedicated line. The operator in country A can call a subscriber in country B in the same way as another subscriber in country B would do, since the TRANSMITTING AND RECEIVING devices establish a genuine remote connection between the operator in A and the automatic switching equipment in B.

Use by the two countries A and B of the devices described here permits semi-automatic operating, since the operator in A is in a sense a subscriber of the B network. Only terminal traffic will be allowed between the two countries, all transit traffic being excluded. Further, the two countries will have to agree on the facilities afforded to the operators in A (calling of special services such as information, calling in assistance-operators in B or other operators to reach subscribers in B not connected to an automatic exchange).

These specifications are concerned only with the compatibility of the TRANSMITTING and the RECEIVING devices permitting the remote connection of the outgoing operator to the incoming automatic switching equipment.

1. Interconnection

1.1 *The TRANSMITTING device* is connected on one side to the operating centre (operators) and on the other to the radiotelephone circuit:

- on the operating centre side: the operator must transmit to the TRANSMITTING device, for example, by separate wires, the SEIZING, DIALLING, END-OF-DIALLING and CLEARING information;
- on the radiotelephone circuit side: the TRANSMITTING device is placed in series on the *send* direction of the four-wire circuit.

1.2 *The RECEIVING device* is placed in the *receive* path of the four-wire circuit.

The voice circuit and the supervisory and signalling paths from the RECEIVING device are connected to the automatic exchange.

2. Signals transmitted in the forward direction

Information in the forward direction, i.e. from outgoing country A to incoming country B, supplied by the operator in A is converted into signals by the TRANSMITTING device using frequency modulation, which is particularly well suited to transmission on radiotelephone channels.

The TRANSMITTING device contains a voice-frequency FM oscillator of frequency F with a deviation of $\pm \Delta f$. The value of F is selected, by agreement between the two countries *, from the list of frequencies recommended by CCIR (Recommendation 436) with a frequency-shift according to Recommendation 246 of $\pm$ 85 Hz.

Table I below lists the various types and uses of signals

TABLE I

Signal	Signal transmitted on the radiotelephonic circuit	Recognition tolerance at the receiving end
SEIZING	frequency $F \pm \Delta f$ modulated at 100 ± 1 bauds for 300 ms and followed by the frequency $F+\Delta f$ permanently emitted until the beginning of the DIALLING signals	frequency $F \pm \Delta f$ modulated at 100 bauds for a period of 200 to 400 ms followed by the frequency $F+\Delta f$ for at least 300 ms
DIALLING	frequency $F \pm \Delta f$ modulated at the dial pulse rate (66/33 ms or 50/50 ms); the "off" corresponds to the frequency $F+\Delta f$, and the "on" (open) to frequency $F-\Delta f$	Minimum duration of "on" condition (frequency $F-\Delta f$): 25 ms
END-OF-DIALLING	frequency $F \pm \Delta f$ modulated at 100 bauds for 300 ms. No signalling frequency is emitted after this signal	Duration: 200 to 400 ms
CLEARING	frequency $F \pm \Delta f$ modulated at 100 bauds for 600 ms. No signalling frequency is emitted afterwards	Duration more than 500 ms

3. Signals used in the reverse direction

At all times the operator must be able to hear the supervisory signals generated by the distant automatic exchange.

This requires:

3.1 that the TRANSMIT and RECEIVE devices provide control signals to disable any echo suppressors or singing suppressors, included in the circuit, during the period between seizing and the end of dialling;

3.2 that in cases where supervisory signals are too low in frequency to be transmitted directly they must be translated into the voice-frequency band.

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* Different frequencies must be available when there are several circuits equipped with TRANSMITTING or RECEIVING devices in one and the same radiotelephone (transmitting) system to avoid false seizing caused by inter-channel cross-talk.

RECOMMENDATION 455-1

IMPROVED TRANSMISSION SYSTEM FOR HF RADIOTELEPHONE CIRCUITS

(Question 13/3)

(1970-1974)

The CCIR,

CONSIDERING

(a) that, to maintain a satisfactory standard on international radiotelephone circuits operating at frequencies below 30 MHz and connected to the national network, it is necessary to compensate, at the transmitting end, for most, if not all, of the variations in the subscribers' speech volume and of the losses between the subscriber and the international exchange;

(b) that, as a result, the circuit often operates under a condition of overall gain (two-wire to two-wire) and it is necessary to use a singing-suppressor to maintain stability;

(c) that the singing-suppressor markedly degrades the performance of the circuit, due to its switching action and its tendency to misoperation by noise or interference on the radio path;

(d) that the use of a singing-suppressor to maintain overall stability of the radiotelephone channel inhibits the interconnection, on a four-wire basis (see CCITT Recommendation G.101, Fascicle III.1) of radio circuits and long-distance cable or satellite circuits;

(e) that, if HF radiotelephone circuits were operated at a nearly constant overall transmission loss, the singing-suppressor could be eliminated and a radio circuit could be integrated into an international chain;

(f) that, to maintain a constant overall loss, while catering for variations in subscribers' speech volume and line loss, it is necessary to insert, at the receiving end of the circuit, a loss equivalent to the gain inserted at the transmitting end;

(g) that the advantages of compandor operation, as used on some line transmission systems, are well established, but cannot be directly realized on a radio circuit subject to fading;

(h) that, on such a radio circuit, an alternative means of conveying information as to the state of the compressor is necessary to control the expander;

(j) that these alternative means enable advantage to be taken of a compression ratio in excess of that employed in line compandors, which is generally 2/1;

(k) that the behaviour and advantages of a system employing a linked compressor and expander have been established (see Report 354);

(l) that with such an arrangement the two ends of a circuit will be complementary and the essential parameters of the system will have to be standardized,

UNANIMOUSLY RECOMMENDS

1. that, wherever possible, HF radiotelephone circuits should be operated on the basis of a constant overall transmission loss (two-wire to two-wire);

2. that a system comprising a compressor and expander linked by a control channel, which is separate from the speech channel and is resistant to fading distortion, should be used to achieve this performance; *

3. that the system should maintain optimum loading of the transmitter at all times despite variations in subscribers' speech volumes and line losses;

4. that the speech and control signals should both be contained within a single 3 kHz channel;

* Such a system is commonly known as Lincompex which is a convenient acronym for the phrase "linked compressor and expander". Lincompex is neither a proprietary name nor does it refer to the manufacturer of a particular equipment.

5. that such a system should be in accordance with the description and parameters listed below:

5.1 *General*

For convenience, the performance requirements of this document are based on a system configuration (one end is shown in Fig. 1) which on the transmit side employs pre-compressor delay in conjunction with a voice-signal amplitude assessor. This does not preclude other configurations which meet the requirements.

5.2 *Transmit side (Fig. 1a)*

5.2.1 *Speech channel*

5.2.1.1 *Steady-state conditions*
(compression and overall characteristics)

For input levels between +5 dBm0 to −55 dBm0 (Note 1) the output should lie within the limits shown in Fig. 2.

The overall amplitude/frequency response for the speech channel under both fixed-gain and assessor-controlled conditions at any level within the range +5 dBm0 to −55 dBm0 should be:

Above 250 Hz:

Attenuation relative to the maximum response in the band 250 to 2500 Hz (dB):

– For frequencies in the band 250 to 2500 Hz	⩽ 2
– For frequencies in the band 2500 to 2700 Hz	⩽ 6
– For frequencies in the band 2800 Hz and above	> 55

Below 250 Hz:

Increase in overall gain for frequencies below 250 Hz (dB)	⩽ 1

5.2.1.2 *Transient response*
(overall, including amplitude assessor but excluding additional delay)

Attack time, Fig. 3a (ms) (Note 2)	7 ± 2
Recovery time, Fig. 3b (ms) (Note 2)	20 ± 5

5.2.2 *Control channel*

Frequency-modulated oscillator
(frequency controlled by amplitude assessor output):

Nominal centre frequency (Hz)	2900 ± 1
Maximum frequency deviation (Hz)	± 60
Change of frequency for each 1 dB change of input level (Fig. 4) (Hz)	2
Input level to transmit side to produce nominal centre frequency (dBm0)	−25
Oscillator frequency resulting from an input level of 0 dBm0 (Hz)	2850
Oscillator frequency when there is no input to the transmit side (Hz)	⩽ 2980
For sudden increases in the input that exceed 3 dB, the time taken for the oscillator to complete 80% of the corresponding change in frequency should be (ms)	5 to 7
For sudden decreases in the input that exceed 3 dB, the rate of change of oscillator frequency should lie between (Hz/ms)	1.5 and 3.5
Output spectrum effectively limited between (Hz)	2810 and 2990
Output level relative to test tone level in the speech channel (dB)	−5

5.3 *Receive side (Fig. 1b)*

5.3.1 *Speech channel*

5.3.1.1 *Steady-state conditions*

The relative overall amplitude frequency response of the speech channel under fixed and controlled gain conditions should be:

Above 250 Hz:

Attenuation relative to the maximum response in the band 250 to 2500 Hz (dB):

– For frequencies in the band 250 to 2500 Hz	$\leqslant$ 2
– For frequencies in the band 2500 to 2700 Hz	$\leqslant$ 6
– For frequencies in the band 2800 Hz and above (fading regulator at fixed gain)	> 55

Below 250 Hz:

Increase in overall gain for frequencies below 250 Hz (dB)	$\leqslant$ 1

5.3.1.2 *Fading regulator*

Steady-state conditions

For input levels between +7 dB and −35 dB, relative to the nominal design input level to the fading regulator, the output should be within the limits shown in Fig. 5. The nominal design input level which may vary between Administrations is the value measured at the input of the fading regulator, under steady-state conditions, when 0 dBm0 is applied to the transmit side.

Transient response

Attack time: Fig. 3c (ms)	11 ± 2
Recovery time: Fig. 3d (ms)	32 ± 6

5.3.1.3 *Expander*
(controlled by the discriminator output)

Effective dynamic range (dB)	60

5.3.2 *Control channel*

5.3.2.1 *Amplitude/frequency and differential-delay characteristics of filter*

Attenuation within the band 2810 Hz to 2990 Hz (relative to that at 2900 Hz) (dB)	−1 to +2
Differential delay within the band 2840 to 2900 Hz (ms)	< 3
Attenuation below 2700 and above 3150 Hz (relative to that at 2900 Hz) (dB)	> 55

5.3.2.2 *Discriminator* (Frequency/amplitude translator)

Characteristic at nominal control tone level

Changes in the expander output with changes in the frequency of the control tone between 2840 Hz and 2960 Hz, should lie within the limits shown in Fig. 6.

5.3.2.3 *Amplitude range of discriminator*

The performance quoted in § 5.3.2.2 should be met for control tone input signal levels to the discriminators from 0 dB to −30 dB relative to the nominal input level; with control tone input levels between −30 dB and −50 dB relative to nominal, an additional tolerance of ± 1 dB could be added to the limits shown in Fig. 6.

5.3.3 *Overall attack and recovery time*
(A sudden change of 24 Hz in the frequency of the control tone is used to simulate a 12 dB step)

Attack time: Fig. 3e (ms)	20 ± 5
Recovery time: Fig. 3f (ms)	20 ± 5

5.4 *Equalization (overall) of transmission time*

To ensure a reasonable transmission standard, in particular of tone pulses, such as would be used for ringing or signalling, the overall transmission times of the speech and control channels should be equalized at the input to the expander to within 4 ms. In addition, the differential delay over the section of the passband of the speech channel, i.e., 250 Hz to 2500 Hz, should not exceed 4 ms.

To ensure that this can be achieved with independent designs of equipment, the time equalization provided should be divided equally between the transmit and receive sides of the equipment and should be adjustable so that the time delay encountered in privacy systems can be taken into account.

5.5 *Ringing and dialling*

Care should be taken to ensure that ringing and dialling signals are either passed completely through the equipment at both ends or completely by-pass both ends. The first method is to be preferred.

5.6 *Transmitter loading*

To enable transmitters to be fully loaded whilst keeping intermodulation products and out-of-band radiation to an acceptable level, speech channel and control channel levels for each telephone channel as shown in Table I are recommended. These figures are based on a total mean power output of −6 dB relative to the peak-envelope-power rating (p.e.p.) of the transmitter and a carrier power of −20 dB relative to p.e.p.

TABLE I

Number of channels	Individual channel power dB relative to p.e.p.	
	Speech channel	Control channel
1	−7	−12
2	−10	−15
3(1)	−12	−17
4	−13	−18

(1) For operational convenience it may be desirable to use the same power levels for 3 channels as are used for 4 channels.

5.7 *Transmission path linearity*

The above loading conditions provide an adequate margin in the radio transmitter to allow for normal changes from the line-up condition on the Lincompex equipment and in the transmission path to the transmitter. Bearing in mind that the compressed nature of the Lincompex signal has a peak-to-mean ratio of about 8 dB with the possibility of transient peaks at the compressor output, adequate linearity margin should be allowed in the transmission equipment between the Lincompex transmit terminals and the transmitter. Similar considerations apply to equipment between the radio receiver output and the Lincompex receive terminals.

Fixed service receivers in current use are adequate for carrying Lincompex channels, but signal levels must be chosen such that adequate linearity margins exist.

5.8 *Frequency stability*

The maximum allowable end-to-end frequency error of each Lincompex channel should be within ± 2 Hz.

Note 1. – For definition of signal-to-test-level ratio (dBm0) see the relevant CCITT texts.

Note 2. – The definitions of attack time and recovery time which are similar to those defined by the CCITT for compandors (Recommendation G.162, Fascicle III.1), are as follows:

– *the attack time* of a compressor is defined as the time between the instant when a sudden increase of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 1.5 times its steady-state value;

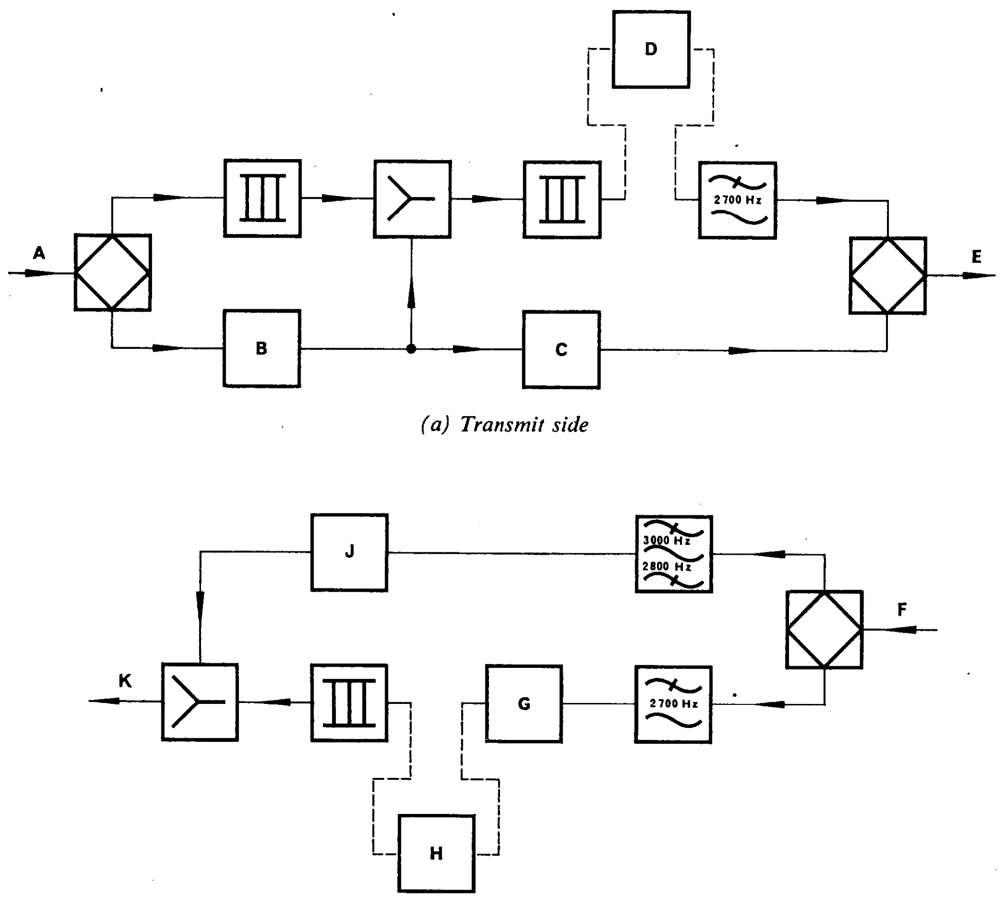
– *the recovery time* of a compressor is defined as the time between the instant when a sudden decrease of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 0.75 times its steady-state value.

Note 3. – The parameters listed above are considered to be the minimum that should be agreed if compatibility between equipment is to be ensured. In addition, maximum tolerances have been quoted, but it has been assumed that these will not be used as design limits.

Note 4. – The temperature and power source variations with time, over which the parameters should be maintained, will vary between Administrations and have not therefore been included. The CCITT, however, in their specification for compandors (Recommendation G.162), state that the performance should be maintained over a temperature range of +10 °C to +40 °C and with power source variations of ± 5% of nominal.

Note 5. – Additional parameters which would normally be included in a specification for this class of equipment, i.e., input and output impedances and levels, signal-to-noise ratio, harmonic distortion, etc., have not been included as their value is not considered essential to compatibility between equipments. Administrations will wish to add their own values to ensure the satisfactory integration of the equipment into their own networks.

Note 6. – The type of transmission in the control channel according to this Recommendation is not considered as class of emission F3E; therefore any provision of the Radio Regulations according to which class of emission F3E is prohibited for the fixed services in the bands below 30 MHz does not apply.



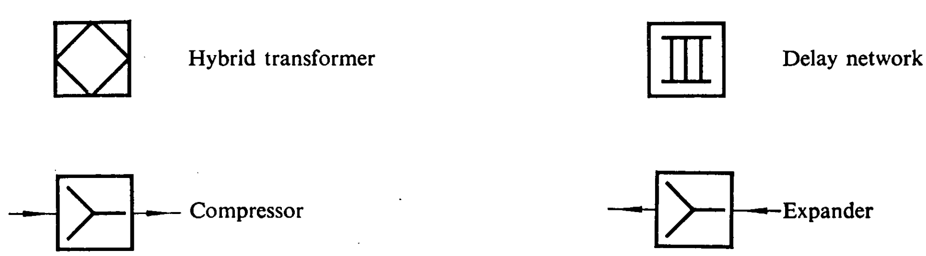
(a) Transmit side

(b) Receive side

FIGURE 1 – *Schematic diagram of system*

A: From landline
B: Amplitude assessor
C: Frequency-modulated oscillator
D: Privacy device
E: To radio transmitter

F: From radio receiver
G: Fading regulator (constant-volume amplifier)
H: Privacy device
J: Frequency discriminator
K: To landline



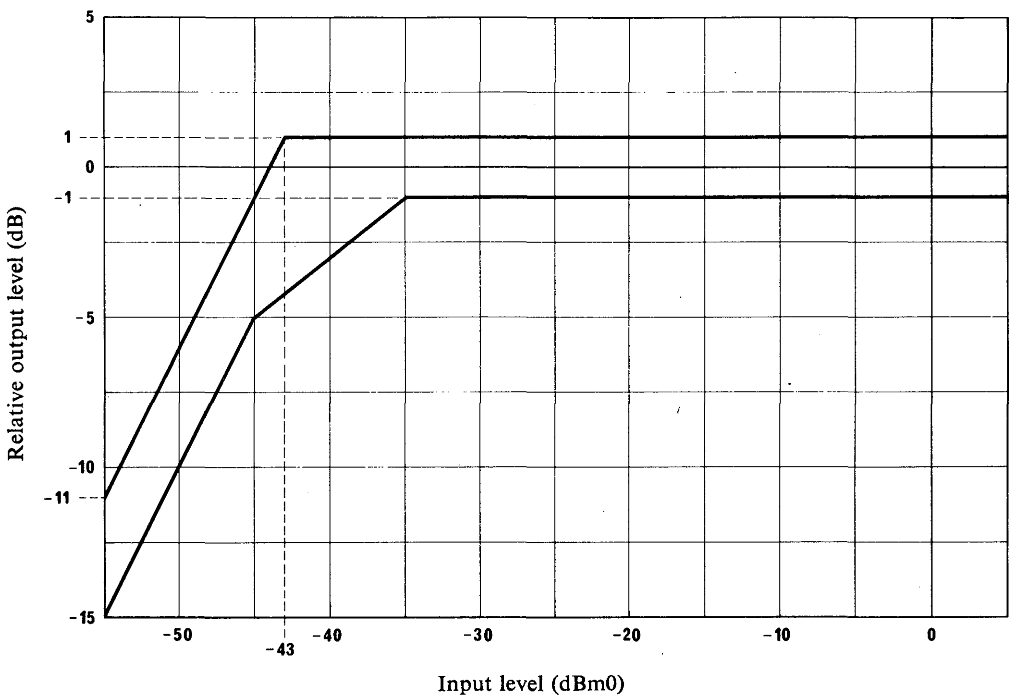
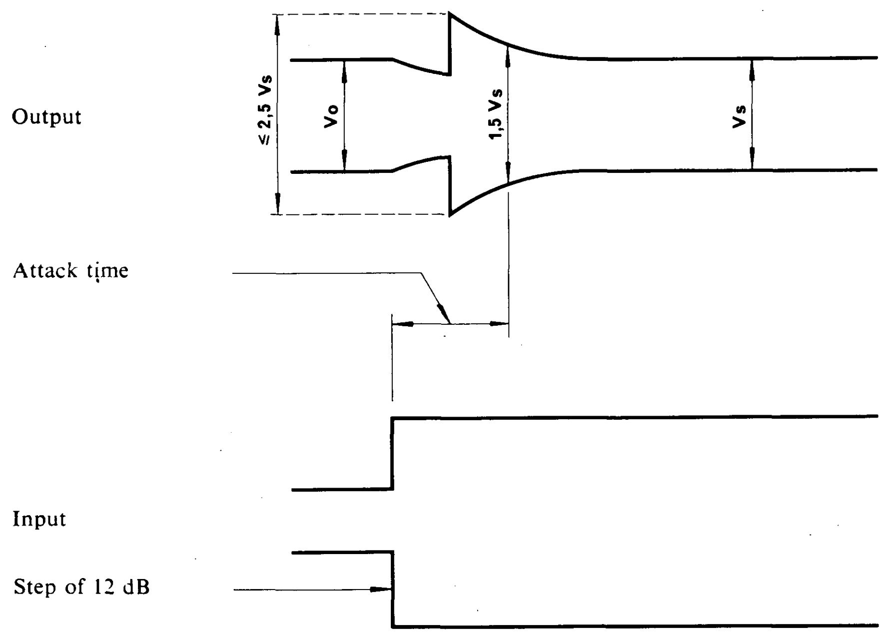
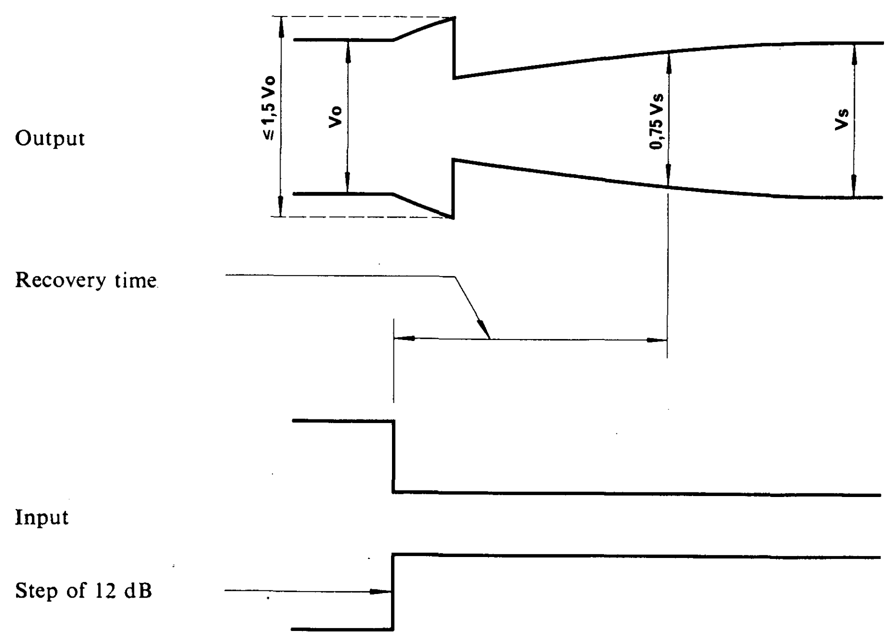


FIGURE 2 – *Input/output characteristic of transmit side*

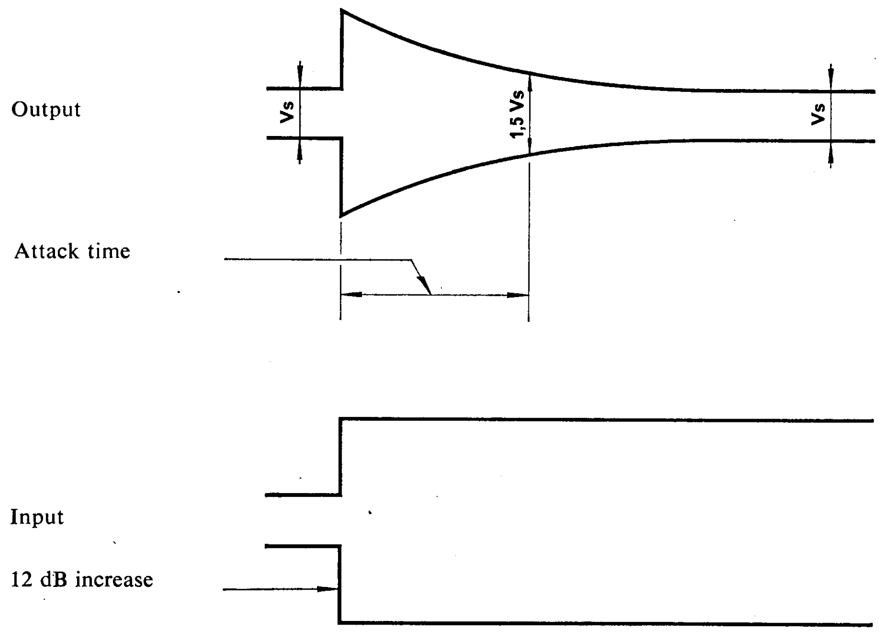


(a) Attack time

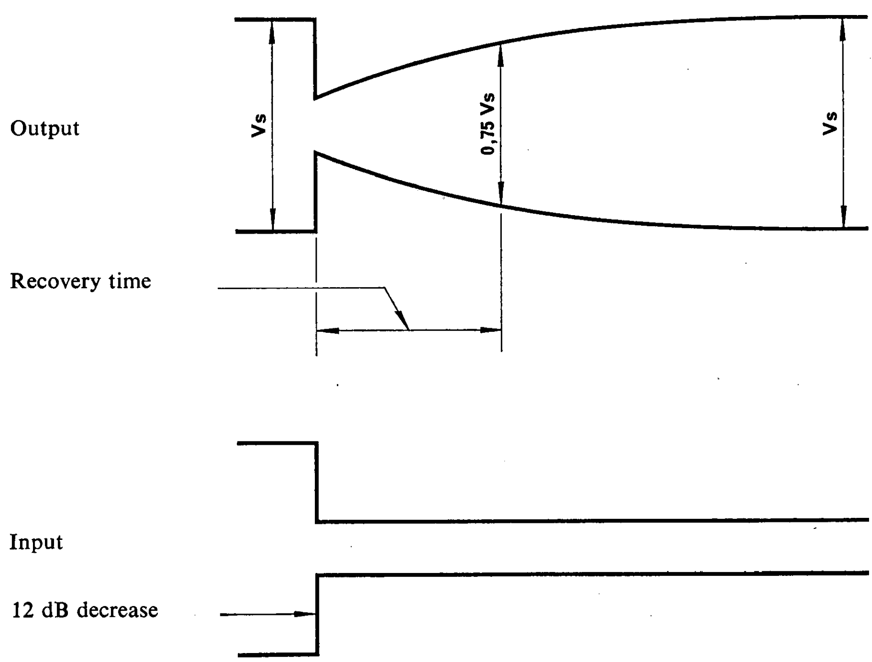


(b) Recovery time

FIGURE 3 – *Transient response of transmit side*

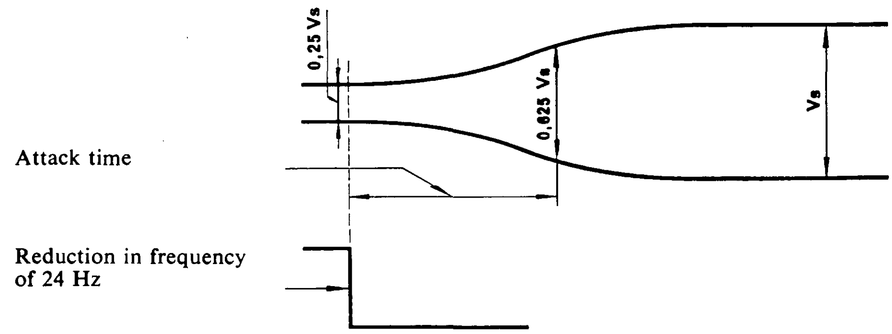


(c) Attack time

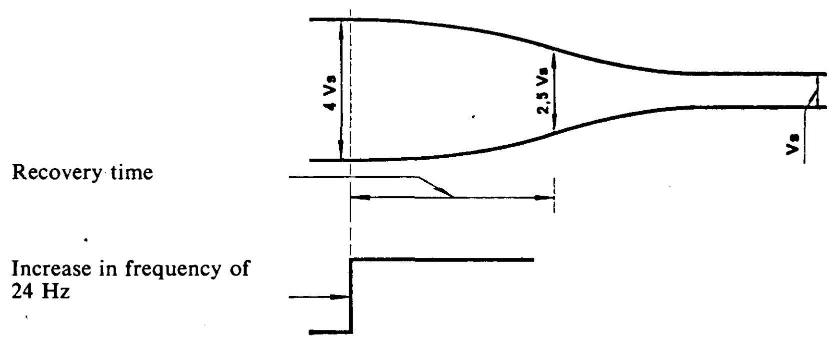


(d) Recovery time

FIGURE 3 (cont.) – *Transient response of fading regulator*



(e) Attack time



(f) Recovery time

FIGURE 3 (cont.) – *Transient response of receive side*

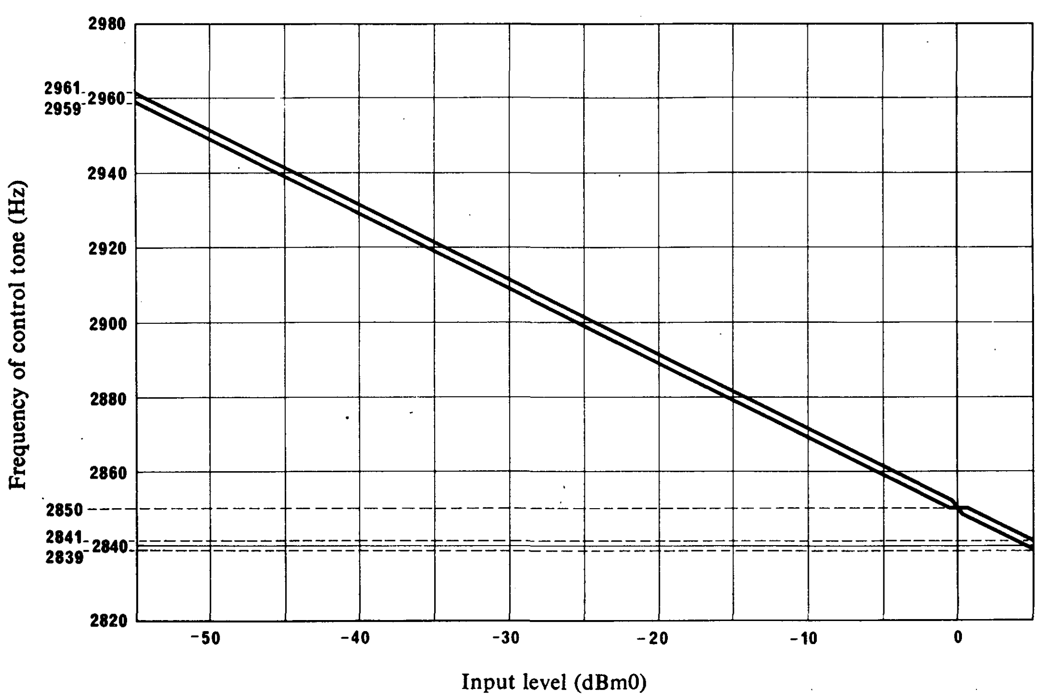


FIGURE 4 – *Variation in frequency of the control tone with changes of input level to the transmit side*

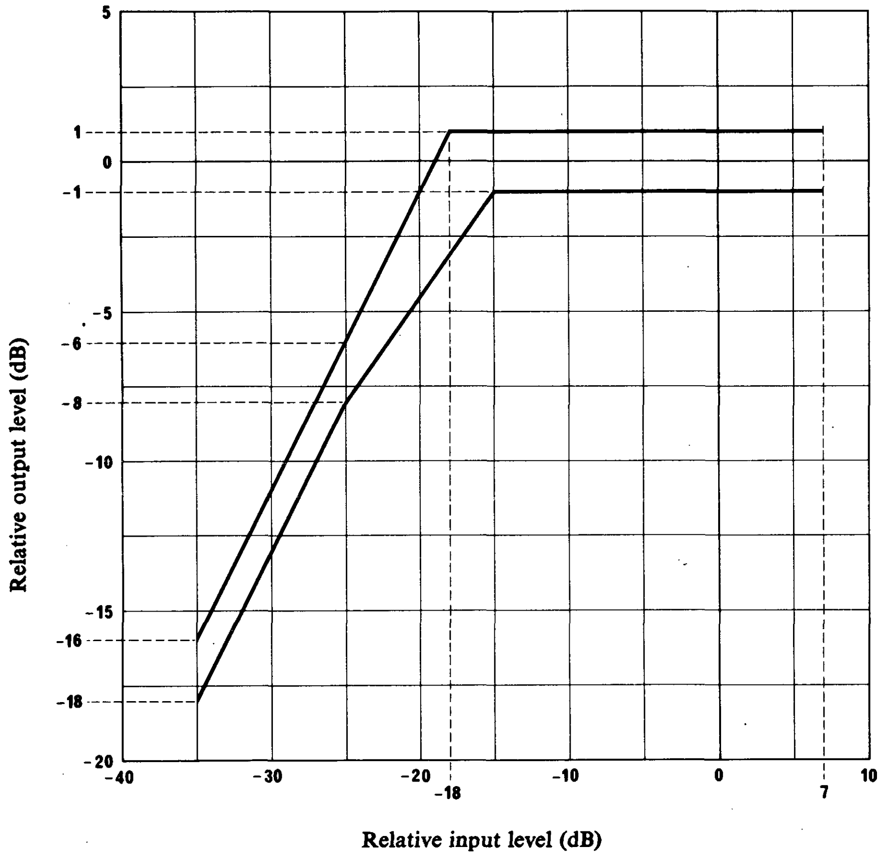


FIGURE 5 – *Input/output characteristic of fading regulator*
(see § 5.3.1.2)

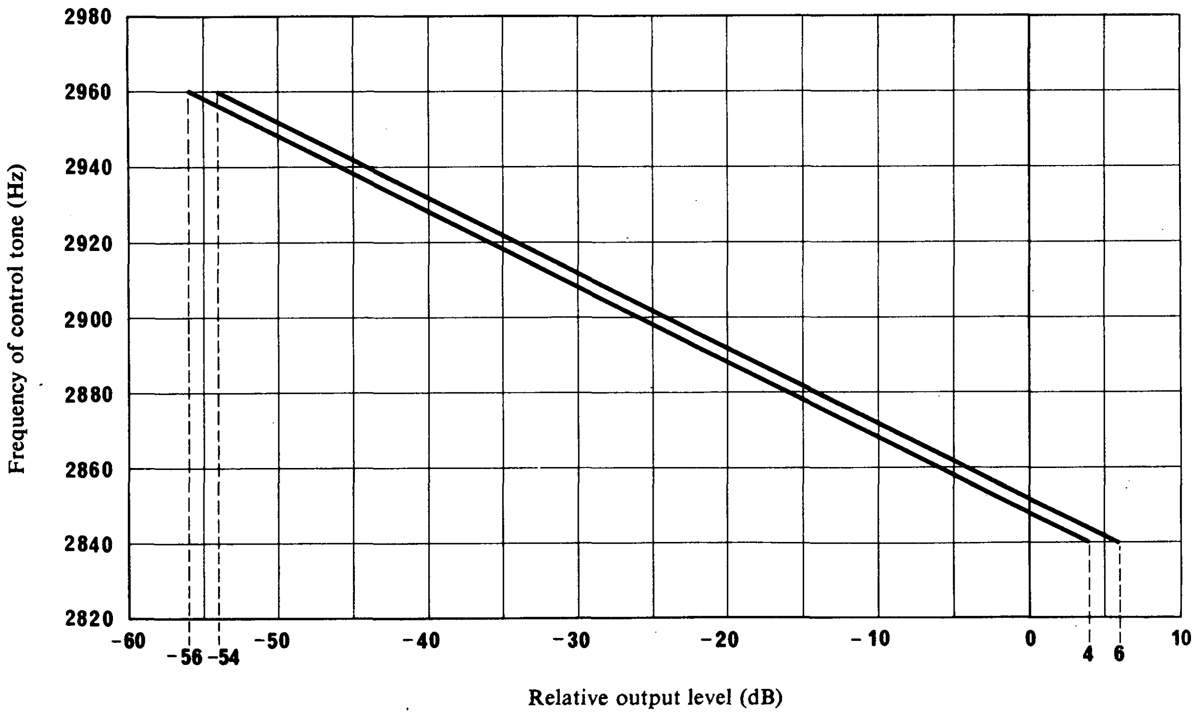


FIGURE 6 – *Variation in output level at the receiver side with change in frequency of the control tone*
(see § 5.3.2.3)

REPORT 354-4

IMPROVED TRANSMISSION SYSTEMS FOR USE OVER HF RADIOTELEPHONE CIRCUITS

(Question 13/3)

(1966-1970-1974-1978-1982)

1. Introduction

This Report provides information on the performance of linked compressor and expander systems which can significantly improve the quality of HF radiotelephone circuits. The principles of these systems are summarized as follows:

For the Lincompex * system, the speech is compressed to a sensibly constant amplitude and the compressor control current is utilized to frequency-modulate an oscillator in a separate control channel. The speech channel, which contains virtually only the frequency information of the speech, and the control signal channel which contains the speech amplitude information, are combined for transmission over a 3 kHz channel. As each speech syllable is individually compressed the transmitter is more effectively loaded than in current practice. On reception both the speech and the control signals are amplified to constant level, the demodulated control signal being used to determine the expander gain and thus restore the original amplitude variations to the speech signal. Because the output level at the receiving end depends solely on the frequency of the control signal, which is itself directly related to the input level at the transmitting end, the overall system loss or gain can be maintained at a constant value. Operation with a slight loss (two-wire to two-wire) permits singing suppressors to be discarded, although echo suppressors will be needed, as on long-line circuits.

Preferred values for the parameters of the system have been given in Recommendation 455.

Another technique which is called Syncompex * (synchronized compressor and expander) is now being developed. This system differs basically from Lincompex in that digital, rather than analogue techniques are used to modulate the control channel. The use of digital modulation for the control information gives the system greater tolerance to end-to-end frequency error, thus widening the range of application.

Characteristics of the Syncompex system are contained in Annex II.

Another system, described as a small automatic HF radiotelephone system, is at an advanced stage of development and undergoing field trial. The objective is to provide small remote communities with a low-cost, low capacity communication system which can access the national switched network without operator intervention. System reliability has been enhanced through the use of microprocessors controlling frequency agile transceivers; this allows a technique to be implemented which affects evaluation and selection of available frequency channels without technical operator attention.

A description of the system is contained in Annex III.

2. Quality assessment

[CCIR, 1966-69a] describes field trials of a radioterminal equipment based on the same principles as Lincompex. A comparison of the quality of a 600 km circuit between Tokyo and Osaka, equipped with this system, and a public telephone circuit routed over a cable or radio relay system is given in Table I. The results are based on interviews with 85 participants engaged in test calls.

3. "In service" performance

The references [CCIR, 1966-69b, c and d] give information on the "in service" advantages obtained with Lincompex.

3.1 [CCIR, 1966-69b] summarizes the results of special observations carried out by trained personnel on the London-Nairobi and London-Johannesburg circuits. Comparisons were made between a channel fitted with the new arrangement and a conventional channel in the same 4-channel group.

* The names "Lincompex" and "Syncompex" are neither proprietary nor do they refer to manufacturers of particular equipments.

TABLE I – *Results of listening test, August, 1967*

Items for interviews	Evaluation	Percentage of calls
Comparisons with public telephone	No difference	47·0
	Lincompex slightly worse than cable	51·8
	Lincompex much worse than cable	0
	No comment	1·2

The results may be summarized as follows:

increase in number of calls passed compared with conventional channels 100%

increased chargeable time per call 6% (88% to 94%)

increased average length of call 6%

percentage of calls graded "smooth" increased by 25% (60% to 85%)

3.2 [CCIR, 1966-69c] summarizes the improvements that have been obtained with "in service use" of Lincompex equipment on circuits between the United States and a number of other countries.

Analysis of traffic patterns on trunk groups having Lincompex-type equipped channels on one or more circuits indicates the following:

– the Lincompex channel handled 26% of the total number of calls in a 12-channel trunk group: almost that of the next three busiest channels in the group;

– the increase in minutes per call on the Lincompex-equipped channel amounted to 16.5%;

– the Lincompex channel accounted for 29% of the chargeable minutes in a 12-channel trunk group;

– the estimated increase in useful circuit time of Lincompex channels was from 16% to 20%.

3.3 [CCIR, 1966-69d] comments upon the advantages that have been obtained by the use of Lincompex equipment on the Johannesburg-London circuit over the period September, 1967 to May, 1968. It draws attention to the possibility of staff reductions, as little or no monitoring is required, and the improvement in the quality of reception of special news "broadcasts" which in general is, with Lincompex, of a sufficiently high standard to permit retransmission without further processing, or, in some cases, being re-read locally.

Table II shows that the Lincompex equipped circuit carried nearly twice as much traffic as the normal circuit during the period of January to April 1968. Table III shows the improvement in relative grade of service offered by the Lincompex system. During the period between 0600 to 1800 UTC the circuit is generally stable, and the advantage of Lincompex is primarily the increase in the quality of the circuit. During the less stable periods 0000 to 0600 UTC and 1800 to 2400 UTC the Lincompex circuit in addition provides a marked increase in commercial time availability.

TABLE II

	Number of calls passed					Duration (min)		Average duration (min)	Percentage effective time
	Jan.	Feb.	March	April	Total	Overall	Effective		
Lincompex	719	633	1198	244	2794	15 574	15 478	5·57	99·38
Normal	377	336	27	719	1459	7 836	7 518	5·37	95·94

TABLE III

Period		Good, quiet (%)	Slightly noisy, commercial (%)	Noisy, un-commercial (%)	Slight interference commercial (%)	Interference un-commercial (%)	Uncommercial due to frequency changes, equipment and line failures (%)	Total time commercial (%)
0000 to 0600 UTC	Lincompex	57.3	19.7	15.0	1.2		6.8	78.2
	Normal	7.6	22.5	15.3	1.5	46.3	6.8	31.6
0600 to 1800 UTC	Lincompex	96.4	1.3	1.0			1.3	97.7
	Normal	70.0	26.6	2.1			1.3	96.6
1800 to 2400 UTC	Lincompex	57.2	24.6	8.4	0.4	1.1	8.3	82.2
	Normal	7.7	32.3	22.2		29.5	8.3	40.0

The document concludes by summarizing the improvements as follows:

- less time required by traffic operators for passing details of booked calls, and consequently a higher traffic carrying capability,
- easier conversation, and consequently a higher percentage effective circuit time,
- transmission of news items of a standard which permits retransmission to broadcast listeners, thus obviating the necessity to re-read locally,
- very little maintenance,
- a minimum of attention by the technical operators.

3.4 Eight Syncompex equipments have been brought into trial service in Canada over a period of two years as development has progressed. The subjective improvement obtained during normal telephone conversation is judged to be comparable to that of Lincompex, and it has been observed that the improvement is maintained when end-to-end frequency errors of up to 20 Hz are present.

4. Modification of Lincompex system to provide echo suppression capability

4.1 Lincompex-equipped radiotelephone circuits normally require conventional echo-suppressor devices (CCITT Recommendation G.161, Fascicle III.1) at the terminal ends of the voice circuit in order to overcome problems of echo created by the imperfect balance of the four-to-two-wire hybrid.

4.2 [CCIR, 1970-74a and b] describe methods that utilize the control channel of the Lincompex system and provide echo-suppression within the Lincompex system. Developed independently by the two administrations the designs are based on almost identical principles.

4.3 Both systems cause the far-end expander to provide maximum loss whenever the near-end received signal level is greater than the near-end transmitted signal level; the far-end expander operates in its normal mode whenever the near-end transmitted signal level is greater than the near-end received signal level.

Three basic differences exist between the two systems:

- In the U.S.S.R. system the far-end expander provides maximum loss until the near-end transmitted signal exceeds a predetermined threshold level.
- In the Japanese system the far-end expander provides maximum loss whenever the near-end received signal exceeds a predetermined threshold level, except during the break-in condition.
- In the Japanese system the near-end expander provides 6 dB additional loss whenever the near-end transmitted signal exceeds the near-end received signal level by a predetermined value.

4.4 Tests on simulated HF radio facilities with one-way propagation times of up to 100 ms [CCIR, 1970-74a] and on long HF radio paths [CCIR, 1970-74b], show that both systems operate satisfactorily, and in addition both systems operate compatibly when the far-end of the voice circuit is equipped with conventional echo-suppressors.

4.5 [CCIR, 1970-74a] suggests that the operational parameters of their system are substantially in accordance with the characteristics for echo-suppression devices set forth in CCITT Recommendation G.161.

4.6 Details of the Japanese and U.S.S.R. systems are contained in the attached Annex I to this Report.

5. Necessity for additional information on the Lincompex system

The characteristics of the Lincompex system set forth in Recommendation 455 are the minimum requirements necessary to ensure system performance and compatibility. Additional information is desired which will lead to improved performance, particularly in the areas concerning large signal transient response, such as can occur during dialling or at the onset of speech.

Tests wherein the fading regulator characteristics were modified to provide a wider operating margin, a median gain position during the no-signal condition, more rapid gain decrease on attack and syllabically-controlled gain-increase show the possibility for such improvement [CCIR, 1970-74c].

Recommendation 455, §§ 5.2 and 5.3 specify the response of the Lincompex system to sudden changes in input signal level of 12 dB in accordance with CCITT practice. It is not established that the response to greater signal changes, such as occur at the onset of speech, can be satisfactorily extrapolated from the Recommendation.

Further, in the absence of the control channel signal, the gain of the expander could with advantage revert to a predetermined value of gain without exhibiting any disturbing transient phenomena [CCIR, 1970-74c]. The value of the predetermined gain would have to be adjustable so as to conform to the noise requirements of the various administrations. (Such a facility is already provided in some existing equipment.)

Further studies leading to the specification of characteristics in the above-mentioned areas are desirable.

REFERENCES

CCIR Documents

[1966-69]: **a.** III/19 (Japan); **b.** III/7 (United Kingdom); **c.** III/29 (USA); **d.** III/30 (Republic of South Africa).

[1970-74]: **a.** 3/47 (Japan); **b.** 3/57 (U.S.S.R.); **c.** 3/15 (France).

ANNEX I

A NEW ECHO SUPPRESSION SYSTEM FOR A LINCOMPEX-EQUIPPED CIRCUIT

1. The essentials of the new system comprise a comparator which examines the signal levels at the four-wire side of the system hybrid. The output of the comparator is connected to the frequency-modulated control-tone oscillator. During reception of speech from the distant terminal, the receive-side of the two inputs to the comparator predominates significantly. The comparator produces an output which is used to clamp the control-tone oscillator frequency to the upper end of its range; consequently, the distant-end expander will close down to received signals, preventing the passage of any echoes from the near end. During transmission of speech from the near terminal, the transmit-side of the two inputs to the comparator predominates. The comparator output is inadequate to clamp the control-tone oscillator, which thus operates normally.

To allow for permissible transmission errors in the co-relation of envelope levels and control-channel signals and for protection against undue sensitivity to interference, noise or insignificant signal levels, the comparator is given an operational threshold.

The systems described in [CCIR, 1970-74a and b], differ mainly in aspects of their comparator configurations, and the essential differences are brought out in the following descriptions.

2. [CCIR, 1970-74a]

2.1 *General*

Fig. 1 indicates schematically the signal comparator and associated elements of the Lincompex terminal.

Operation of the system is as follows:

2.1.1 In the presence of received signals only (no transmit signals other than echoes):

As the discriminator d.c. output exceeds a pre-set threshold level, the threshold detector M produces an output which passes via the inoperative inhibitor N to clamp the frequency of oscillator C at 2980 Hz. The remote-terminal expander suppresses the receive-side output at that terminal. No signal appears at the output of the level comparator L.

2.1.2 In the presence of transmitted signals only, the threshold detector M produces no output; the level comparator L produces an output; oscillator C functions normally; the discriminator control reduces receive-path output by 6 dB.

2.1.3 In the presence of signals in both paths:

- When the transmitted signal predominates;
  operation is as in § 2.1.2; however, the threshold detector will operate.
- When the received signal predominates, the level comparator L will produce no output. The frequency of oscillator C will be clamped at 2980 Hz if the threshold detector M is operated.

2.2 *Test results*

2.2.1 The new system worked normally with an echo return loss across the four-wire termination of more than 4 dB.

2.2.2 An acceptable speech quality was obtained in a simulator test for the case of the longest HF circuit with a one-way propagation path time of 100 ms.

2.2.3 Tests between Lincompex terminals, one of which was equipped with the new echo-suppression system and the other of which was equipped with a conventional echo suppressor, showed the terminals to be fully compatible.

2.2.4 Typical test data on echo suppression follow in Table IV.

TABLE IV – *Echo-suppression operate time*

Final build-up level of received signal	Echo-suppression operate time
6 dB above threshold	3·5 ms
3 dB above threshold	11·0 ms

3. [CCIR, 1970-74b] *

3.1 *General*

Fig. 2 indicates schematically the signal comparator and associated elements of the Lincompex terminal, for one of possible variants of the system.

Operation of the system is as follows:

3.1.1 The signal comparator comprises units P, Q and R. The potential at point c is proportional to the difference in levels between the transmit and receive sides.

3.1.2 Under condition of no signal in either path, an output from R clamps the frequency of oscillator C to the upper end of its range, and the distant-end expander is held closed.

* See [Kloeck, 1970] and [Bukhviner *et al.*, 1971].

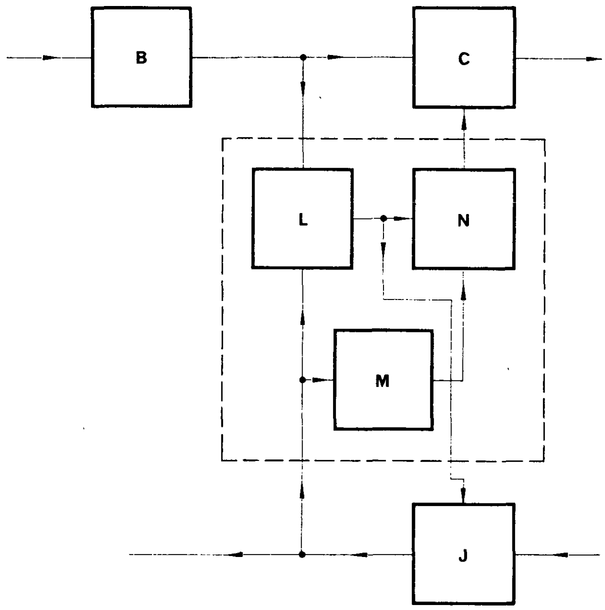


FIGURE 1 – *Schematic diagram of echo-suppression – Japanese system*

Lincompex Units

B: Amplitude assessor
C: Frequency-modulated oscillator
J : Frequency discriminator

Additional Units

L : Level comparator
M: Threshold detector
N : Inhibit circuit

3.1.3 When signals exist in the receive path only, operation is as in § 3.1.2.

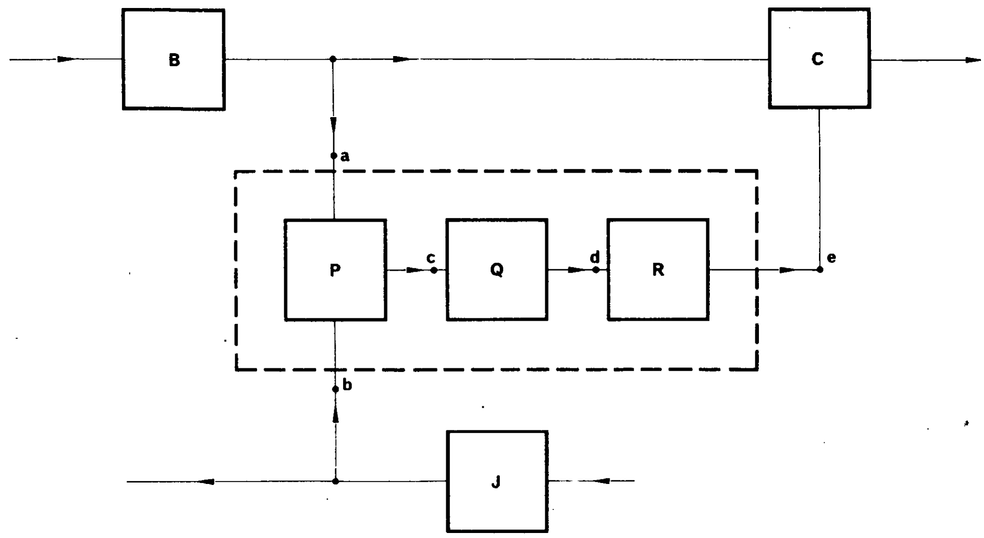
3.1.4 When signals exist in the transmit path only, the potential at point e changes. When a pre-set threshold level (ΔU) at d is exceeded, the output from R is removed and the oscillator C operates normally.

3.1.5 When signals exist in both paths the level differential will determine which path has priority.

3.2 *Test results*

Field trials over long-distance HF radiotelephone trunk circuits, show a high degree of efficiency in echo and singing suppression. The new system is demonstrably fully compatible with Lincompex terminals equipped with functionally independent echo suppressors.

Experience shows use of the new-type echo-suppressor system to improve the radio-circuit performance and to enhance equipment reliability. The operate time (τ) and release time (T) of the echo suppressor are 4 ms and 200 ms respectively.



Lincompex units

B: Amplitude assessors
C: Frequency-modulated oscillator
J: Frequency discriminator

Additional units

P: Subtraction stage
Q: Integrator
R: Threshold stage

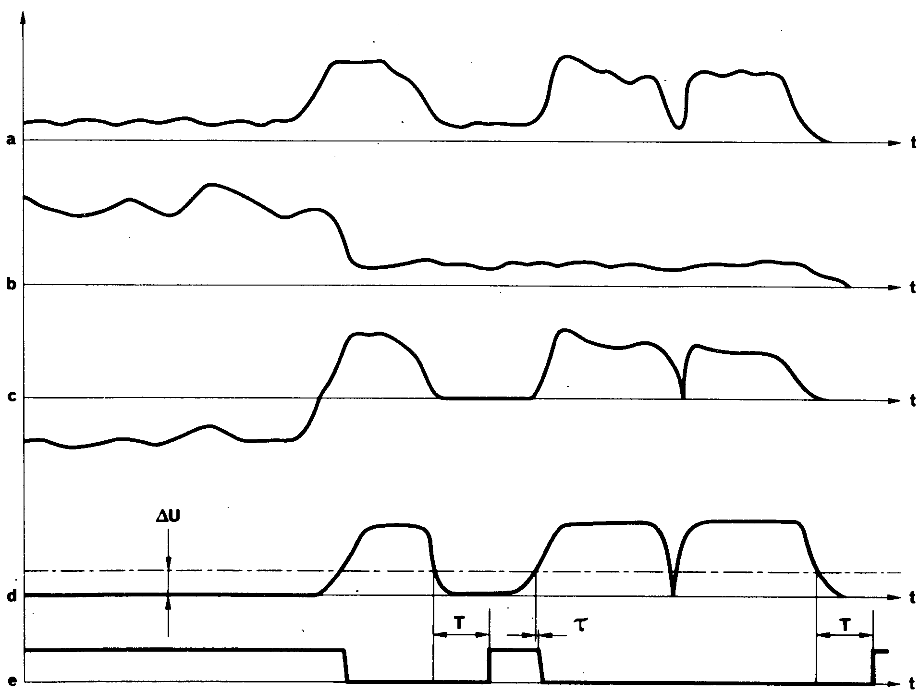


FIGURE 2 – *Schematic and timing diagram of echo-suppression – U.S.S.R. system*

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ANNEX II

SYSTEM DESCRIPTION OF SYNCOMPEX

The Syncompex system [Chow and McLarnon, 1978] is being developed to bring the advantages of linked compressor and expander systems to all classes of HF telephony service.

In its simplest application, Syncompex may be connected to a radio system at the audio input and output points. In equipment developed specially, the FSK control channel may be additionally used for automatic gain control and automatic frequency control by suitable connections to the radio frequency circuits.

Block diagrams of the system are shown in Figs. 3a and 3b.

1. Transmission

The output of the audio bandpass filter is sampled by an analogue-to-digital (A-D) converter at 9600 samples per second under the control of a microprocessor. The microprocessor stores 128 successive samples defined as a "syllable" with duration 13.33 ms. The microprocessor determines the instantaneous gain to be applied to each syllable. The compressor gain is limited to 6 dB steps from 0 dB to 48 dB with gain change limited to a single 6 dB step every 13.33 ms syllabic period. The direction of the gain change is determined by the instantaneous amplitude of the voice, an increasing amplitude causing a decrease in the gain of the compressor by 6 dB. The microprocessor, after applying the appropriate gain to the samples, drives a digital-to-analogue (D-A) converter which converts the samples to analogue form which after filtering constitutes the audio input to the transmitter.

The gain change applied in the compression process is available at a digital output port of the microprocessor which is used as input to a pair of FSK modulators. The FSK signals called the control channel are centred at 1105 and 2125 Hz and have ± 42.5 Hz shift. The compressed voice is eliminated from two bands centred about 1105 and 2125 Hz to allow the FSK signal to be transmitted. Identical information is transmitted in the two FSK channels to minimize the effects of selective fading and narrowband interference often encountered in HF circuits.

2. Reception

The receiver output is separated by filters into the two FSK signals and the compressed voice signal. Each FSK channel is separately demodulated. They are then diversity combined so that fading of one FSK channel does not cause errors to occur in the combiner output. The compressed voice, after appropriate filtering, is sampled by an A-D converter operating at 9600 samples per second under the control of the microprocessor. The microprocessor adjusts the gain of the syllable according to the information received in the control channel. A gain change of +6 dB in the compressor is matched with a −6 dB change in the expander. The analogue output is formed by filtering the D-A converter output.

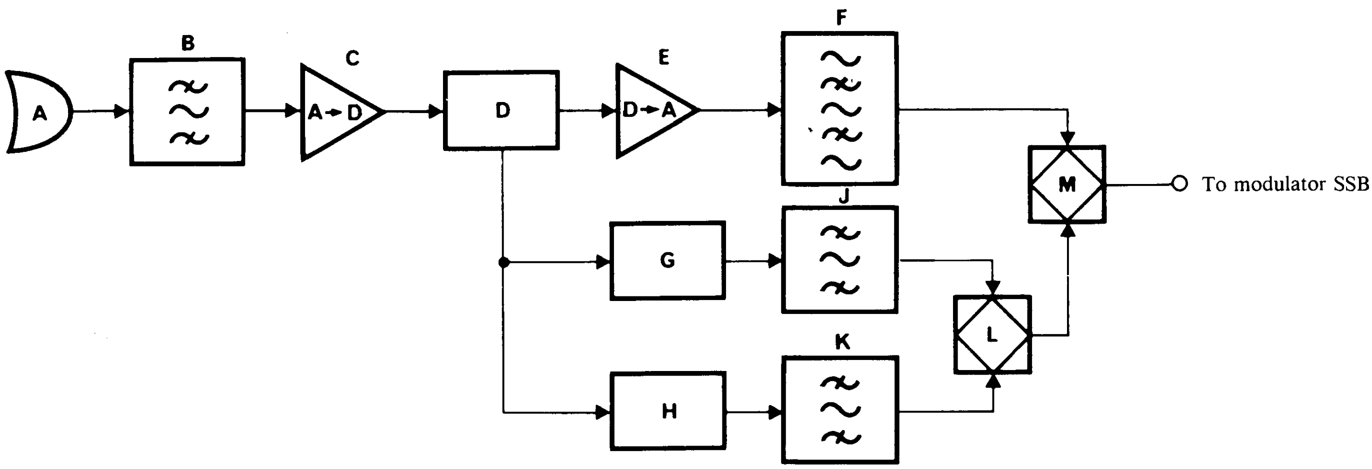

FIGURE 3a – *Block diagram of Syncompex compressor*

A: microphone
B: bandpass filter 300-2800 Hz
C: analogue to digital (A-D) converter
D: microprocessor
E: digital to analogue (D-A) converter
F: band elimination filter
— stop bands at 1105 and 2125 Hz

G: FSK modulator 1105 ± 42.5 Hz
H: FSK modulator 2125 ± 42.5 Hz
J: bandpass filter 1105 ± 125 Hz
K: bandpass filter 2125 ± 125 Hz
L: hybrid
M: hybrid

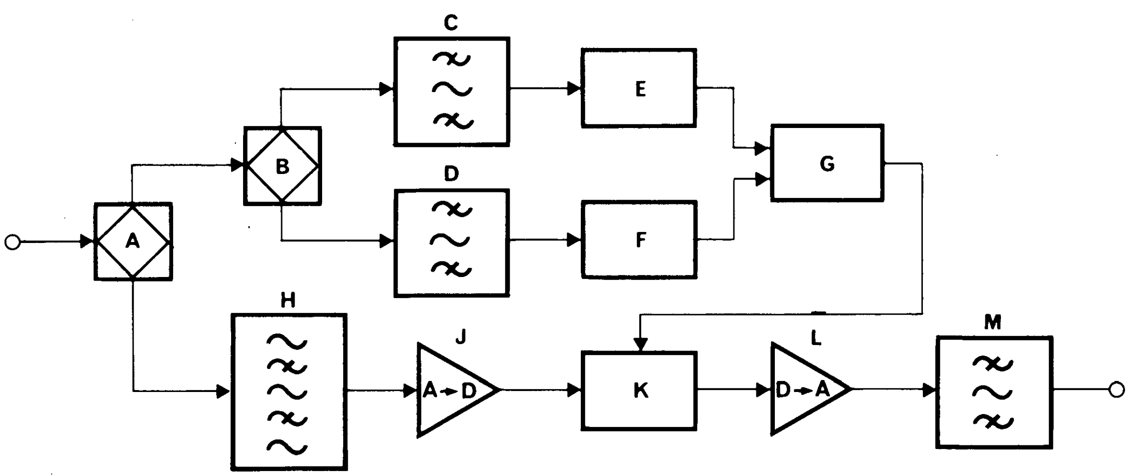

FIGURE 3b – *Block diagram of Syncompex expander*

A: hybrid
B: hybrid
C: bandpass filter 1105 ± 125 Hz
D: bandpass filter 2125 ± 125 Hz
E: FSK demodulator 1105 ± 42.5 Hz
F: FSK demodulator 2125 ± 42.5 Hz
G: diversity combiner

H: band elimination filter
— stop bands at 1105 and 2125 Hz
J: analogue to digital (A-D) converter
K: microprocessor
L: digital to analogue (D-A) converter
M: bandpass filter 300-2800 Hz

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ANNEX III

A SMALL AUTOMATIC RADIOTELEPHONE SYSTEM

1. Introduction

An automatic HF radiotelephone system [Chow *et al.*, 1981] developed in Canada is undergoing a field trial as an adjunct to the switched telephone network. The system has enhanced performance with the following general characteristics:

- real-time HF frequency evaluation and selection;
- access to the switched network without operator intervention;
- storage and updating of information for channel selection, billing, and traffic evaluation;
- economical for deployment in remote areas;
- enhanced reliability through modern design.

2. System configuration

The network of HF stations is allocated a number of frequencies (up to 8) covering all expected propagation conditions. All HF subscribers can be accessed by or can access any subscriber within or outside of the HF network. The HF radiotelephone system described operates in a voice activated mode using the same frequency in both directions of transmission (simplex mode). This does not preclude future employment of different frequencies in the two directions of transmissions (half-duplex or full-duplex mode).

3. System description

The automatic HF station consists of an all-solid-state 100 W HF/SSB transceiver, a broadband antenna, a 75 bit/s modem, and a controller/interface unit which provides the automatic functions and interface characteristics for telephone compatibility.

A three-station system deployed in Canada is depicted in Fig. 4. Two types of remote station are shown, one having a single telephone and the other interconnected to an optional small PABX switch in order to serve a larger community. Since the master station would normally be located in a larger community, it was also provided with an optional PABX switch. This switch could be eliminated if not required to service subscribers in the vicinity of the master station; its presence is not required in order to interface the HF radiotelephone to the switched network.

All subscribers in the system are assigned seven digit numbers according to the standard numbering plan; however, abbreviated (three digit) dialling is used for calls within the HF network. An access digit is used to differentiate these calls from those destined for the direct distance dialling network.

When no calls are taking place in the system the master station continuously cycles through the assigned channels (eight in the experimental system), transmitting a 48-bit digital message on each one. The digital messages are in the form of FSK data using the 75 bit/s modem. To avoid the problems of selective fading, in-band frequency diversity is employed.

The remote stations synchronize themselves to the master station and maintain short-term statistics on the quality of the channels, derived from an examination of the integrity of the received data. The quality assessment is partly based upon detection of bit errors by means of error detection coding in the data. In addition, a "pseudo-error" measurement technique [Gooding, 1968] is used to define the selection process when several channels have similar error rates

. When a landline subscriber dials a number requiring the HF network, the master station and the appropriate remote station begin an interchange of digital messages and transfer to the channel selected by the channel evaluation algorithm. If the procedure is successful, the voice paths are established and the usual telephone supervisory tones are transmitted to the calling party. If the HF network is unavailable or the call set-up procedure fails for some reason, a fast busy tone is returned to the calling party as an indication that he should attempt the call later. When one party hangs-up at the end of a call the HF station to which he is connected begins transmitting a digital "disconnect" message. This results in another brief message interchange and the system is returned to the idle state.

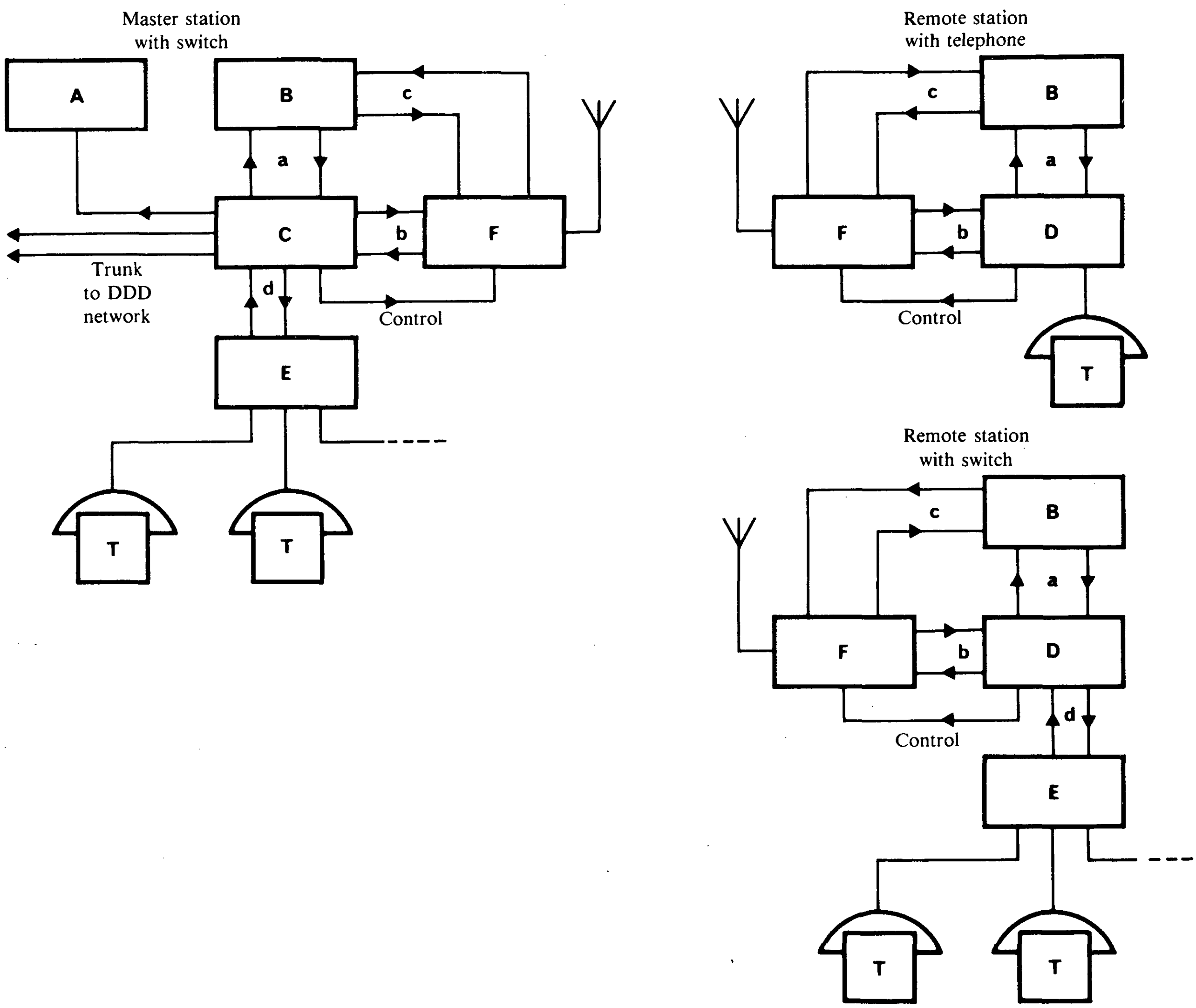

FIGURE 4 – *Block diagram of experimental system*

A: printer (call detail recording)
B: 75 bit/s modem
C: master controller interface unit
D: controller interface unit
E: PABX switch
F: HF transceiver
T: telephone set

a: data
b: speech
c: data (modulated)
d: tie trunk

In the case of a call from one remote station to another the procedure begins as above but when the master station recognizes from the contents of the message interchange that the destination of the call is another remote station, it transfers control temporarily to the remote station which initiates the call. The role in the channel evaluation procedure played by the master station is taken over by the remote station initiating the call during the call set-up. When the call set-up is complete the master station returns to the idle state and is available for other calls (the channel in use by the call is automatically busied). The remote stations therefore communicate directly with one another during the call; this both frees the master station for other calls and avoids problems associated with operating two HF links in tandem.

When one party hangs-up, the master station is informed that the call is ended. The "disconnect" process occurs as described before.

4. Test results and evaluation

Test and evaluation were carried out in two phases. The first phase tested the HF portion of the system alone. The second phase tested the HF system linked to the switched telephone network. Calls were made to and from the system from the switched network without operator intervention. The test sites were selected to provide radio circuits ranging from 60 km to 1000 km. Eight frequencies from 2.6 MHz to 21 MHz were used in each phase. Each phase lasted for about four months, and the stations were manned for periods of several days. During the days when the stations were not manned, automatic recording devices were activated to continuously measure the signal quality on each frequency.

In analyzing the channel quality data, two levels of performance were distinguished. The first, referred to as level 1, is reached when the bit error rate on the channel is such that virtually all digital messages are received without errors. Such a channel generally offers very good voice communications. The criterion for level 2 is that approximately one-third or more of the messages are received without error. This level was arrived at empirically and corresponds roughly to the lowest quality level at which voice communications can be carried on without major difficulties. Several dialling attempts will often be required when the channel quality is near this lower limit.

The results of the on-the-air tests were as follows: level 1 quality on at least one channel was attained for an average of about 70% of the test period. Level 2 quality on at least one channel was attained for 98% of the time (see Fig. 5).

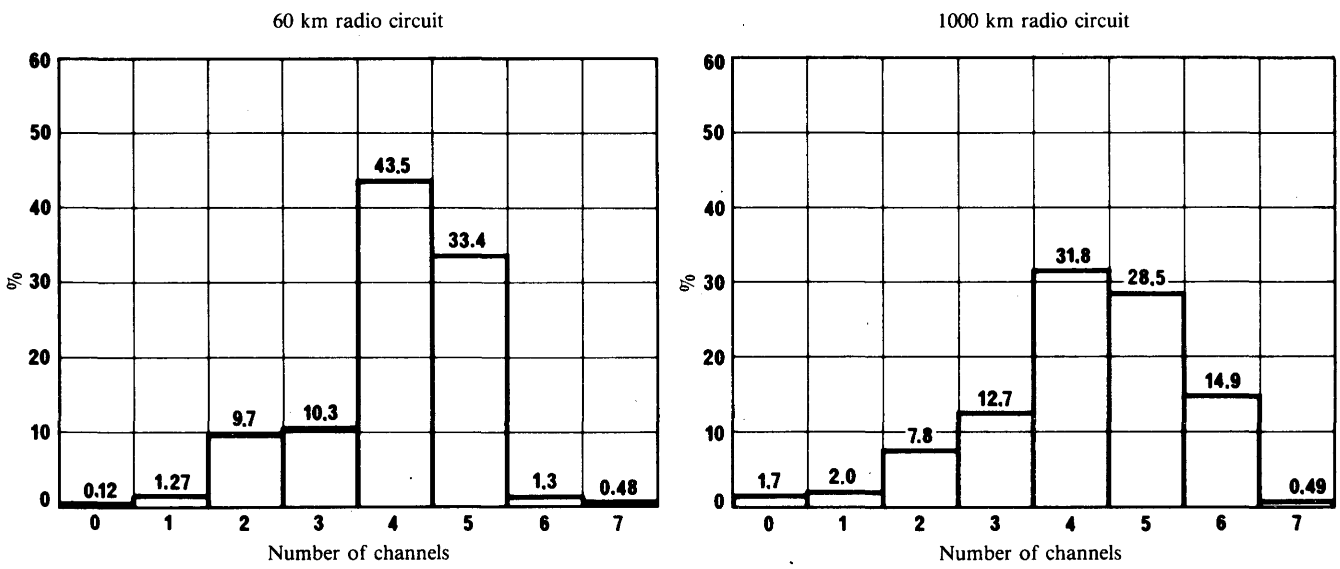

FIGURE 5 – *Percentage of test period for which the number of channels exceeded level 2 quality*

5. Comments on the test results

Disturbed propagation conditions were encountered several times during the test period, including geomagnetic storms on at least two occasions. The effects of these storms were observed in the recordings obtained during these periods and resulted in two blackouts each of about 6 hours duration. These periods were short compared to the total time of the trial and were included in the statistics.

The test results revealed that there was nearly always more than one usable channel available for a given circuit; in fact, there were at least four channels available in the majority of instances. Moreover, the set of usable channels for two different circuits at a given time was often quite different, particularly where the circuit lengths differed considerably. One conclusion that might be drawn from these observations is that the availability of a suitable channel for setting up a call tends to remain relatively high even if several of the total set of channels are busy. There is also a strong indication that fewer than eight channels would provide good propagation probability; in fact, if only the best four channels for each circuit had been available, a usable channel would still have been present for more than 98% of the test period.

Finally, the results of the on-the-air tests clearly demonstrated the value of real-time channel evaluation. Many instances of propagation well above the predicted maximum useable frequency (MUF) were encountered. On the 60 km circuit, for example channels at 13.7 MHz and 20.5 MHz were useable on a number of occasions when the predicted MUF was in the 5 to 7 MHz range. Interference from distant stations sharing the same channel, another unpredictable element in HF communications, was also found to be a very important factor in determining the best channel to use. Fig. 6 provides a graphic illustration of the unpredictable nature of HF channels and the utility of real-time channel evaluation. The best channel, as determined by the channel evaluation algorithm, was recorded for each circuit at the same time of day on successive days. The percentage of days during the test period that a given channel was best at that time, is shown by the histogram. The approximate frequencies of the channels numbered 1 through 8 were 3.2, 5.3, 6.8, 7.6, 9.4, 11.6, 13.7 and 20.5 MHz respectively. Even for the 60 km circuit it can be seen that the higher-frequency channels were best for a significant proportion of the time, even though these frequencies were above the MUF.

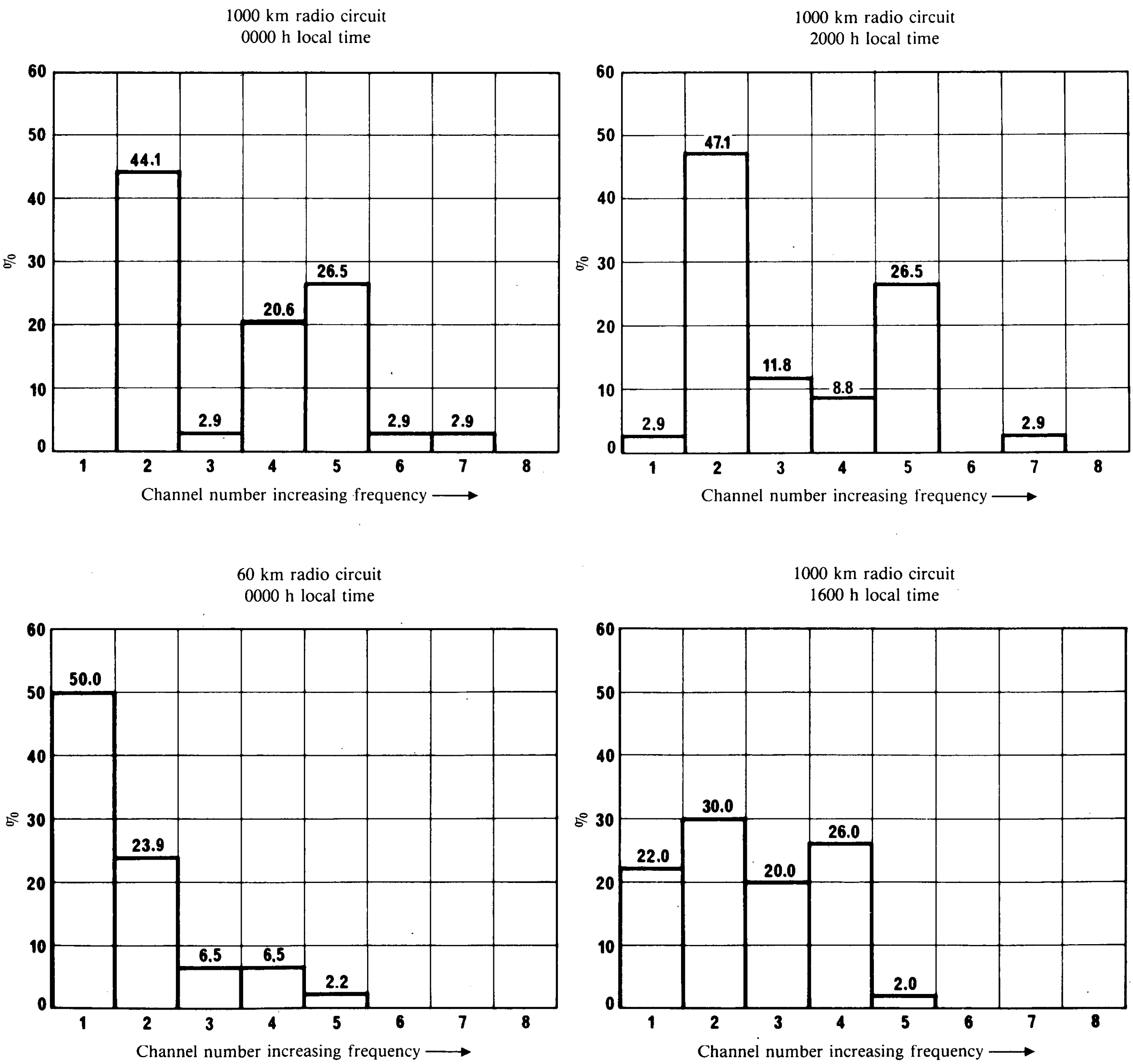

FIGURE 6 – *Distribution of best channels at various times of day*

Additional field trials are in progress in which Syncompex [Chow and McLarnon, 1981] is incorporated. The addition of Syncompex would improve system performance and voice quality at little additional cost because the control channel portion of the Syncompex is used in place of the modem.

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REPORT 434-1

SEMI-AUTOMATIC WORKING ON HF RADIOTELEPHONE CIRCUITS

(Question 13/3)

(1970-1974)

1. In view of the difficulty of connecting HF radiotelephone circuits to international automatic exchanges using CCITT signalling code No. 4 or No. 5, the French PTT Administration, convinced of the advantages of semi-automatic operating, developed and brought into use in 1966 semi-automatic dialling devices which are based on the following principles:

A circuit is specially assigned for traffic between OUTGOING country A and INCOMING country B. The information given by the operator in country A – seizing, numerical, clear-forward – is converted into voice-frequency signals by a device placed in the radioterminal centre. The signals are transmitted in this form to the other terminal, where a receiving device restores the outgoing signals and performs the seizing, dialling etc. at the automatic switching equipment in country B, just as a subscriber in that country would do. The operator at A is thus "remote-connected" to the switching system in country B.

The transmitting and receiving devices required can be accommodated in the network connection cabinets at both terminals without any adaptation of these equipments.

This system has proved entirely satisfactory and its use is limited only by the quality of the channel used for the call. It is being introduced on a wide scale by the French Administration.

2. Recommendation 455, in answer to Question 13/3, describes an improved transmission system for HF radiotelephone circuits (Lincompex). In [CCIR, 1970-74a] tests are reported that show that even with Lincompex, satisfactory operation of CCITT signalling system No. 5 is difficult over long-distance HF radio paths, although it might be possible over short paths not subject to selective fading. Interface equipment which would reduce the effects of selective fading and of interference might be designed.

Tests with the signalling system developed by the French Administration described in § 1 have given much more satisfactory results. Tests were carried out with this system and Lincompex through a fading simulator and, later, over a radio link from London to Johannesburg with a return cable circuit. Five-digit test numbers were sent repetitively over the circuit, the sample size being at least 300 calls. In the fading simulator tests, near-end noise was introduced to give specific non-fading signal-to-noise ratios. With a 20 dB signal-to-noise ratio the average success rate was 99.5 per cent for both selective and non-selective fading conditions. When the signal-to-noise ratio was reduced to 15 dB success rates of 96 per cent for selective fading and 97.5 per cent for non-selective fading were obtained. The London-Johannesburg circuit tests showed a success rate of over 98 per cent.

3. [CCIR, 1970-74b] describes another semi-automatic signalling system which is successfully used over Lincompex HF radio circuits. The operator is connected to a distant exchange via a radio circuit which functions in a similar manner to a d.c. circuit.

Two states, "current" and "no-current" are required to mark the conditions in the transmission of signalling information. The *no-current* state is transmitted as an FSK signal consisting of 100 baud reversals on a centre frequency of 2500 Hz by using a shift of 200 Hz (f_1 = 2400 Hz and f_2 = 2600 Hz). The *current* state is marked by the absence of signal.

Some examples of signalling conditions on the radio circuit are:

No traffic: a "no-current" state is established and is indicated on the radio circuit by the transmission of a FSK signal.

Seizing: which establishes a "current" state and is indicated over the radio circuit by the removal of the FSK signal.

Dialling: a sequence of elements (60 ms) of "no-current" state and elements (40 ms) of "current" state.

Speech period: a "current" state (no FSK signal).

Clear: a "no-current" state (restore FSK signal).

The received signal is fed to an impulse demodulator. A guard circuit is inserted which protects against false operation on speech currents. During idle time, the presence of the control tone and the FSK signal shows that a radio circuit has been established.

The use of the two frequencies 2400 and 2600 Hz permits the application of frequency diversity techniques in the signalling receiver. The modulation rate of 100 bauds in the FSK signal differs sufficiently from the syllabic rhythm of 5 to 15 Hz in speech.

When, during the transmission of signalling information, the level of the Lincompex control tone in the guard circuit drops by more than 30 dB, the process of setting up a circuit is stopped and a "number engaged" tone is transmitted back to the operator.

4. Tests described above suggest that the use of a frequency-modulated sub-carrier could provide an answer to the problem of using CCITT signalling system No. 5 over HF radio circuits. Studies are continuing along these lines.

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REPORT 353

USE OF COMMON-FREQUENCY SYSTEMS ON INTERNATIONAL RADIOTELEPHONE CIRCUITS

(Question 23/3)

(1966)

1. Introduction

This Report deals with the technical characteristics required for common-frequency operation of radiotelephone circuits using single-sideband and independent-sideband emissions.

2. The characteristics to be specified for radiotelephone systems using the principles of common-frequency operation

It is preferable to use the channel configurations shown in Recommendation 348 and only to shift the radiated frequency spectra between the two directions of transmission by about 150 Hz when using reduced carrier.

3. Minimum difference in level, at the input of the receiver, between the received signal from the distant station, and signals from the nearby transmitting station, to avoid interference between the wanted signal and that from the nearby transmitter operating at the same frequency

In the fixed service, the signal level received from the nearby transmitting station is usually lower than that from the distant station. However, if the signal from the nearby transmitting station exceeds the signal from the distant station by a considerable amount, the distortion products generated in the nearby transmitter will appear as cross-talk in the remaining channels of the distant multi-channel system. Tests have indicated that, where the nearby transmitter has an intermodulation level (see Recommendation 326) of 30 dB, the signal from the nearby transmitter should not exceed that from the distant transmitter by more than 10 dB.

4. The extent to which the use of transmitting and receiving antennas with different characteristics reduce the possibilities of application of this technique

For point-to-point commercial communications, where the separation between transmitter and receiver of one terminal is approximately 30 km, it is not normally necessary to take such a problem into account.

5. The extent to which the possibilities of application of this technique are reduced by the presence of different noise levels at the receiving location

The effectiveness of the common-frequency technique is independent of the noise level at the receiving station.

6. Other factors to be taken into account when planning systems

6.1 *Characteristics of the carrier filter*

In several instances of the practical application of this type of operation, the crystal filter used in the carrier branch amplifier for isolating the reduced carrier had a nominal bandwidth of 20 Hz. The actual characteristics of this filter are in Table I as follows:

TABLE I

Bandwidth (Hz)	Loss (dB)
± 10	0 ± 2
± 20	10
± 50	38
± 70	50

In an effort to determine the effect that the carrier frequency received from the nearby transmitter might have on the receiver when it was receiving a signal from the distant transmitter, a test was made to determine the strength of signal required at various separations to make the receiver lose control.

The following data in Table II indicate that, if the two frequencies can be kept separate by 50 Hz or more, the near-end transmitter signal level can be considerably greater than that received from the distant transmitter.

A review of the above data shows that, if the frequency stabilities of the two transmitters are adequate to maintain a separation of greater than 50 Hz, there is no danger of the nearby transmitter taking control of the receiver away from the desired distant end signal. Assuming that the spacing is maintained between 50 and 250 Hz, the distortion products received from the near-end transmitter would be excessive, long before its signal strength would be great enough to take control of the receiver.

6.2 *Frequency stability of the equipment*

To prevent an audible beat note in the channel adjacent to the reduced carrier, the frequencies of the two transmitters must not differ by more than 250 Hz, assuming that the passband of the voice circuit is 250 to 3000 Hz. At the same time, because of the characteristic of the carrier filter, the frequency separation must be 50 Hz or more. From this we arrive at the most desirable separation of 150 Hz. This will allow a deviation of ± 100 Hz without exceeding the permissible limits, and is well within the capabilities of modern equipment, even at the highest frequencies.

TABLE II

Received frequency (MHz)	Separation frequency (Hz)	Signal generator input simulating distant transmitter (μV)	Signal generator input simulating near-end transmitter. Input varied from 0.5 μV to 50 mV
5	50 100 200	0.5 0.5 0.5	The a.f.c. was not affected up to a level of 50 mV
10	50 100 200	0.5 0.5 0.5	
15	50 100 200	0.5 0.5 0.5	
20	50	0.5	The a.f.c. was disturbed at 5 mV

7. Practical results

A number of systems operating on this basis have been in service since 1951. The experience from this operation has shown that radiotelephone systems using terminals having VODAS equipment will operate successfully on a common-frequency basis. Based on this experience, and the tests noted above, Annex I summarizes the several methods of operation with reduced and suppressed carrier. The left column lists the important characteristics which need to be defined for use of common-frequency systems on radiotelephone circuits and the right column contains associated definitions and remarks which have resulted from the above tests.

ANNEX I

1. Reduced carrier multi-channel operation

	Criteria	*Remarks*
1.1	*Recommendation 335.* The characteristics of the radiotelephone system shall be as specified in Recommendation 335.	The equipments used in the system described above generally agree with the characteristics specified in this Recommendation.
1.2	*Level of signal received from local transmitter.* Important characteristics include physical separation between local receiving and transmitting stations, frequency of operation, physical terrain (hills, etc.), antenna patterns, antenna radiation efficiency, transmitting power, etc.	The physical separation between local receiving and transmitting stations must be great enough that the carrier signal level from the nearby transmitter will normally be less than the signal received from the distant transmitter and will rarely exceed it by as much as 10 dB. The use of transmitting and receiving antennas of differing characteristics will affect this type of operation only to the extent that they influence the strength of the signal received at the local receiver from the local transmitter.
1.3	*Mode of operation.* Reversible simplex operation.	VODAS equipment used on each voice circuit.
1.4	*Intermodulation distortion at the transmitter*	The intermodulation level (Recommendation 326) should be lower than −30 dB.

1.5	*Frequency stability of the transmitter*	Transmitter frequencies must be sufficiently stable to maintain a space of 150 ±100 Hz between transmitted carriers.
1.6	*Bandwidth of a.f.c. filter*	The carrier filter should have an attenuation of approximately 40 dB at the ±50 Hz points.

2. Suppressed carrier multi-channel operation

	Criteria	*Remarks*
2.1	*Recommendation 335.* The characteristics of the radiotelephone system shall be as specified in Recommendation 335.	See Recommendation 335.
2.2	*Level of signal received from local transmitter.* Important characteristics include physical separation between local receiving and transmitting stations, frequency of operation, physical terrain (hills, etc.), antenna patterns, antenna radiation efficiency, transmitter power, etc.	The physical separation between local receiving and transmitting stations must be sufficiently great, that the signal level from the nearby transmitter will normally be less than the signal received from the distant transmitter and will rarely exceed it by as much as 10 dB. The use of transmitting and receiving antennas of differing characteristics will affect this type of operation only to the extent that they influence the strength of the signal received at the local receiver from the local transmitter.
2.3	*Mode of operation.* Reversible simplex operation.	VODAS equipment used on each voice circuit.
2.4	*Distortion at the transmitter*	The intermodulation level (Recommendation 326) should be lower than −30 dB.
2.5	*Frequency stability of receiver and transmitter*	Transmitter and receiver must be sufficiently stable to maintain an overall frequency difference not exceeding 20 Hz.

3. Suppressed carrier, single-channel operation

	Criteria	*Remarks*
3.1	*Recommendation 335.* The characteristics of the radiotelephone system shall be as specified in Recommendation 335.	See Recommendation 335.
3.2	*Level of signal received from local transmitter.* Important characteristics include physical separation between local receiving and transmitting stations, frequency of operation, physical terrain (hills, etc.), antenna patterns, antenna radiation efficiency, transmitter power, etc.	For single-channel operation, the physical separation between the local receiving and transmitting stations must be great enough, that the level of residual noise at the receiver in the desired sideband is not increased by more than 1 dB when the transmitter power amplifier is operating normally but with no modulation applied. Under this condition, the transmitter is producing broadband noise from the exciter and driver which can, if sufficiently high, interfere with the signal received from the distant station. (See § 3.6 below.)
3.3	*Mode of operation.* Reversible simplex operation.	VODAS equipment used on the voice circuit.
3.4	*Transmitter distortion*	The intermodulation level (Recommendation 326) of the transmitters should be lower than −30 dB.
3.5	*Frequency stability of receiver and transmitter*	Transmitter and receiver must be sufficiently stable to maintain an overall frequency difference not exceeding 20 Hz.
3.6	*Residual noise level at the transmitter*	The residual-sideband noise level should not exceed −56 dB relative to the peak envelope power.

3.7 *Blocking characteristics of the receiver*

The receiver blocking characteristics must be such that the receiver will recover from a severe overload in less than 0.1 s if the front end of the receiver is not desensitized during the period of transmission from the local transmitter. In this case, the local transmitter and receiver can be much closer together because there is no a.f.c. problem, only problems of interference and blocking remain. In some cases, the two may be co-located. The receiver can be left operative, during the period of transmission by the local transmitter, if it can receive a signal from the distant transmitter immediately after the local transmitter has ceased operation.

REPORT 355-1

USE OF DIVERSITY ON INTERNATIONAL HF RADIOTELEPHONE CIRCUITS

(Questions 1/3 and 13/3)

(1966-1970)

1. Introduction

This Report discusses some diversity techniques for the HF radiotelephone service, including wide-spaced diversity, in-band diversity, and time diversity.

2. Wide-spaced diversity for voice operation

In addition to the absence of correlation in the fast phase-interference fading of radio-frequency signals at receiving stations separated by a number of miles, there is some lack of correlation in the slower fading. To investigate the latter, interstation tests were made, over a telephony link from Amsterdam, operating at 18 MHz in class of emission R3E, with receivers at two sites in New Jersey about 135 km (85 miles) apart.

The antenna outputs were recorded over the operating hours of a period of ten months, using equipment having a time constant of 40 s. Analysis of the charts showed:

- signal strength differences up to 10 or 20 dB and lasting for an hour or more were not uncommon, despite the fact that there was a strong correlation between the general (hourly median) levels at the two sites, both during normal and magnetically disturbed days;
- as was to be expected, the interstation diversity would not have helped appreciably against sudden ionospheric disturbances;
- in general, on days when the overseas transmission was disturbed, the interstation improvements, in decibels, on the average did not differ greatly from that obtained on other days;
- the distribution of the simultaneous differences, in decibels, between the antenna outputs, approximated closely to the normal;
- the standard deviation of this distribution (for an analysed period of about three months) was 8.5 dB. The correlation between the two outputs was about 0.85;
- the average difference (for this period) was 0 dB;
- the average of the signal improvement, in decibels, useful half of the time, was 7 dB. During two-thirds of the time that one branch signal was depressed more than 20 dB from the median, the average improvement was greater than 8 dB; and for 15% of this time, greater than 23 dB.

To utilize the potential signal-to-noise improvement, an automatic selecting arrangement and the necessary additional wire lines would have to be used. The amount of lost circuit time resulting otherwise from poor radio transmission which would be reclaimed by the interstation diversity would depend upon the value, relative to the median value, of the signal strength representing the commercial limit. The latter, in turn, depends largely upon the noise. To the degree that the effective noise input to the receiver is constant, as it tends to be if set noise, or to a lesser extent cosmic noise, is controlling, the distributions of signal-to-noise ratio would tend to have the same variances as those of the signals. On this basis, and assuming an ideal selecting and utilizing system, the fraction of lost circuit time reclaimed on the 18 MHz Amsterdam circuit would have been roughly one-third.

The method is also effective in the case of co-channel interference from a distant undesired station. During the tests a marked diversity effect between Amsterdam signals and those of a co-channel interfering telegraph station in Europe was observed. The telegraph signal was present in the Amsterdam channel sometimes for hours, and during these periods, its intensity relative to the Amsterdam signal was observed to vary over wide ranges. There were also large differences at times between the outputs of the antennas at the two receiving sites on these telegraph signals, and still larger differences at the outputs of the receivers whose gains were controlled by the Amsterdam signals. This "compounded" diversity effect was so great at times that the interference might render one receiver uncommercial and at the same time be hardly audible on the other. This effect may become increasingly important in problems in the future when radio reception may be increasingly limited by unwanted signals other than radio noise (see Report 414, Oslo, 1966).

In addition to the foregoing tests, a comparison of several thousand paired measurements of the signal-to-noise ratio at the two sites, using similar receiving antennas on a London circuit, was made. The estimated average diversity improvement, useful half of the time, which an ideal selecting system would have yielded was 5.5 dB. Data for several operating frequencies were lumped together in arriving at this result. The 5.5 dB value can be compared with the 7 dB figure given above for the Amsterdam tests at 18 MHz and based upon signal recordings alone rather than recordings of the signal-to-noise ratio.

Subsequently, an experimental comparator to select the better receiver branch was used. Briefly, this comparator measures the received noise and interference during outgoing speech (under the control of the VODAS), and selects the output of the quieter receiver. The time-constants are such that the switch does not operate on isolated noise impulse peaks. The noise outputs of both the accepted and rejected branches were recorded on a dual pen recorder which was equipped also with an event recording pen to provide a continuous record of the switch position. An example of noise distributions for the accepted branch, and the rejected branch, as derived from recordings covering portions of three days, is shown in Fig. 1. This short sample is, of course, inadequate to represent results over a much longer time.

No effort was made to determine the correlation of the slower fading as a function of the separation of the receiver sites. In addition to separation, topographical differences of a kind which would affect the directional response of the antennas differently would influence the results.

The improvement afforded by wide-spaced diversity may justify its use on some important systems.

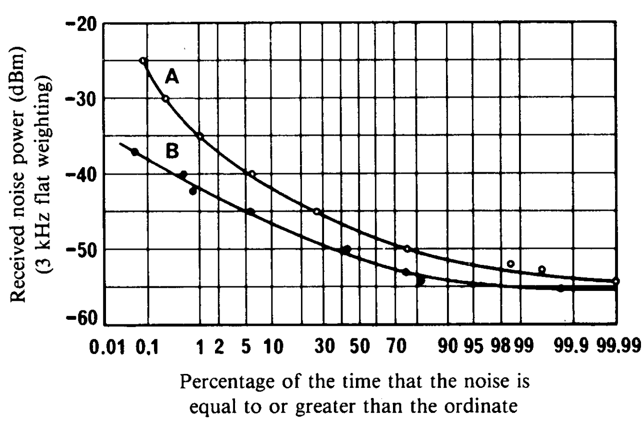

FIGURE 1 – *Wide-spaced diversity, 16 430 kHz, 11 to 13 June, 1962*

Receiving stations at Manahawkin and Netcong, NJ

3. Time diversity of voice operation

The new time-diversity system for radiotelephone transmissions described below is suitable for push-to-talk type operation, broadcast relay, and other similar services but, since the system introduces a time delay of up to a second, it is not suitable for normal telephone service where almost instantaneous replies are required. The system relies upon the fact that there is appreciable frequency redundancy in speech waves, so that if one frequency segment is lost the other segments will normally carry the intelligence.

The equipment used at the transmitting site separates the speech wave into a number of small frequency bands; for example, the centre frequencies of the filters may be at 360, 570, 900, 1430, 2270, 3600 Hz. The output of the first filter is fed directly to the transmitter, the second filter to a time delay of one-half second, a third filter fed to a time delay of one second, the fourth filter is fed directly to the transmitter, etc. as shown in Fig. 2.

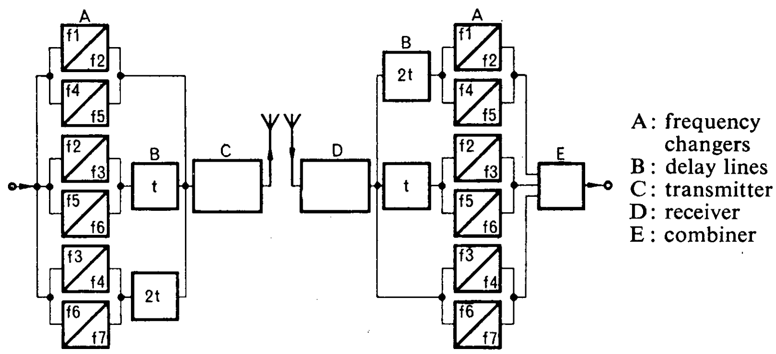

FIGURE 2 – *Simplified block diagram of Echoplex*

The output of the receiver is fed to similar equipment, but in this case the frequency segments that are not delayed at the transmitter are delayed a full second at the receiver and the frequency segments that are delayed one-half second are delayed an additional one-half second at the receiver and finally the segments that are delayed a full second at the transmitter base are fed undelayed to the combiner network at the receiver. Thus, a natural sounding wave delayed one second results.

The system has three desirable effects:

– if a fade lasts for less than a second, the bulk of the highly redundant speech wave will be received;

– there is a 6 to 7 dB measured reduction in peak level for a constant average level. The reason for this improvement is that the peaks of the voice wave form are reduced relative to the average level. The energy is more evenly distributed because of the time delays;

– the technique provides privacy in that the reception of the signal requires decoding equipment. However, if time delays of 1.5 to 2 s are used, the privacy effect is for all practical purposes eliminated. Experiments with this system indicate that to achieve the reduction in peak-to-average levels a time delay of at least 0.1 s is required. The amount of time delay required for achieving diversity gain is, of course, a function of the fading rate and it would appear that a delay of at least 1 s is desirable if one wishes to achieve a substantial reduction in the effects of fading.

4. Audio-frequency band-splitting combiner for space diversity

In this system a combiner splits each of the two receiver audio-frequency bands into three segments. Each segment is processed through two band-pass filters, a comparator and two amplifiers.

The output signals from the band-pass filters are applied to the amplifiers and also to the comparator circuit. The comparator converts the a.c. input signals into two d.c. voltages of opposite polarity. These voltages are compared on a continuous basis to determine which is the stronger signal.

The comparison output drives a differential control amplifier. The type of variable-gain action obtained prevents any thumps, clicks and transients of the signal applied to the two filters for that segment. However, should the signal at Filter 1 fade by 2 dB or more, compared with the signal at Filter 2, the selected output signal (signal at Filter 2) will be at least 20 dB greater than the weaker signal (signal at Filter 1).

The outputs from the three segments are combined in linear addition to reproduce the audio spectrum. The audio output response is improved over the non-diversity case for any amount of signal fading.

4.1 [CCIR, 1966-69] describes tests carried out over a New York-Frankfurt radiotelephone circuit. In this test, the audio-frequency outputs of two space-diversity receivers were separated by splitting them into five bands 550 Hz wide, by means of the filter units of an ordinary privacy equipment. A switching device selected, from each of the five pairs of corresponding frequency bands, the branch with the greater amplitude. The combined diversity telephone signal was then compared with the by-passed non-diversity outputs from the two receivers. Special care was taken to eliminate the influence of differing characteristics of the two receivers and extension circuits, the selection devices and the tape recorders.

The results of the tests may be summed up as follows:

- for "barely acceptable commercial quality" with dual-diversity reception and the selection of five partial bands, the method reduces the fading probability, or the proportion of fading time in the service period (fading depth $\geqslant$ 10 dB below the median value) to about 20% of the value without selection;
- extension to multiple-diversity reception and sub-division into a larger number of partial bands than used in the tests would not appreciably increase efficiency;
- the method leads to a substantial increase in speech fidelity, but to no perceptible increase in intelligibility. It is supposed therefore that the improvement in logatome clarity, which is near the perceptibility threshold, cannot be more than a few per cent;
- the higher the quality of transmission, for instance, as characterized by the articulation index [Fletcher, 1953], the smaller the improvement that can be obtained. It would therefore seem better to use methods which effectively increase the signal-to-noise ratio to momentary speech values (Lincompex, or constant net loss operation).

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REPORT 701

IMPROVEMENTS IN THE PERFORMANCE OF HF RADIO TELEPHONE CIRCUITS BY MEANS OF RECEIVER DESIGN

(Question 13/3)

(1978)

A common disadvantage of suppressed carrier single-sideband (SSB) class of emission (J3E) for radiotelephone is that, if the automatic gain control (AGC) recovery time of the receiver is too short, the audio output level of the background noise increases during pauses in the voice transmission. The AGC of SSB receivers used in radiotelephone systems employing the J3E class of emission is designed to provide an audio output signal whose level is independent of the RF input signal level. With this AGC design, such receivers compensate for the fading of RF signals due to propagation conditions. However, if the AGC recovery time is not long enough, then, during pauses in the voice transmission, the audio output level of the noise rises to the same level as when the voice signal is present. This increased noise level results in a degradation of the quality of the communications channel.

The increased audio output level of the noise during pauses can be reduced by selecting an AGC recovery time consistent with the pauses in the voice transmission and the fading characteristics of the RF signal. The recovery time chosen must be related to the type of service: that is, for a service used by trained operators sending brief messages an AGC recovery time of a few seconds is appropriate; for a service used by the public, where the messages are likely to be longer, a longer AGC recovery time is appropriate. For example, in a semi-duplex radiotelephone circuit operating in Canada, an AGC recovery time of between 25 and 30 seconds is used [Adcock, 1976].

While noise reducers and similar equipment may reduce the noise more effectively than a receiver with a long AGC recovery time, such equipment, by comparison, is usually more expensive to buy and maintain.

Notwithstanding the benefits from the application of this principle, there are two possible penalties; firstly, strong interfering signals can increase the AGC level and desensitize the receiver for the recovery period, and secondly, the AGC will not maintain the output at a usable level during deep fade periods.

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REPORT 176-5 **

COMPRESSION OF THE RADIOTELEPHONE SIGNAL SPECTRUM IN THE HF BANDS

(Question 27/3)

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

The CCIR has studied a number of systems for the compression of the radiotelephone signal spectrum and particularly the possibility of using such systems in the HF bands.

The French Administration [CCIR, 1962a] described a system invented by Marcou and Daguet which provides quite good articulation and, as developed presently, occupies about one third of the usual bandwidth on stable transmission channels such as those provided by submarine cables or wideband radio-relay systems, but is eight times more sensitive than a normal single-sideband circuit to variations in the attenuation of the transmission medium.

The United States [CCIR, 1962b] discussed two systems and later examined a number of other systems [Beery and Nesenbergs, 1962]. Systems such as the time-assigned speech interpolation (TASI) scheme are useful only when a large number of channels are involved. Other systems, some of which theoretically require only very narrow bandwidths, lack naturalness and, in some cases, all personal inflexions are removed and information about the personality of the speaker is not conveyed.

Generally, these systems cannot be used with time-varying channels, i.e., with channels in which variable propagation conditions introduce amplitude or phase distortion.

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* Class A3J has become class J3E in Radio Regulations, 1982.

** This Report has been transferred from Study Group 1 to Study Group 3 during the XIVth Plenary Assembly, Kyoto, 1978; the Report should be brought to the attention of Study Group 8.

Systems using pulse-code modulation, which may be used in very severe propagation or noise conditions, do not usually conserve bandwidth when only one or a small number of channels are coded in the same code sequence.

The most promising field is the use of single-sideband transmission with reduced or suppressed carrier. This system can yield almost twice as many voice channels in the same spectrum as compared with double-sideband systems, and unlike a number of other spectrum reducing systems, it is well suited to HF radiotelephone transmissions. The single-sideband signal provides a better signal-to-noise ratio, with an appropriate receiver, and is considerably less affected by selective fading (See Recommendation 100).

It has been shown theoretically that for time-varying channels, the most promising systems would make use of a small part of the available channel width to transmit some kind of pilot carrier which would be used, at the receiving end, to determine continuously the phase and amplitude properties of the channel and automatically control compensating devices in the receiver. In these systems the bandwidth allocated to the auxiliary channel depends upon the rate of variation of the parameters representing the properties of the channel. This bandwidth, if it is contained within the total available bandwidth, reduces the bandwidth available for the transmission of the original signal. But this latter bandwidth could then be considered as being that of a channel having stable characteristics, the capacity of which could be evaluated by the usual methods. It would be very desirable to encourage research and studies of such systems.

One system, known as "Lincompex", which uses an auxiliary control channel, is described in Recommendation 455. The signal is heavily compressed at the transmitter and information concerning the degree of compression is continuously conveyed by frequency modulation over a separate narrow-band channel to restore the original signal shape at the receiver. Though not in itself producing bandwidth compression, the ability to communicate over a noisy channel is considerably enhanced. Furthermore, the possibility has been demonstrated practically that, by partial overlapping of several such channels, spectrum economies of up to 50% are possible. The system is particularly effective where fading occurs in the propagation path.

The Japanese Administration [CCIR, 1970-74a and b] described another system, which reduces the bandwidth to one-half and provides a speech quality which differs little from that obtained from conventional single sideband communications. This system, which is being developed in Japan, makes use of the fact that a speech signal in conversational speech is characterized by quasi-periodic waveforms, with frequency spectra composed of fundamentals and their harmonics. The frequency-band compression system described in this Report was devised, taking account of such characteristics. In this system, the telephone signal is transmitted with its components above 1.65 kHz cut-off. At the receiving end, harmonic components are generated from the received signal (0.3 to 1.65 kHz) to be substituted for the cut-off components (above 1.65 kHz) and are mixed with the received signal to obtain a frequency spectrum closely resembling that of the orginal one.

A more complete description of this system and the results of preliminary tests are given in Annex I.

Furthermore, Japan has developed a narrow-band Lincompex system which is characterized by the combination of the compression system described in Annex I to the Report and the maritime Lincompex system specified in Recommendation 475. By the use of this system, the occupied bandwidth of the conventional maritime Lincompex system can be reduced by approximately 25%. It has been demonstrated [CCIR, 1978-82] that distortion caused by interference close to or in the control channel is lower for narrow-band than for maritime Lincompex. A detailed description and the test results of this system are given in Annex II.

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ANNEX I

1. Block diagram

Fig. 1 shows a block diagram of the frequency-band compression system. The frequency components above 1.65 kHz of the telephone signal are cut off through the band-pass filter BPF1 and only the remaining lower components are transmitted. At the receiver, harmonic components of the received signal (0.3 to 1.65 kHz) are generated in the harmonic generator (HG) and filtered through the band-pass filter BPF2 to result in components of 1.65 to 3.4 kHz, which are mixed with the received signal in the hybrid network to produce a received signal. The naturalness and articulation of the speech reproduced by this system are excellent as compared with speech having a spectrum of only 0.3 to 1.65 kHz.

2. Test results

To evaluate this system, syllable articulation tests using elements of the Japanese language were made on:

- speech signals with frequency band of 0.3 to 3.4 kHz;
- speech signals with frequency band of 0.3 to 1.65 kHz;
- the speech signals resulting from this band-compression system.

The results of syllable articulation tests carried out in the laboratory are given in Table I.

Table II shows the syllable articulation obtained from a test made on the single sideband HF radiotelephone circuit between Tokyo and Osaka.

TABLE I – *Results of syllable articulation tests in the laboratory*
(Room noise: 60 phones, Hoth spectrum noise)

Case	Syllable articulation (%)		Standard deviation (%)	
	male	female	male	female
(A)	93·3	89·7	0·53	0·87
(B)	80·3	74·1	0·69	0·73
(C)	83·9	76·0	0·66	0·86

(A) Speech signals with frequency band of 0.3 to 3.4 kHz
(B) Speech signals with frequency band of 0.3 to 1.65 kHz
(C) Speech signals resulting from the band-compression system

TABLE II – *Results of the syllable articulation test on the HF radio circuit*

Case	Syllable articulation %	Standard deviation %
(A)	89·5	0·76
(B)	78·5	0·99
(C)	82·2	0·74

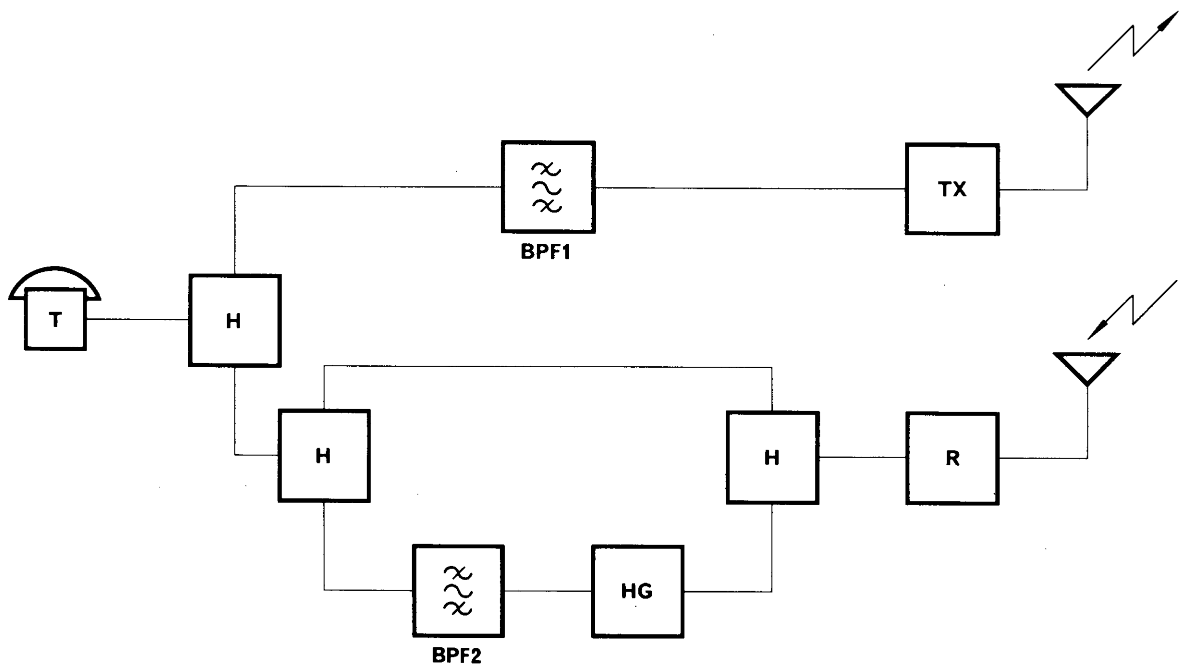


FIGURE 1 – *A block diagram of a voice-frequency band-compression system*

T:	telephone set
H:	hybrid network
HG:	harmonic generator
BPF1:	band-pass filter, 0·3 to 1·65 kHz
BPF2:	band-pass filter, 1·65 to 3·4 kHz
TX:	radio transmitter
R:	radio receiver

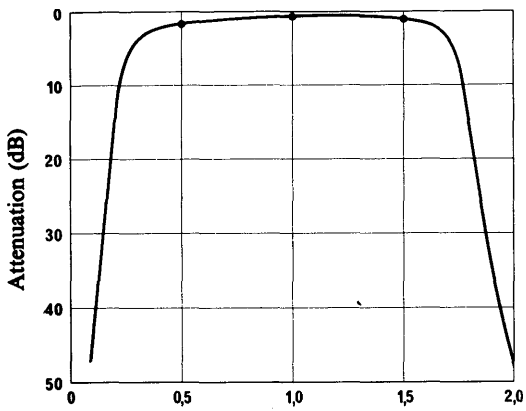


FIGURE 2*a* – *Frequency characteristics of BPF1*

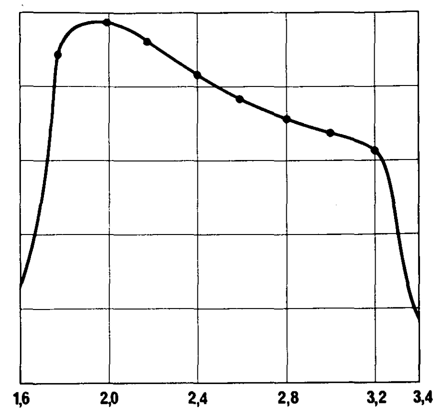


FIGURE 2*b* – *Frequency characteristics of BPF2*

ANNEX II

NARROW-BAND LINCOMPEX SYSTEM

1. Block diagram

Fig. 3 shows the functional block diagram of the narrow-band Lincompex system. This system has a low-pass filter at the sending input (SI) and a harmonic generator (HG) at the receiving output (RO) at each end of the system. These are shown within the dashed line.

The bandwidth of the speech channel is reduced by approximately 600 Hz, compared with that of the conventional maritime Lincompex system (see Figs. 4a and 4b). The frequency spectrum gained by this reduction could be utilized for the transmission of frequency-shift signals as well as selective-calling signals. Moreover, if the control channel is located adjacent to the speech channel as shown in Fig. 4c, the total occupied bandwidth may be narrower by approximately 600 Hz.

2. Test method

2.1 *Assessment of syllable articulation*

One hundred randomly arranged Japanese syllables spoken by five men and five women were first recorded on a magnetic tape. Syllables reproduced from the tape were then heard through a typical telephone circuit by five male students who had previously undegone many hours of hearing training under normal speech conditions.

2.2 *Assessment of naturalness*

Assessment of naturalness was conducted by comparing the speech quality through the conventional telephone circuit with that of the narrow-band Lincompex system with and without higher-order harmonics, and with that of the maritime Lincompex. The subjects were thirty-eight male students.

3. Test results

Fig. 5 shows signal-to-noise ratio in the speech channel at receiving input (RI) against the mean value of syllable articulation obtained with the assessment method described above. As shown in the figure, the syllable articulation of this system compares favourably with that of the maritime Lincompex system.

Fig. 6 shows the results of assessment of naturalness in the test using the Japanese language. The values for the assessment are expressed as a percentage of those who answered "more natural than through a normal telephone" to the total of test subjects. The value of assessment of this system far exceeds that of the system without the harmonic generator. In addition, when signal-to-noise ratio is lower than 20 dB, almost no difference in naturalness between this system and the maritime Lincompex system is observed, while with signal-to-noise ratio of higher than 20 dB a slight difference is apparent.

Table III shows the results of assessment of syllable articulation trials conducted on maritime radio channel between Tokyo and Okinawa (about 2000 km distance) using elements of the Japanese language. When the test subjects are male, no difference was recognized between this system and the maritime Lincompex system, but with female test subjects the articulation of this system was improved about 8% over that of the maritime system.

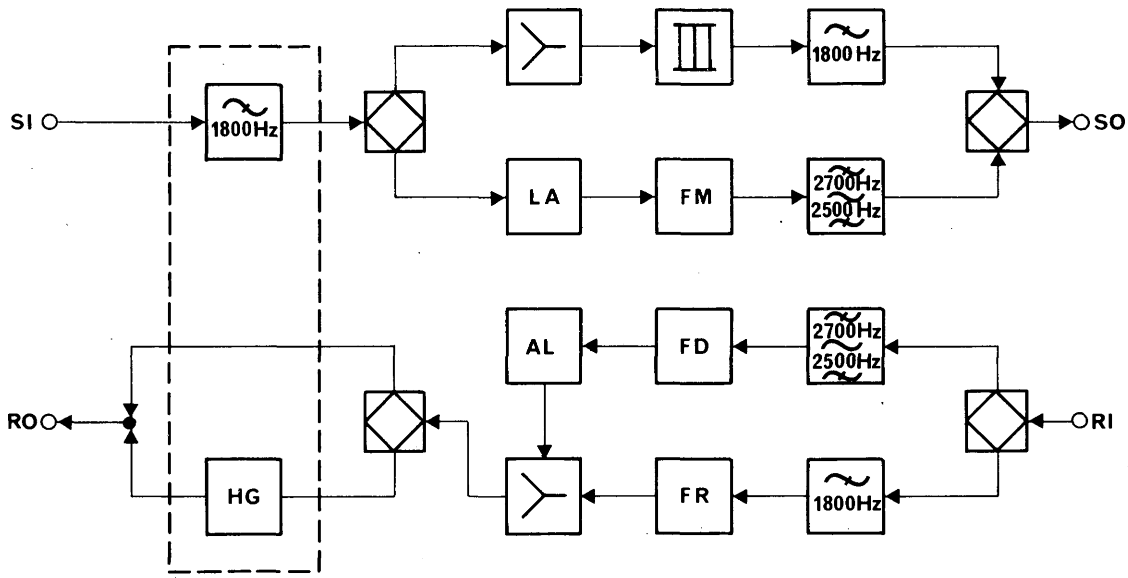
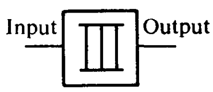
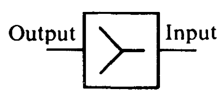


FIGURE 3 – *Block diagram of narrow band LINCOMPEX terminal equipment*

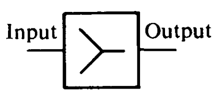
SI : sending input
SO : sending output
RO: receiving output
RI : receiving input
LA: amplitude detector and logarithmic amplifier
FM: frequency modulator
AL : anti-logarithmic amplifier
FD : frequency demodulator
FR : fading regulator
HG: harmonic generator



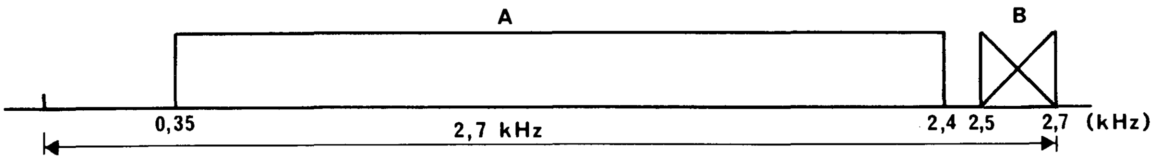
Delay network



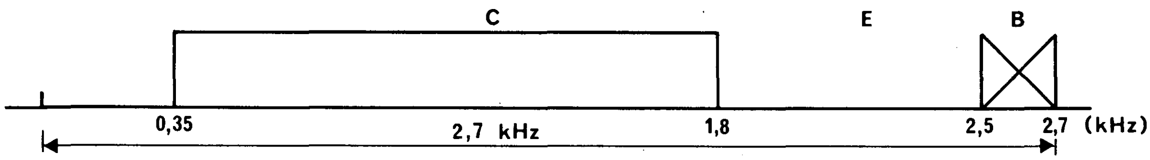
Expander



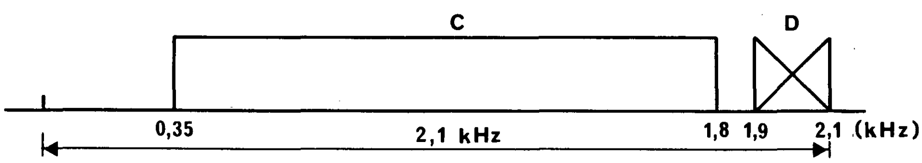
Compressor



a) Maritime LINCOMPEX system



b) Narrow-band LINCOMPEX system



c) Narrow-band LINCOMPEX system
(without vacant spectrum)

FIGURE 4 – *Occupied band in LINCOMPEX system*

A: voice signal band (0.35 to 2.4 kHz)
B: control signal band (2.5 to 2.7 kHz)
C: voice signal band (0.35 to 1.8 kHz)
D: control signal band (1.9 to 2.1 kHz)
E: vacant spectrum (1.8 to 2.5 kHz)

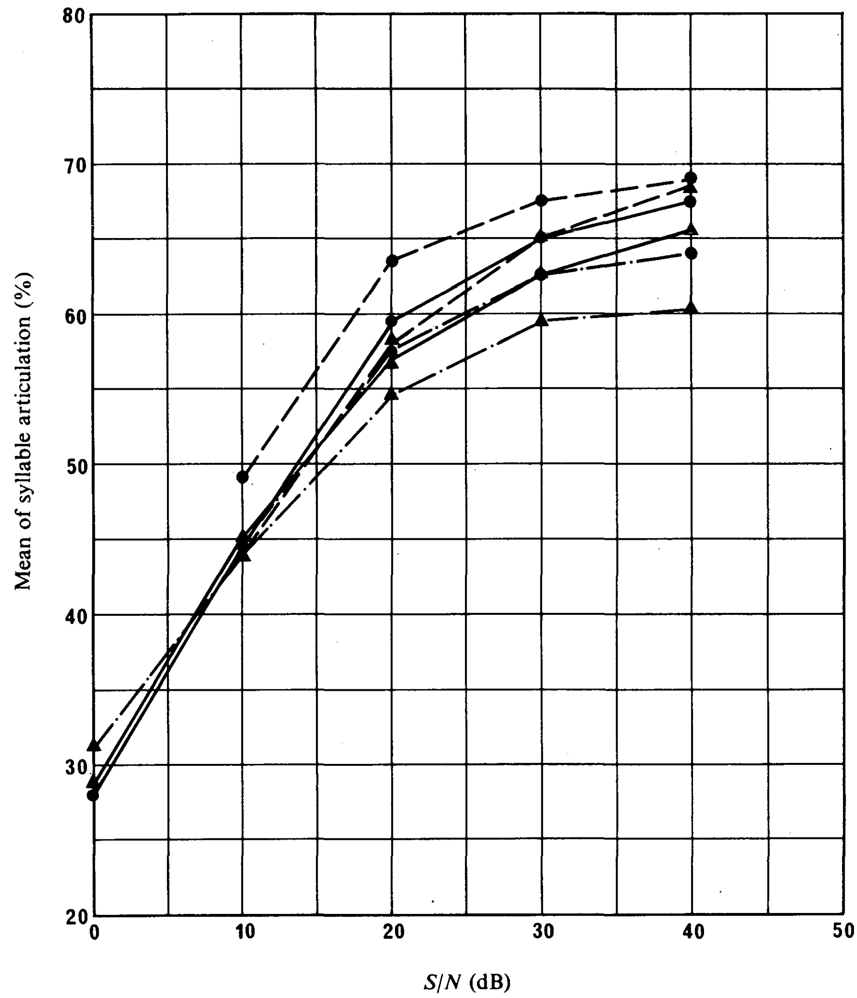


FIGURE 5 – *S/N versus mean of syllable articulation*

●	:	male
▲	:	female
————————	:	narrow-band LINCOMPEX system
— — — — —	:	maritime LINCOMPEX system
·—·—·—·	:	narrow-band LINCOMPEX system (without higher order harmonics)

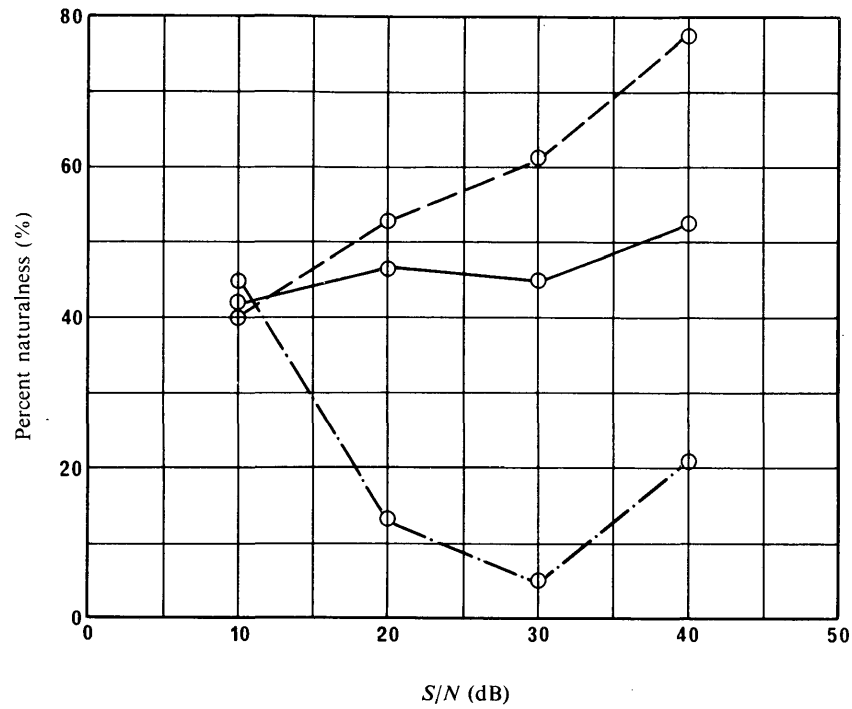


FIGURE 6 – *S/N versus percent naturalness*

——————— : narrow-band LINCOMPEX system
— — — — : maritime LINCOMPEX system
·—·—·—· : narrow-band LINCOMPEX system (without higher order harmonics)

TABLE III – *Articulation of field test*

Kind of system	Male (%)	Female (%)
Narrow-band Lincompex	51	46
Maritime mobile Lincompex	51	38

REPORT 862 *

REJECTION OF INTERFERENCE BY USING FREQUENCY-BAND COMPRESSION TECHNIQUE

(Questions 13/3 and 27/3)

(1982)

1. Introduction

In the HF band the capability of receivers to reduce interference is critical for the efficient use of the radio frequency spectrum. Based on this background, a new provision defining receiver characteristics was added by the WARC-79 to Article 5 of the Radio Regulations.

This Report describes tests that were made to determine whether the receiver configuration given in Annex I of Report 176 is useful not only for receivers of frequency-band compression systems but also as a means to improve interference rejection in conventional SSB telephony systems.

Results of these tests show that when interference appears in the higher part (1.65 - 3 kHz) of the passband (0.3 - 3 kHz) of an SSB receiver, the previous grade of service can be restored, in the majority of cases, by using a narrower passband (0.3 - 1.65 kHz) and compensating for the deterioration of speech quality due to this band limitation by adding harmonic components as described in Report 176, Annex I.

2. Laboratory

Figure 1 shows the arrangements of the laboratory tests. In this figure, the FS signal (frequency-shift: 800 kHz, modulation: 50 baud 1:1 dot signal) from the FSK (frequency-shift keyer) simulated an interfering signal. The SSG was a synthesized SSB signal generator modulated by a speech signal in Japanese from a magnetic tape loop (tape recorder E1).

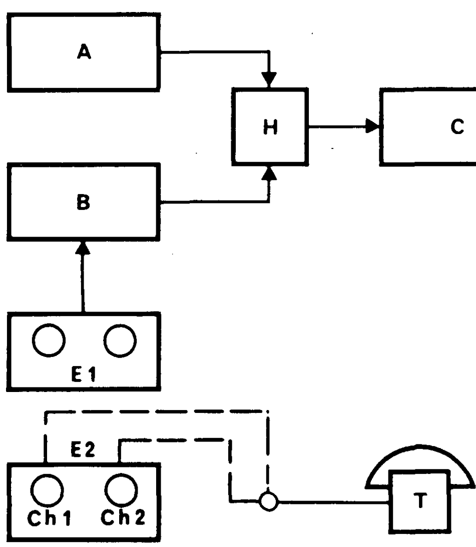


FIGURE 1 – *Arrangement of the laboratory tests*

A: frequency-shift keyer, FSK
B: synthesized SSB signal generator, SSG
C: conventional SSB receiver
D: band-compression circuit, BC
E_1, E_2: magnetic tape recorders
T: telephone set
H: hybrid coupler

* This Report should be brought to the attention of Study Group 8.

The carrier frequency f_s of the SSG was 7000 kHz, and the output signal frequency f_k of FSK was adjusted so that the centre frequency (denoted by f'_k) of the interference signal in the passband of the receiver would be at 1.65, 2.0 and 2.5 kHz.

The ratios (S/I) of speech signal level to interfering signal level were set at 10, 20, 30 and 40 dB by changing the FSK signal level to 40, 30, 20 and 10 dB(μV), respectively. The SSG mean output level was fixed at 50 dB(μV).

For each combination of f'_k and S/I ratio, the output speech signal of the receiver was recorded with the tape recorder (E2) for one minute. The output of a conventional SSB receiver was recorded in Channel 1 (Ch 1) of E2, and the output of the narrow-band SSB receiver was recorded in Channel 2 (Ch 2).

The quality of these speech signals recorded by E2 was evaluated through the subjective test method as specified in CCITT Recommendation P.77 (Fascicle V).

A pause of 30 s was provided after each one minute of listener test so that the subjective judgement on the quality of each test is mutually independent. Twelve test subjects were selected who had limited experience as telephone operators.

3. Results of the laboratory tests

Table I shows the mean opinion score obtained when the S/I ratios were set at 10, 20, 30 and 40 dB and the interfering frequencies at 1.65, 2.0 and 2.5 kHz.

Figure 2 shows the relation between the S/I ratio and mean opinion score (MOS) with the interfering frequency as a parameter, and Fig. 3 shows the relation between the interfering frequency and MOS with the S/I ratio as a parameter.

As is evident from Table I and Figs. 2 and 3, results for the narrow-band SSB receiver at each interfering frequency of 1.65, 2.0 and 2.5 kHz are better than those for the conventional SSB receiver. Particularly, this superiority is remarkable when the S/I ratio is 10 dB.

TABLE I – *Mean opinion score (MOS) in the laboratory tests*

f'_k (kHz)	System	S/I (dB)			
		10	20	30	40
1.65	C	0.4	0.5	1.3	2.0
	N	0.6	0.5	1.7	2.2
2.0	C	0.6	1.3	1.8	2.9
	N	1.4	1.8	2.6	2.8
2.5	C	1.1	1.4	1.8	2.8
	N	2.7	3.0	3.0	2.8

C : conventional SSB reception.
N : narrow-band SSB reception.
f'_k: interfering frequency.

4. Field tests

Over a period of approximately one month, tests were made using signals from 31 ship stations. Each station was observed in turn and a number of tape recordings were made, with and without narrow-band reception, when interference was present. These recordings were later evaluated by 12 listeners in the same manner as used in the laboratory tests. Figure 4 illustrates the MOS results when using narrow-band reception and Fig. 5 illustrates the results of comparing narrow-band with conventional reception.

Tests with fixed stations were not performed because a sufficient number of suitably located stations was not available. During the test period, 539 cases of interference to signals from ship stations using emission 3K00R3E or 3K00J3E were observed.

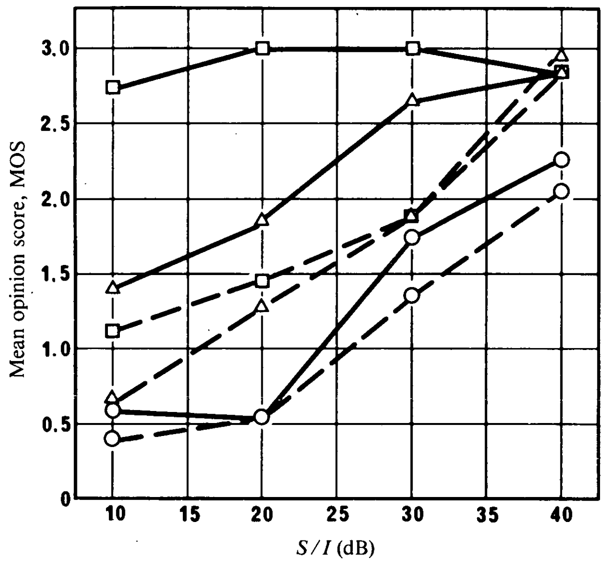


FIGURE 2 – *Mean opinion score (MOS) vs. S/I*

○ : f'_k = 1.65 kHz (interfering frequency)
△ : f'_k = 2.0 kHz
□ : f'_k = 2.5 kHz
——— : narrowband SSB reception
– – – : conventional SSB reception

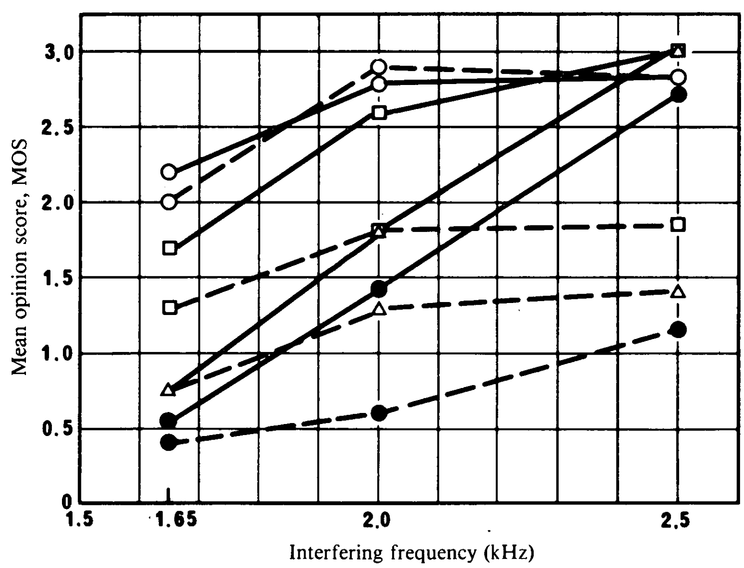


FIGURE 3 – *Mean opinion score (MOS) vs. interfering frequency*

● : S/I = 10 dB
△ : S/I = 20 dB
□ : S/I = 30 dB
○ : S/I = 40 dB
——— : narrowband SSB reception
– – – : conventional SSB reception

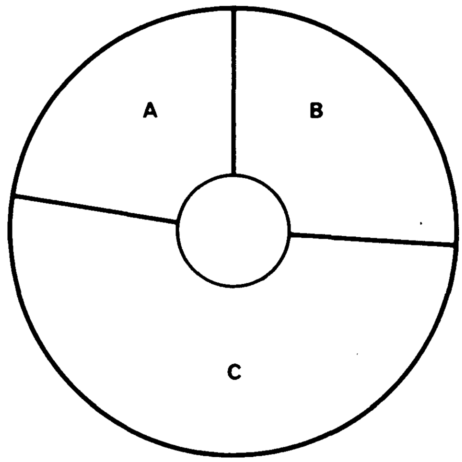


FIGURE 4 – Mean opinion score (MOS) for narrowband SSB reception in the presence of interference

A: 22.5 % (poor)
B: 26 % (fair)
C: 51.5 % (good + excellent)

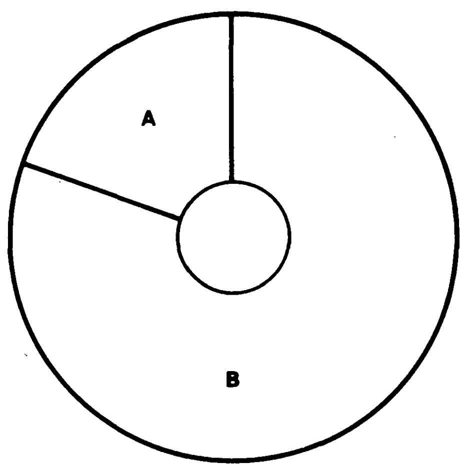


FIGURE 5 – *Subject improvement due to interference rejection by narrowband SSB reception*

A: 19.5 % (not improved)
B: 80.5 % (improved)

5. Conclusion

From the results of the laboratory and field tests, it is evident that the configuration of receivers as shown in Report 176, Annex I, provides an effective means to improve interference rejection in HF radiotelephone circuits.

SECTION 3C: RADIOTELEGRAPHY AND FACSIMILE

3C a: Radiotelegraph circuits

Recommendations and Reports

RECOMMENDATION 345

TELEGRAPH DISTORTION

(Question 1/3, Study Programme 1A/3)

(1953-1956-1959-1963)

The CCIR,

CONSIDERING

that the definitions applying to telegraph distortion and to the mutilation of telegraphic signals, which appear in Section 33, Part I, of the List of Definitions of Essential Telecommunication Terms, published by the International Telecommunication Union, give an answer to Question 18 (Stockholm, 1948), which required a general definition of telegraph distortion capable of being usefully applied to the cause of radiotelegraphy,

UNANIMOUSLY RECOMMENDS

that the following definitions, contained in Section 33 of the above-mentioned List of Definitions of Essential Telecommunication Terms, should be applied to radiotelegraphy:

Perfect modulation (or restitution) (Definition 33.01 of the List)

Modulation (or restitution) such that all the significant intervals are associated with correct significant conditions and conform accurately to their theoretical durations.

Incorrect modulation (or restitution)
Defective modulation (or restitution) } (Definition 33.03 of the List)

Modulation (or restitution) containing one or more elements, the significant condition of which differs from that corresponding to the kind prescribed by the code.

Telegraph distortion (of a modulation or a restitution) (Definition 33.04 of the List)

(a) A modulation (or restitution) suffers from telegraph distortion, when the significant intervals have not all exactly their theoretical durations.

(b) A modulation (or restitution) is affected by telegraph distortion, when significant instants do not coincide with the corresponding theoretical instants.

Transmitter distortion (Definition 33.059 of the 1st Supplement to the List)

A signal transmitted by an apparatus (or a signal at the output of a local line with its termination) is affected by telegraph distortion, when the significant intervals of this signal have not exactly their theoretical durations.

Degree of individual distortion of a particular significant instant (of a modulation or of a restitution) (Definition 33.06 of the List)

Ratio to the unit interval of the displacement, expressed algebraically, of this significant instant from an ideal instant.

This displacement is considered positive when the significant instant occurs after the ideal instant.

The degree of individual distortion is usually expressed as a percentage.

Degree of isochronous distortion (Definition 33.07 of the 1st Supplement to the List)

(a) Ratio to the unit interval of the maximum measured difference, irrespective of sign, between the actual and the theoretical intervals separating any two significant instants of modulation (or of restitution), these instants being not necessarily consecutive.

(b) Algebraical difference between the highest and lowest value of individual distortion affecting the significant instants of an isochronous modulation. (The difference is independent of the choice of the reference ideal instant.)

The degree of distortion (of an isochronous modulation or restitution) is usually expressed as a percentage.

Note. – The result of the measurement should be completed by an indication of the period, usually limited, of the observation.

For a prolonged modulation (or restitution), it will be appropriate to consider the probability that an assigned value of the degree of distortion will be exceeded.

Degree of start-stop distortion (Definition 33.08 of the 1st Supplement to the List)

(a) Ratio to the unit interval of the maximum measured difference, irrespective of sign, between the actual and theoretical intervals separating any significant instant of modulation (or of restitution) from the significant instant of the start element immediately preceding it.

(b) The highest absolute value of individual distortion affecting the significant instants of a start-stop modulation.

The degree of distortion of a start-stop modulation (or restitution) is usually expressed as a percentage.

Note 1. – See Note to Definition 33.07.

Note 2. – Distinction can be made between the degree of *late* (or positive) distortion and the degree of *early* (or negative) distortion.

Degree of gross start-stop distortion (Definition 33.09 of the List)

Degree of distortion determined when the unit interval and the theoretical intervals assumed are exactly those appropriate to the standardized modulation rate.

Note. – See Note to Definition 33.07.

Degree of synchronous start-stop distortion (i.e. at the actual mean modulation rate) (Definition 33.10 of the List)

Degree of distortion determined when the unit interval and the theoretical intervals assumed are those appropriate to the actual mean rate of modulation (or of restitution).

Note 1. – See Note to Definition 33.07.

Note 2. – For the determination of the actual mean modulation rate, account is only taken of those significant instants of modulation (or restitution), which correspond to a change of condition in the same sense as that occurring at the beginning of the start element.

Characteristic distortion (Definition 33.15 of the List)

Distortion caused by transients which, as a result of the modulation, are present in the transmission channel and depend on its transmission qualities.

Fortuitous distortion (Definition 33.16 of the List)

Distortion resulting from causes generally subject to random laws (accidental irregularities in the operation of the apparatus and of the moving parts, disturbances affecting the transmission channel, etc.).

Bias distortion, asymmetrical distortion (Definition 33.17 of the List)

Distortion affecting a two-condition (or binary) modulation (or restitution), in which all the significant intervals corresponding to one of the two significant conditions have longer or shorter durations than the corresponding theoretical durations.

Character error rate of a telegraph communication* (Definition 33.19 of the 1st Supplement to the List)

Ratio of the number of alphabetic signals of a message incorrectly received (after automatic translation, where applicable), to the number of alphabetic signals of the message, the keying being correct.

Note 1. – A telegraph communication may have a different error rate for the two directions of transmission.

Note 2. – The notion of character error rate could be applied to any operation taking place in a telegraph communication (e.g. keying, translation, etc.).

Note 3. – The statement of the error rate will be accompanied by that of the time interval, generally limited, during which the observation was made. For a communication established for a sufficiently long time, the probability of exceeding an assigned value of error rate could be considered.

Note 4. – Faulty translation, resulting from a previous error in functional control (such as shift, line feed, synchronism, etc.), is not counted in calculating a character error rate; in such a case, the error in the functional control signal is alone counted and is counted only once.

* *Note by the CCIR Secretariat (1982).* – The CCITT uses the English term "error ratio" instead of "error rate" in CCITT Recommendation G.702: Vocabulary of PCM and digital transmission terms (see CCIR Vol. XIII, Report 971, Appendix A, term 2015).

Element error rate * [CCIR, 1963] **

The ratio of the number of unit elements incorrectly received to the total number of unit elements sent.

Efficiency factor in time (of a telegraph communication with automatic repetition for the correction of errors) (Definition 33.23 of the List).

Ratio of the time necessary to transmit a text automatically without repetition, at a specified modulation rate, to the time actually taken to receive the same text with a given error rate.

Note 1. – The whole of the apparatus comprising the communication is assumed to be in the normal conditions of adjustment and operation.

Note 2. – A telegraph communication may have a different efficiency factor in time for the two directions of transmission.

Note 3. – The actual conditions in which the measurement is made should be specified, in particular the duration of the measurement.

Mutilation (Definition 33.24 of the List)

A transmission defect in which a signal element becomes changed from one significant condition to another.

Transposition (Definition 33.25 of the List) (See also Annex II, Part 2, definition *k* of Recommendation 342)

A transmission defect in which, during one character period, one or more signal elements are changed from one significant condition to the other, and an equal number of elements are changed in the opposite sense.

REFERENCES

CCIR Documents

[1963]: Geneva, 203.

REPORT 200-1

TELEGRAPH DISTORTION, ERROR RATE

(Question 1/3, Study Programme 1A/3)

(1963-1966)

1. Distribution of telegraph distortion

The study of the relationship between telegraph distortion and error rate has received further consideration. The statistical distribution of distortion can be of value for assessing the quality of a radiotelegraph circuit (see Report 351, Geneva, 1974).

2. Isochronous telegraph distortion

2.1 The measurement of isochronous telegraph distortion can be applied meaningfully at several points in a radiotelegraph system.

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* *Note by the CCIR Secretariat (1982).* – The CCITT uses the English term "error ratio" instead of "error rate" in CCITT Recommendation G.702: Vocabulary of PCM and digital transmission terms (see CCIR Vol. XIII, Report 971, Appendix A, term 2015).

** *Note by the CCIR Secretariat (1970).* – This term is now defined in the 2nd supplement to the List (Definition 52.28): The ratio of the number of elements incorrectly received to the total number of elements sent.

2.2 In making measurements of isochronous distortion of the separate components of the system, the following CCITT Recommendations (see Fascicle VII.1) should be taken into consideration:

Recommendation R.4 – Methods for the separate measurements of the degrees of various types of telegraph distortion.

Recommendation R.5 – Observation conditions recommended for routine distortion measurements on international circuits.

Recommendation R.74 – Choice of type of telegraph distortion-measuring equipment.

2.3 The measurement of the variation in restitution delay is important in determining the fortuitous distortion contributed by the transmission medium.

2.4 Bias distortion is one component of the distortion produced by equipment and its measurement is useful in determining equipment performance.

3. Statistical measurements of error rate on the Warsaw-New York circuit did not indicate any direct relationship between error rate and the level of the received signal.

REPORT 195

PREDICTION OF THE PERFORMANCE OF TELEGRAPH SYSTEMS IN TERMS OF BANDWIDTH AND SIGNAL-TO-NOISE RATIO IN COMPLETE SYSTEMS

(Question 1/3, Study Programme 1A/3)

(1959-1963)

1. Study Programme 1A/3 sets out some questions, the answer to which would form a basis for the evaluation of the performance of complete systems. The questions include terms like "excellent service", the interpretation of which depends greatly on the type of traffic the system is intended to carry and the grade of service. This Report will not discuss such questions in detail, but rather attempt to give a basis for a more objective method of performance specification in the light of recent work on communication systems.

Theoretical studies of the mechanisms of detection of telegraph signals in the presence of noise, having a Gaussian distribution [Kotelnikov, 1947; Law, 1957], have made it possible to define the performance of a system, in terms of element error rate, as a function of the signal-to-noise ratio just prior to the detector. The word "detector" is used here in a very general sense and the detector might be a limiter-discriminator. It is convenient to use a quantity called the "normalized signal-to-noise ratio", R, which is defined as the quotient of the average of the specific energies of the mark and the space signals, and the noise power per unit bandwidth. For systems which use two equally probable signals of equal energy, this ratio is equal to the signal-to-noise power ratio per baud per unit bandwidth, or the ratio of the signal power to the noise power per unit bandwidth, divided by the number of bauds. Direct comparison between receivers, even when working at different speeds is, therefore, possible.

In these studies, it was also found possible to specify the performance of a telegraph receiver by a single parameter. This parameter has been called the "demodulation factor" and it is the amount (in dB) by which the signal-to-noise ratio (normalized), applied to the receiver under test, exceeds that applied to an idealized receiver of the same type for the same element error rate. For the purpose of this work, we have to distinguish between coherent and non-coherent receivers. The coherent receiver has *a priori* knowledge of the phase of the elementary waveform. The mark- and space-elements are assumed to be equally probable.

1.1 *Coherent reception. No fading*

Assume that $x_1(t)$ and $x_2(t)$ are the two signal waveforms, that τ is the unit interval (duration of one element), and that N is the noise power per Hz. Then if:

$$y^2 = \frac{1}{4N}\int_0^\tau [x_1(t) - x_2(t)]^2 \, dt,$$

the element error rate P_e is given by:

$$P_e = \frac{1}{\sqrt{\pi}} \int_y^\infty \exp\left(-z^2\right) dz = \tfrac{1}{2}\,\mathrm{erfc}\,(y) = \tfrac{1}{2} - \tfrac{1}{2}\,\mathrm{erf}\,(y).$$

In terms of the "normalized signal-to-noise ratio", R, this error-rate can be expressed in the form:

$$P_e = \tfrac{1}{2}\,\mathrm{erfc}\,(\alpha R)^{\frac{1}{2}}\ ;$$

- for phase-reversal modulation $\alpha_1 = 1$;
- for frequency-shift keying with two orthogonal signals $\alpha_2 = ½$;
- for amplitude keying (on-off signals) too, $\alpha_3 = ½$.

For large values of R, the complementary error function can be well approximated by an exponential curve:

$$P_e \approx \frac{1}{2\sqrt{\pi \alpha R}} \exp\left(-\alpha R\right)$$

1.2 *Non-coherent reception. No fading*

For non-coherent reception of a steady signal, the error rate is of the form:

$$P_e = \tfrac{1}{2} \exp\left(-\alpha R\right)$$

Again:

- for differentially coherent reception [Lawton, 1959] of phase-reversal modulation $\alpha_1 = 1$;
- for matched filter reception and envelope detection [Reiger, 1953] of frequency-shift keying $\alpha_2 = ½$ (for narrow-band FSK with shifts of the order $(0.8/\tau)$, the effect of correlation leads to better results);
- for amplitude keying, we get approximately [Reiger, 1953] $\alpha_3 = ½$.

1.3 *Coherent diversity reception. Flat fading*

It is assumed that the fading is of Rayleigh type, that the fadings in different branches are uncorrelated (but that they are the same for mark and space signals), that the mean signal-on energies of all branches are equal, and that the fading is so slow, relative to the speed of signalling, that the signal power may be regarded as constant during any one signal element. The outputs of the diversity branches are assumed to be weighted, according to the signal energy and combined (maximal ratio combination).

For Rayleigh fading and one receiver, we get the following error rate:

$$P_{e1} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R/(\alpha R + 1)}$$

For dual diversity:

$$P_{e2} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R\left(\alpha R + \frac{3}{2}\right)^2 \Big/ (\alpha R + 1)^3}$$

For triple diversity:

$$P_{e3} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R\left(\alpha^2 R^2 + \frac{5}{2}\alpha R + \frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{2!}\right) \Big/ (\alpha R + 1)^5}$$

For quadruple diversity:

$$P_{e4} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R\left(\alpha^3 R^3 + \frac{7}{2}\alpha^2 R^2 + \frac{7}{2}\cdot\frac{5}{2}\cdot\frac{1}{2!}\alpha R + \frac{7}{2}\cdot\frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{3!}\right) \Big/ (\alpha R + 1)^7}$$

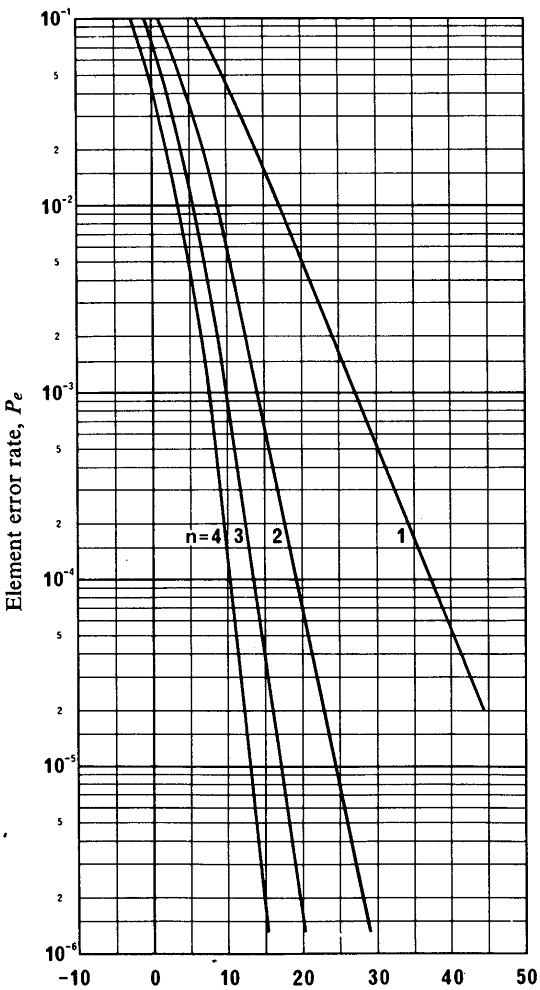
For large values of R, these results are closely approximated by:

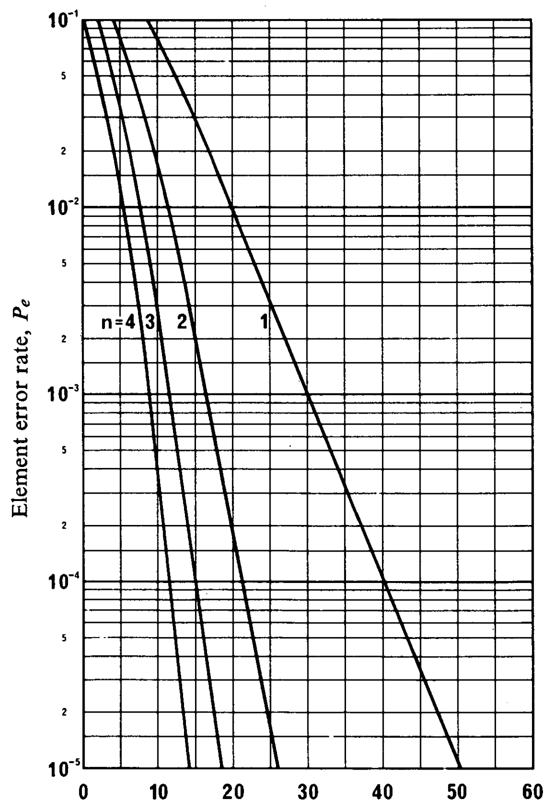
$$P_{e1} = 1/4\alpha R; \; P_{e2} = 3P_{e1}^2 = 3/(4\alpha R)^2; \; P_{e3} = 10\,P_{e1}^3 = 10/(4\alpha R)^3; \; P_{e4} = 35\,P_{e1}^4 = 35/(4\alpha R)^4$$

respectively.

In the definition of the normalized signal-to-noise ratio R, the average signal energy and signal power per branch should now be substituted for signal energy and signal power respectively.

The basic curves, for idealized coherent reception of frequency-shift signals in fading ($\alpha = \frac{1}{2}$), are given in Fig. 1 for single, double, triple and quadruple diversity systems.





Normalized signal-to-noise ratio per diversity branch (dB)
$R_n = 10 \log R$ (n = number of diversity branches)

FIGURE 1 – *Coherent reception*

FIGURE 2 – *Non-coherent reception*

1.4 *Non-coherent reception. Flat fading*

The equations for the error rate for non-coherent reception, under the circumstances otherwise specified in § 1.3 (maximum ratio combining), are:

$$P_{e1} = \frac{1}{2(1 + \alpha R)}, \text{ Rayleigh fading, one receiver;}$$

$$P_{e2} = \frac{1}{2(1 + \alpha R)^2}, \text{ dual diversity;}$$

$$P_{e3} = \frac{1}{2(1 + \alpha R)^3}, \text{ triple diversity;}$$

$$P_{e4} = \frac{1}{2(1 + \alpha R)^4}, \text{ quadruple diversity.}$$

The basic curves for this case are given in Fig. 2, again for the reception of frequency-shift signals in fading ($\alpha = ½$).

1.5 *Coherent reception. Independent fading*

1.6 *Non-coherent reception. Independent fading*

If it may be assumed that the frequencies corresponding to the two significant conditions of modulation are sufficiently widely separated for the fading in the two branches to be independent, then independent reception in the two branches is possible.

If, furthermore, the same assumptions are made as in §§ 1.3 and 1.4, the resulting error rates may be derived directly from the above. Then, going from flat fading to independent fading is equivalent to doubling the order of diversity, while having the power in each diversity branch [Barrow, 1962].

2. Demodulation factor

If the performance curve of an actual receiver for coherent reception is of the complementary error function type, then a constant factor indicates the extent by which a practical receiver falls short of the ideal, and it is the same for all types of diversity.

Also, if the performance curve of an actual receiver for non-coherent reception is of the exponential type, the demodulation factor will be a constant.

Equipment for measuring the demodulation factor of a receiver in the laboratory, under simulated fading conditions, has been described elsewhere [Law *et al.*, 1957]. Alternatively, a measure of the demodulation factor may be obtained by calculation from the performance of the receiver under non-fading conditions, as in Annex I.

In this Report we have only discussed maximum-ratio combining. In the literature [Brennan, 1959], one can find a comparison of this type of diversity with equal-gain and selection diversity. The loss for equal-gain combining is apparently of the order of 1 dB.

The performance of a circuit is usually expressed in terms of character error rates. Calculations from the probability functions involved give a simple conversion from an element error rate to a character error rate for various types of telegraph code, thus providing a simple relationship between the signal-to-noise ratio and the number of errors on the printed copy. The particular case for random arrival of element errors represents a useful limiting condition which is approached closely when the error rate is low.

Relationships between element and character error rates are shown in Figs. 3 and 4.

In Fig. 3, curve 1 represents the upper limit of the character error rate for a synchronous seven-unit code, when the element errors are mutually independent. It should be noted here, that the character error rate is defined as being the number of characters subject to error at the output of the detector and thus an error in "letter shift" or "figure shift" is counted only once and similarly for other errors, such as those occurring in "carriage return" or "line feed". However, if the fading characteristics give rise to groups of errors, then the curve showing the relationship between element and character error rates becomes asymptotic to curve 2 which was calculated on the assumption that the signal level remains constant during a character. For element error rates lower than 1×10^{-3}, the curve 1 is appropriate.

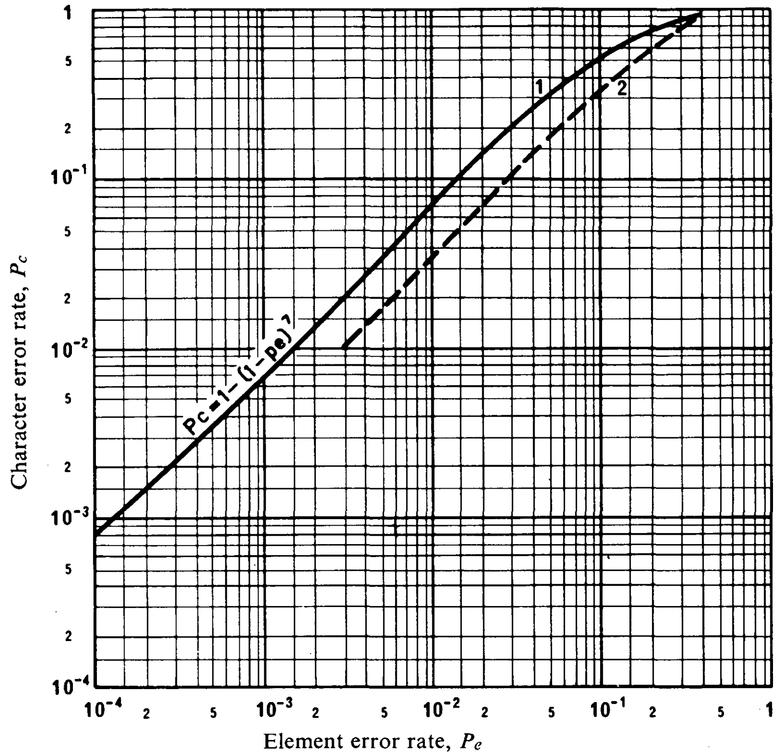


FIGURE 3

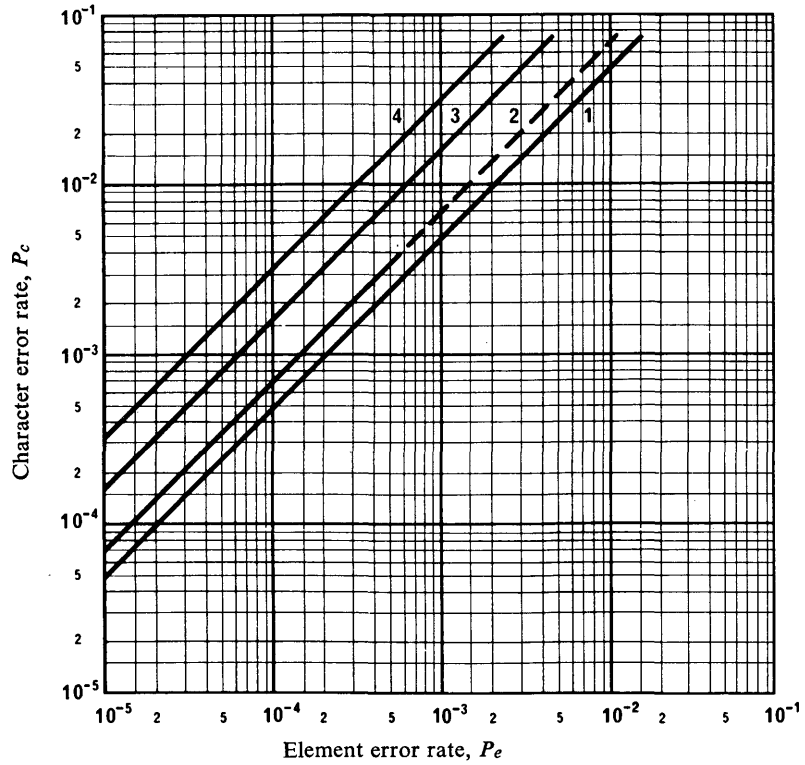


FIGURE 4

Curve 1: 5-unit synchronous code,
Curve 2: 7-unit synchronous code,
Curve 3: 5-unit start-stop, tape printing,
Curve 4: 5-unit start-stop, page printing.

In Fig. 4, the upper limits are shown as follows:

- curve 1: for a five-unit synchronous code: $P_c \approx 5P_e$;
- curve 2: for a seven-unit code: $P_c \approx 7P_e$;
- curve 3: for a five-unit start-stop system with tape printing and allowing for errors due to loss of synchronism, in addition to the simple character errors: $P_c \approx 17P_e$;
- curve 4: for a five-unit start-stop system with page printing i.e., including an additional allowance for multiple errors due to carriage return and line-feed failures. Again, as for the previous curves, errors in "letter shift" or "figure shift" are only counted once: $P_c \approx 34P_e$.

An example is given below to demonstrate the way in which the curves may be used. It is stressed that this example shows the method employed in making one of the steps in the calculations necessary to plan circuits for a specified grade of service, but that the demodulation factor of the receiver must be known as a result of measurement.

First, we take the general case for reception of a steady signal.

Let R_0 : the pre-detection signal-to-noise ratio (dB);

R_n : the normalized signal-to-noise ratio, corresponding to R (dB);
$R_n = 10 \log R$;

S : the modulation rate in bauds (elements/s);

B : the pre-detection bandwidth (Hz) of the receiver in question;

D : the demodulation factor of the receiver for the modulation rate specified, in decibels;

then

$$R_0 = R_n + 10 \log (S/B) + D \qquad (1)$$

Example

A coherent receiver, having a pre-detection bandwidth of 1000 Hz, is used for 50 bauds, 5-unit synchronous working, using triple diversity. The measured demodulation factor of the receiver, for this signalling speed and bandwidth, is 10 dB. A character error rate of 1×10^{-4} is permissible; what must be the pre-detector signal-to-noise ratio?

From Fig. 4, the corresponding element error rate is 2×10^{-5}. From Fig. 1, an ideal receiver using triple diversity produces an element error rate of 2×10^{-5} for $R_n = 16$ dB.

Using equation (1), we find:

$$R_0 = R_n + 10 \log (S/B) + D$$

and inserting the known values we have

$$R_0 = 16 - 13 + 10 = 13 \text{ dB.}$$

This is the required signal-to-noise ratio per branch. The signal-to-noise ratio after combining will be 3 R_0 or 18 dB.

3. Conclusion

Extension of this work, to cover noise other than thermal noise, may result in the need for more parameters to describe fully system performance, but it seems clear that:

- the performance of telegraph circuits should be related to stated character error rates, and for the engineering planning of circuits and design of equipment it is preferable to have these expressed in corresponding element error rates;
- the approach indicated in this Report forms a useful starting point in the development of an objective method determining the performance of telegraph systems.

ANNEX I

In the absence of a fading simulator, it is possible to derive an approximate value of the element error rate under fading conditions from the results of tests under steady conditions. These steady-state tests will give the error rate as a distribution function $g(R)$, of the normalized signal-to-noise ratio R.

If, for coherent reception, $g(R)$ can be expressed in the following form:

$$g(R) = \tfrac{1}{2} \operatorname{erfc} (bR/2)^{1/2}$$

then the demodulation factor is constant, 10 log b, independent of the order of diversity employed.

In practice, this will not generally be the case and then the demodulation factor will be a function of both R and q (the order of diversity). However, by an extension of the work in [Law, 1957], it can be shown that, in general, the element error rate with q diversity branches will be:

$$P_{eq} = [(q-1)!\, N^q]^{-1} \int_0^\infty y^{q-1} \exp\left(-y/R\right) g(y)\, dy.$$

For large signal-to-noise ratios, or small error rates, the following approximation for the demodulation factor D_q, with q diversity branches, and flat fading, can be found:

$$(D_q)^q = [2^q \,.\, q!/(2q-1)!] \int_0^\infty y^{q-1} g(y)\, dy.$$

Measured distribution functions under steady-state conditions can be expressed in the following form:

$$g(R) = \sum a_k \,.\, \exp\left(-b_k R\right)$$

Then for large values of R:

$$(D_q)^q = [2^q \,.\, q!\,(q-1)!/(2q-1)!] \sum (a_k/b_k{}^q)$$

For other forms of the function $g(R)$, similar calculations can be performed.

For non-coherent reception, the reasoning is completely analogous. Again, the answer is simple, if the error rate under steady conditions can be expressed as a single exponential form.

For the more complicated error performance given by a sum of exponentials, as above, the demodulation factor is given in this case by:

$$(D_q)^q = \sum (a_k/2)\,(2b_k)^q$$

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REPORT 436

EFFICIENT USE OF HF RADIOTELEGRAPH CHANNELS IN THE TELEX NETWORK BY MEANS OF AUTOMATIC SELECTION AND ALLOCATION PROCEDURES

(Question 1/3, Study Programme 1A/3)

(1970)

1. Introduction

HF radio circuits are frequently used to link telex networks. The transmission of information passed over such circuits is protected to a sufficient degree by means of duplex ARQ circuits, the main characteristics of which are laid down in Recommendation 342.

The traffic delays occurring in ARQ circuits during periods of conditions unfavourable to radio reception are, due to cycling, of variable duration and interfere with fully automatic switching of telex circuits.

2. In view of the decision by the CCITT that charging on a fully automatic telex network should be made on the basis of elapsed time rather than on non-cycling time, it is desirable that radio sections of a fully automatic switched network should be designed to provide a good quality of service, while protecting the users against unreasonable charges. The main characteristics of such a system, called the "flex" system, are described in Annex I.

3. The development of the "flex" system is based on the following principles and considerations:

3.1 The efficiency of each ARQ channel is monitored continuously. A given telex circuit will be cleared when the efficiency drops below a predetermined value and a new circuit is established, utilizing another ARQ channel of acceptable efficiency, to enable the subscriber to complete his call.

3.2 Although large parts of a telex circuit are duplex, it is to be noted that telex operation is basically simplex. The ARQ part of the circuit has the disposal of a "go" path and a "return" path, for which a radiotelegraph channel is busied in each direction. Depending on the direction into which information is transmitted in simplex operation, each of the radiotelegraph channels will function alternately as a go or as a return path. The return path is needed to close the ARQ loop, but no information is passed over it. Thus, in effect, only 50% of the total channel capacity is utilized. Moreover, during a telex connection, idle-time signals are transmitted over the go path when the active subscriber is not actually transmitting (stop intervals), with the result that, on the average, the channel utilization is even less than 50% of the total capacity.

3.3 If, for the destination considered, several ARQ circuits are available, a subscriber can be offered a circuit that is substantially free from cycling, if a method of re-routing his traffic is found, each time the busied ARQ circuit becomes inefficient. This method does not only offer improved service to the subscriber, but also increases utilization of the radiotelegraph channels. Thus, an ARQ loop will no longer serve as the go path in one direction and the return path in the other direction for one pair of subscribers, but each direction of the ARQ loop becomes a go path for a separate pair of subscribers, of whom the active subscriber occupies that go path as long as his traffic can be transmitted over it. In addition, during periods in which a large amount of traffic is offered, traffic that would otherwise be held up can, with this system, be transmitted over the available channels during idle periods of calls in progress.

ANNEX I

1. The "flex" system is a method that deals with the automatic connection and disconnection of telex circuits to and from ARQ channels, which makes it possible:

1.1 to re-route telex circuits from ARQ channels in which the efficiency has dropped below a predetermined value to ARQ channels that are efficient;

1.2 to disconnect an ARQ channel from a telex circuit during the idle intervals in the traffic flow, so that the ARQ channel becomes available for another telex circuit;

1.3 to allot each of both paths of an ARQ channel to different telex circuits;

1.4 to effect forced clearing of a telex circuit if none of the functions described in §§ 1.1, 1.2 or 1.3 can be performed.

2. An ARQ channel is connected to the telex network at both ends via a telex adaptor panel (hereafter referred to as TP), which performs the functions prescribed in CCITT Recommendation U.20 (Fascicle VII.1).

A number, *N*, of TP terminals and a number, *M*, of ARQ channels are interconnected by the automatic switching device of the flex system (*N* and *M* need not necessarily be equal). This arrangement replaces the direct connection between a TP and a specific ARQ channel via a patching board in conventional ARQ circuits.

3. If no telex circuit is established, all the TP in the flex system are disconnected from the ARQ channels, and all non-cycling ARQ channels transmit "signal β".

4. At the interface to the flex system, each TP has a sending and a receiving terminal. The sending terminal of a TP is automatically connected to the front end of an efficient ARQ channel when, from the landline circuit:

- a call criterion is received by the TP,
- traffic is brought into the storage device of the TP,
- a clearing criterion is received by the TP.

5. The front end of an ARQ channel can only be seized, if:

- the ARQ channel is efficient,
- the ARQ channel is not cycling,
- the front end has not yet been allotted to another TP.

6. Associated with each TP is an address generator which, as soon as the TP sending terminal is connected to the front end of an ARQ channel, transmits the address signal over this connection. The address signal is specific for each individual TP, and consists of a 5-unit signal, transmitted thrice in succession. The remote ARQ receiver recognizes a signal as an address, when at least two out of three signals are identical, and this group has been preceded by at least two consecutive "signals β". (It is considered that for an efficient ARQ channel the probability of receiving two transposed signals in a group of three, without a fault being detected, is extremely low.)

7. At its receiving end, the ARQ channel finds the corresponding TP receiving end terminal by means of the address signal.

8. A circuit is established to pass:

- a call,
- traffic,
- a clearing signal.

8.1 To pass a call over the ARQ channel, only the address is transmitted. The reception of only the address at an ARQ receiving terminal puts the required TP receiving end to the "called" position.

8.2 Traffic signals transferred over an ARQ channel immediately follow the address signal. The TP receiving terminal is disconnected from an ARQ go path as soon as the traffic flow is interrupted by pause signals (on the ARQ path at least two consecutive "signals β").

8.3 To pass a clearing signal over an ARQ channel, the address signal is immediately followed by seven "signals α". On receipt of two consecutive "signals α" the TP receiving end accepts the clearing condition after which it is disconnected from the ARQ receiver by the flex system.

9. The flex system disconnects a TP sending end from an ARQ front end when:

- during traffic, the traffic flow is interrupted because the TP storage is empty, and moreover three consecutive "signals β" have been successfully transmitted over the ARQ path,
- no traffic is yet available after a call signal has been passed, and three consecutive "signals β" have been transferred over the ARQ path,
- at reception of a clearing signal, seven consecutive "signals α" and three consecutive "signals β" have been passed over the ARQ channel,
- the efficiency of the ARQ channel drops below the predetermined value.

In the last case, the disconnecting of the TP sending end from an ARQ channel might cause the loss of three characters stored in the ARQ storage. However, the disconnecting and re-routing of a TP-user can be performed without loss of characters, by utilization of the system cycle in conjunction with an externally added dummy cycling storage.

10. A peculiar situation arises when a TP-user has a telex circuit at his disposal but fails to re-establish an ARQ connection because all efficient ARQ channels are engaged. In such a case one of these channels is temporarily disconnected from the transmitting TP busying it, and is allotted to the first mentioned TP, only to enable it to transmit a forced clearing signal over the ARQ route. The ARQ channel is returned to its previous user as soon as this clearing signal has been transmitted.

The clearing signal is also sent to the subscriber who was using the TP that cleared the connection over the ARQ route.

RECOMMENDATION 342-2

AUTOMATIC ERROR-CORRECTING SYSTEM FOR TELEGRAPH SIGNALS TRANSMITTED OVER RADIO CIRCUITS

(Question 26/3)

(1951-1953-1956-1959-1963-1966-1970)

The CCIR,

CONSIDERING

(a) that it is essential to be able to interconnect terminal start-stop apparatus employing the International Telegraph Alphabet No. 2 by means of radiotelegraph circuits;

(b) that radiotelegraph circuits are required to operate under varying conditions of radio propagation, atmospheric noise and interference, which introduce varying degrees of distortion which may at times exceed the margin of the receiving apparatus;

(c) that, in consequence, the transmission of 5-unit code signals over radio circuits is liable to errors and that such errors are not automatically detectable by the receiving apparatus;

(d) that an effective means of reducing the number of wrongly printed characters is the use of codes, permitting the correction of errors by detecting the errors and automatically causing repetition;

(e) that the method using synchronous transmission and automatic repetition (ARQ), is now well proven;

(f) that it is desirable to permit the correct phase to be established automatically on setting up a circuit;

(g) that certain circumstances can occur which result in a loss of the correct phase relationship between a received signal and the receiving apparatus;

(h) that it is desirable to permit the correct phase relationship to be re-established automatically after such a loss, without causing errors;

(j) that, to avoid mis-routing traffic, it is essential to prevent phasing to a signal which has been unintentionally inverted;

(k) that there is sometimes a need to subdivide one or more channels, to provide a number of sub-channels at a proportionately reduced character rate;

(l) that the method of automatically achieving the correct phase relationship between the received signal and the sub-channelling apparatus should be an integral part of the phasing process;

(m) that compatibility with existing equipment, designed in accordance with Recommendation 242, Los Angeles, 1959, is a requirement,

UNANIMOUSLY RECOMMENDS

1. that, when the direct use of a 5-unit code on a radio circuit gives an intolerable error rate and there is a return circuit, a 7-unit ARQ system be employed;

2. when automatic phasing of such a system is required, the 7-unit system, described in Annex I, should be adopted as a preferred system;

3. that equipment, designed in accordance with § 2, should be provided with switching, to permit operation with equipment designed in accordance with Recommendation 242, Los Angeles, 1959.

Note. – Methods in accordance with this Recommendation are described in [CCIR, 1962].

REFERENCES

CCIR Documents

[1962]: Geneva, III/17.

ANNEX I

1. Table of conversion

TABLE I

	International code No. 2	International code No. 3
A	ZZAAA	AAZZAZA
B	ZAAZZ	AAZZAAZ
C	AZZZA	ZAAZZAA
D	ZAAZA	AAZZZAA
E	ZAAAA	AZZZAAA
F	ZAZZA	AAZAAZZ
G	AZAZZ	ZZAAAAZ
H	AAZAZ	ZAZAAZA
I	AZZAA	ZZZAAAA
J	ZZAZA	AZAAAZZ
K	ZZZZA	AAAZAZZ
L	AZAAZ	ZZAAAZA
M	AAZZZ	ZAZAAAZ
N	AAZZA	ZAZAZAA
O	AAAZZ	ZAAAZZA
P	AZZAZ	ZAAZAZA
Q	ZZZAZ	AAAZZAZ
R	AZAZA	ZZAAZAA
S	ZAZAA	AZAZAZA
T	AAAAZ	ZAAAZAZ
U	ZZZAA	AZZAAZA
V	AZZZZ	ZAAZAAZ
W	ZZAAZ	AZAAZAZ
X	ZAZZZ	AAZAZZA
Y	ZAZAZ	AAZAZAZ
Z	ZAAAZ	AZZAAAZ
Carriage return	AAAZA	ZAAAAZZ
Line feed	AZAAA	ZAZZAAA
Figures	ZZAZZ	AZAAZZA
Letters	ZZZZZ	AAAZZZA
Space	AAZAA	ZZAZAAA
Unperforated tape	AAAAA	AAAAZZZ
Signal repetition		AZZAZAA
Signal α		AZAZAAZ
Signal β		AZAZZAA

2. Repetition cycles

2.1 Four characters for normal circuits, which are not subject to excessive propagation time. The cycle should comprise one "signal repetition" and three stored characters.

2.2 Eight characters on circuits for which the four-character repetition cycle is inadequate. The cycle should comprise one "signal repetition", three signals β and four stored characters, or one "signal repetition" and seven stored characters.

3. Channel arrangement

3.1 *Channel A*

3.1.1 For equipment employing a four-character repetition cycle: one character inverted followed by three characters erect (see Fig. 1a).

3.1.2 For equipment employing an eight-character repetition cycle: one character inverted followed by seven characters erect (see Fig. 2a).

3.2 *Channel B*

3.2.1 For equipment employing a four-character repetition cycle: one character erect followed by three characters inverted (see Fig. 1b).

3.2.2 For equipment employing an eight-character repetition cycle: one character erect followed by seven characters inverted (see Fig. 2b).

3.3 *Channel C*

As for Channel B (see Figs. 1c and 2c).

3.4 *Channel D*

As for Channel A (see Figs. 1d and 2d).

3.5 *Order of transmission*

3.5.1 Characters of Channels A and B are transmitted consecutively (see Figs. 1e and 2e).

3.5.2 Elements of Channel C are interleaved with those of Channel A (see Figs. 1g and 2g).

3.5.3 Elements of Channel D are interleaved with those of Channel B (see Figs. 1g and 2g).

3.5.4 In the aggregate signal, A elements precede those of C, and B elements precede those of D (see Figs. 1g and 2g).

3.5.5 The first erect character on A, transmitted after the inverted character on A, is followed by the erect character on B (see Figs. 1e and 2e).

3.5.6 The erect character on C is followed by the inverted character on D (see Figs. 1f and 2f).

3.5.7 The inverted character on A is element-interleaved with the erect character on C (see Figs. 1g and 2g).

4. Sub-channel arrangement

4.1 The character transmission rate of the fundamental sub-channel should be a quarter of the standard character rate.

4.2 Sub-channels should be numbered 1, 2, 3 and 4 consecutively.

4.3 Where a four-character repetition cycle is used, sub-channel 1 should be that sub-channel which has opposite keying polarity to the other three sub-channels of the same main channel (see Figs. 3a-d).

Where an eight-character repetition cycle is used, sub-channel 1 should be that sub-channel which has alternately erect and inverted keying polarity (see Figs. 3e-h).

4.4 When sub-channels of half-character rate, or three-quarter-character rate are required, combinations of the fundamental sub-channels should be arranged as shown in Table II.

TABLE II

Proportion of full-channel character rate	Combination of fundamental sub-channels
(1) quarter (2) quarter (3) half	No. 1 No. 3 Nos. 2 and 4
(1) half (2) half	Nos. 1 and 3 Nos. 2 and 4
(1) quarter (2) three-quarters	No. 1 Nos. 2, 3 and 4

5. Designation of aggregate signal

To assist in identifying the signal condition when applying the aggregate telegraph signal to modulate the radio channel, the following designation for the aggregate signal should be used:

TABLE III

Seven-unit code condition	Aggregate signal condition	
	Erect character	Inverted character
A	B	Y
Z	Y	B

6. Diagrams

As a result of the characteristics specified in §§ 2, 3 and 4 of this Annex, the transmission of characters will be as shown in Figs. 1, 2 and 3.

7. Automatic phasing

7.1 Automatic phasing should normally be used. It should be initiated either:

7.1.1 after a waiting period during which cycling due to the receipt of errors has occurred continuously on both channels of a 2-channel system, or on at least two main channels of a 4-channel system;

7.1.2 after equal counts of A and Z elements have been made over at least two consecutive system cycles whilst continuous cycling due to the receipt of errors is occurring on all main channels;

7.2 when the slave station is phasing, it should transmit in each channel, in place of the "signal repetition", a 7-element signal in which all 7 elements are of the same polarity, all other characters in the repetition cycle being transmitted unchanged. (Existing systems without this facility need not be modified because compatibility is assured).

8. CCITT Recommendation S.12 (Fascicle VII.2) recommends that the interval between the beginning of successive start elements of the signals transmitted into the landline network be 145 5/6 ms. Therefore, the duration of the transmission cycle on the radio circuit and also the modulation rate must be chosen correspondingly, if connection to the network is required.

Practical values for the modulation rate in bauds and the duration of the transmission cycle, which enable synchronization to be effected by using a single oscillator for three cases, are shown in Table IV.

TABLE IV

Transmission cycle (ms)	Modulation rate (bauds)	
	2-channel operation	4-channel operation
145 5/6	96	192
This is the preferred standard. See C.C.I.T.T. Recommendations S.12 and S.13		
163 1/3	85 5/7	171 3/7
140	100	200

The transmission cycle of 145 5/6 ms is the preferred standard for connection to 50-baud networks.

The transmission cycle of 163 1/3 ms is suitable for connecting to 45-baud networks.

The transmission cycle of 140 ms is suitable for radio circuits without direct connection to a landline network.

The tolerance on the frequency of the master oscillator, controlling the timing of each terminal equipment, should be $\pm 1 \times 10^{-6}$.

9. CCITT Recommendation U.20 (Fascicle VII.1) gives the signalling conditions to be used when telex communication is to be established by means of such radio circuits:

9.1 for circuits on switched telegraph networks, the conditions of CCITT Recommendation U.20 should apply;

9.2 for point-to-point circuits, Administrations may adopt, at the terminal equipment under their jurisdiction, their own method of stopping and starting the motors of the receiving machines, based on CCITT Recommendation S.7 (Fascicle VII.2);

9.3 signal β should normally be transmitted to indicate the idle circuit condition. However, for signalling purposes, the signals α and β may be employed.

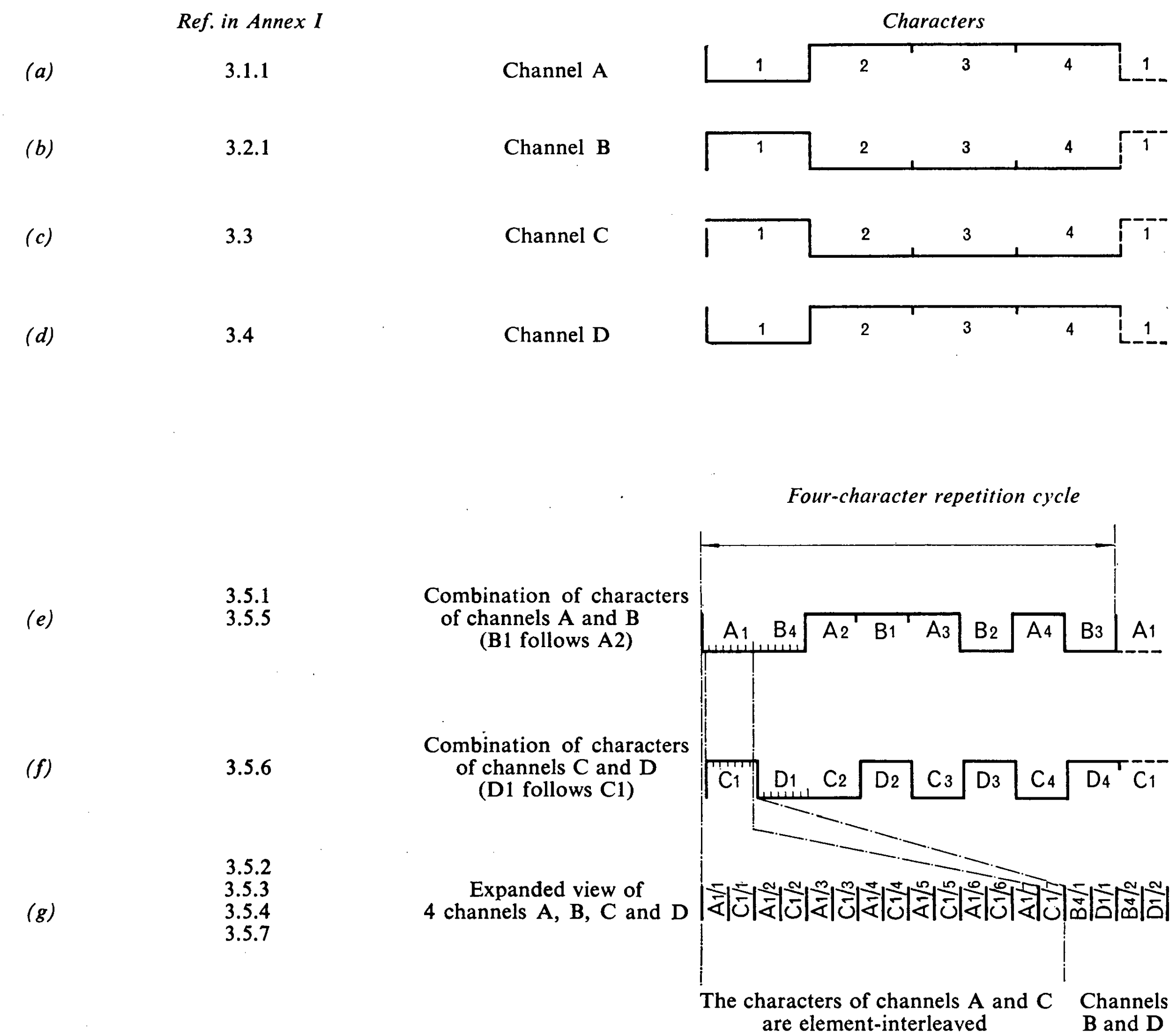

FIGURE 1 – *Channel arrangement for a four-character repetition cycle*

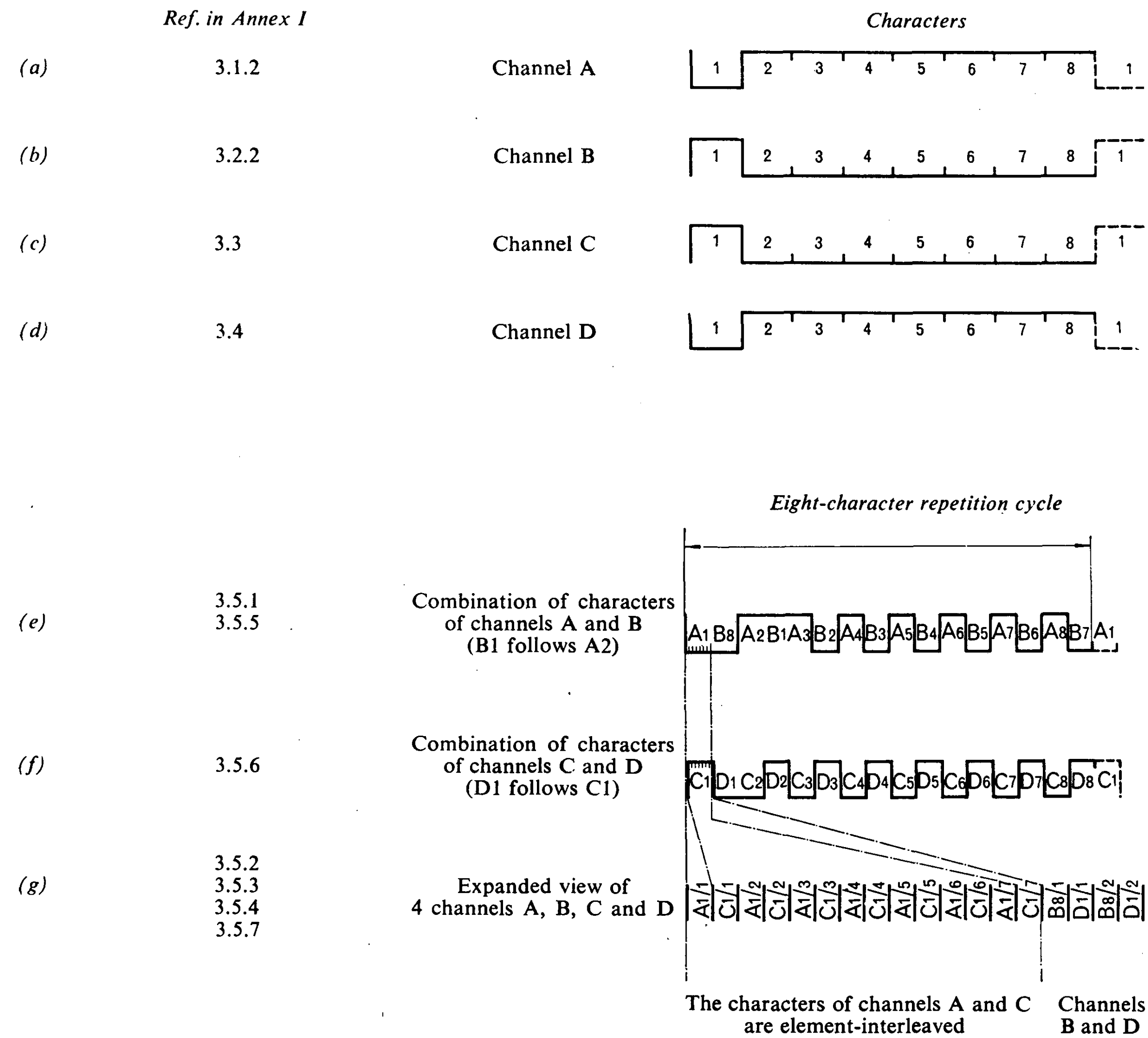

FIGURE 2 – *Channel arrangement for an eight-character repetition cycle*

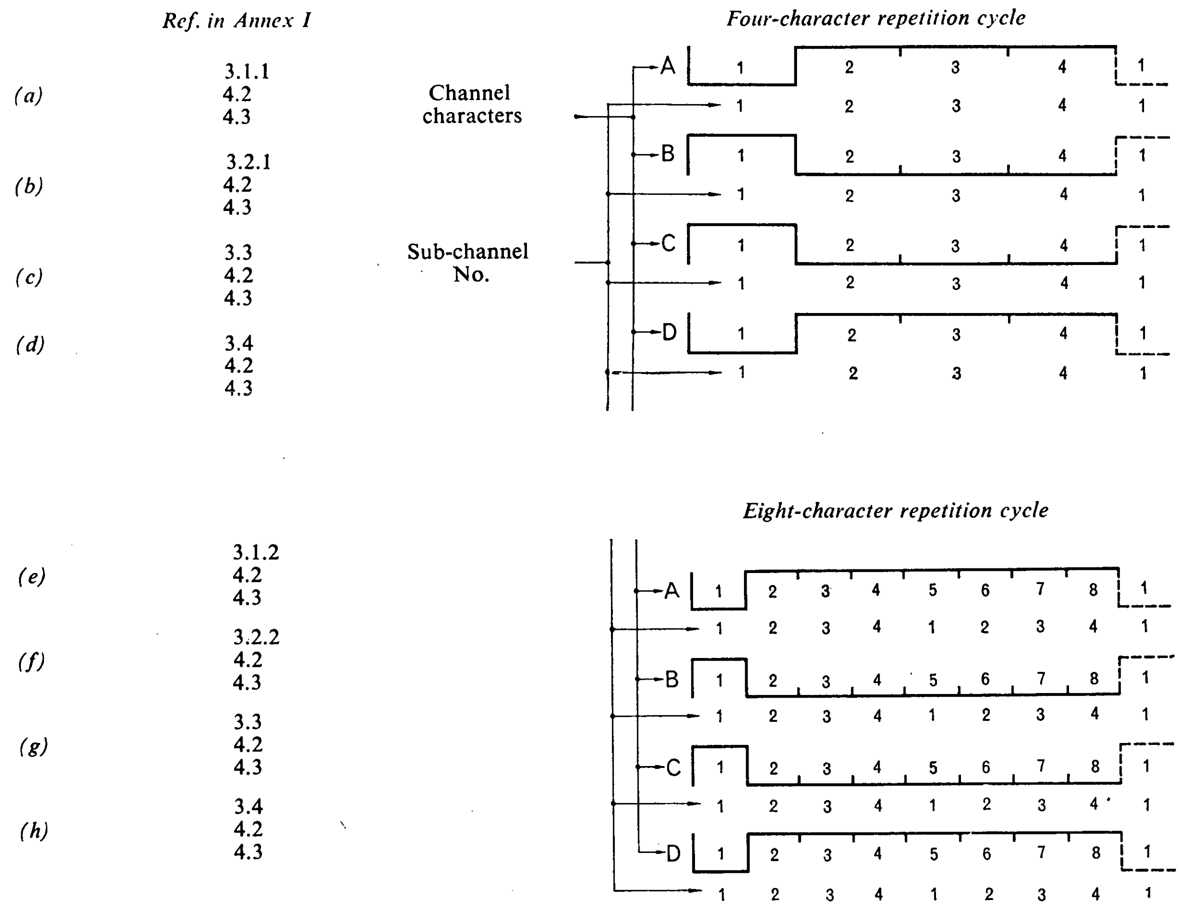

FIGURE 3 – *Sub-channelling arrangements for a four- and an eight-character repetition cycle*

ANNEX II

TERMS RELATED TO ARQ-SYSTEMS *

Part 1

1. Signal repetition
   RQ-signal
   Signal Roman one – the seven unit combination (AZZAZAA) which is used to request a repetition (RQ-signal) or to precede a re-transmission (BQ-signal);

2. Repetition cycle – the sequence of characters, the number of which is determined by the *loop time-delay of the system*, to provide automatic repetition of information;

3. RQ-cycle
   Request cycle – the *repetition cycle* transmitted by ARQ-apparatus at the detection of a mutilation;

4. BQ-cycle
   Response cycle – the *repetition cycle* transmitted by ARQ-apparatus at a request for repetition;

* The twenty-three terms and definitions in Part 1 of this list have been studied by a joint Working Party of Study Groups III and XIV during the Xth Plenary Assembly of the CCIR, Geneva, 1963, as a provisional contribution (see § 2 of the Annex to Resolution 21 (Oslo, 1966) to the "List of Definitions of Essential Telecommunication Terms" (Part II to be published later).

The other terms and definitions contained in Part 2 of this list, which are of more general application, are given as information pending examination by the CCITT.

5. Non-print cycle – the interval at the ARQ-receiver, initiated by the detection of a mutilation or a *signal repetition*, that has the same duration as a *repetition cycle* and during which all signals received are prevented from being printed;

6. Gated RQ – a procedure in which a check is made for the presence of a signal repetition during a *non-print* cycle;

7. Tested RQ – a procedure in which a check is made for the presence of a *signal repetition* and a check is made for the ratio A/Z on all characters received after the *signal repetition* within the *non-print cycle*;

8. Tested repetition cycle – a *non-print cycle* in which a check is made for the presence of a *signal repetition* and for the correct ratio A/Z of all the characters received;

9. cycling – the condition that a repetition procedures is in progress;

10. Marking pattern – a specific pattern of polarity inversions applied to characters in an *aggregate signal*;

11. Marked cycle
System cycle – a cycle consisting of a specific character *marking pattern*, that is continuously repeated and has the duration of a *repetition cycle*;

12. System phase
Marked cycle phase – the condition in which the *marking pattern* of the local timing coincides with the *marked cycle* of the received signal;

13. Phasing
Phase hunting – the condition in which a station is hunting for *character phase* or *system phase*;

14. Manual phasing – *phasing* by manual action only;

15. Semi-automatic phasing – *phasing* completed automatically after manual initiation;

16. Automatic phasing – *phasing*, initiated and completed automatically after automatic detection of "out-of-phase";

17. Master station – the station, the transmitting equipment of which is directly driven by a master oscillator but the receiver timing of which is normally synchronized to the incoming signal;

18. Slave station – the station, receiver and transmitter timing of which are both synchronized to the received signal;

19. End-to-end time delay – the delay between the output terminals of an ARQ-transmitter and the input terminals of the ARQ-receiver at the other end (this is the sum of radio and line circuit delays in one direction of a route);

20. Loop time-delay of a route – the sum of the end-to-end delays in the send and return directions of a route;

21. Master station delay – the period between the beginning of reception of a *signal repetition* at the ARQ-input terminals at the *Master station* and the beginning of transmission of the replying *signal repetition* at that station.

Note. – This comprises the "scanning" and equipment delays and a further delay which, when added to the *loop time-delay of the system*, produces an integral multiple of the *character cycle* duration;

22. Slave station delay – the period between the beginning of reception of a *signal repetition* at the ARQ-input terminals at the *slave station* and the beginning of transmission of the replying *signal repetition* at that station.

Note. – This comprises "scanning" and equipment delays and a "pre-set" delay between the receiver and the transmitter;

23. Loop time-delay of a system (as seen from the master station) – the sum of the *loop time-delay*, measured under working conditions.

Part 2

(a) Aggregate signal – the synchronous signal produced by combining the channel signals;

(b) Balanced aggregate signal – an aggregate signal containing equal numbers of elements of each polarity;

(c) Character cycle – the period in which each channel of a time-division multiplex transmission has completed one character in the synchronous path;

(d) Element synchronism – in synchronous systems:
the condition in which an element of the local timing coincides completely with an element of the received signal;

(e) Synchronizing – the action of adjustment of element synchronism;

(f) Phase relationship – in synchronous systems:
the relative phase of receiving apparatus and incoming signals, or receiving and sending apparatus;

(g) Character phase – the condition in which a *character cycle* of the local timing coincides completely with a character cycle of the received signal.

Note. – Under these conditions, a character of the aggregate signal transmitted on a particular channel is received on the correct channel;

(h) Sub-channel – a teleprinter channel which is allocated a quarter rate of a normal channel, or multiples thereof;

(j) Sub-channel phase – the condition in which a character transmitted on a particular sub-channel is received on the correct sub-channel;

(k) Transposition – Add to definition 33.25 of the ITU "List of Definitions..." (Part I):
"Transpositions may be regarded as of first or higher order according to the number of interchanges occurring within a character."

RECOMMENDATION 518

SINGLE-CHANNEL SIMPLEX ARQ TELEGRAPH SYSTEM

(Question 26/3)

(1978)

The CCIR,

CONSIDERING

(a) that large areas of the world do not yet have the facility of being connected to the international telegraph network, although they have a potential need for the exchange of messages by telegraph;

(b) that the amount of traffic to be dealt with will initially be small and the distances to be bridged will usually be great; therefore, an HF radio system might best be suited to link an isolated station to one of the offices of the world-wide telegraph network;

(c) that use of automatic error correction ARQ can make the quality of the radio circuit comparable with that of landline connections;

(d) that to participate in the telex network, the direction of traffic flow should be instantly reversible;

(e) that the location of such isolated stations often does not permit the simultaneous use of the radio transmitter and radio receiver;

(f) that it may be useful to employ the same frequency in both directions of a circuit,

UNANIMOUSLY RECOMMENDS

that the single-channel simplex ARQ telegraph system described in §§ 1.2 and 3.1 of Annex I of Recommendation 476 for the maritime mobile service, be utilized also for the HF fixed service.

RECOMMENDATION 519

SINGLE-CHANNEL DUPLEX ARQ TELEGRAPH SYSTEM

(Question 26/3)

(1978)

The CCIR,

CONSIDERING

(a) that nowadays, multiplex systems with error correction by automatic repetition (ARQ), are frequently used in the transmission of telegraph signals over radio circuits; the characteristics of such ARQ systems are laid down in Recommendation 342:

(b) that where the volume of traffic does not justify the use of more than one channel, a single-channel ARQ system seems appropriate,

UNANIMOUSLY RECOMMENDS

that the systems based on the principles laid down in Recommendation 342, Annex I, §§ 1, 2, 4, 7 *, 8 ** and 9, where they apply to single-channel operation, are considered appropriate for application to single-channel duplex ARQ telegraph systems.

REPORT 349-1

SINGLE-CHANNEL RADIOTELEGRAPH SYSTEMS EMPLOYING FORWARD ERROR CORRECTION

(Question 26/3)

(1966-1970)

1. Introduction

Contributions by Administrations to the XIth Plenary Assembly, Oslo, 1966, provided a basis for a preliminary report on the question of protection of single-channel radiotelegraph channels by means of methods of forward error correcting. The experimental results reported in [CCIR, 1963-66a and b] are summarized in this Report, as well as the pertinent [CCIR, 1963-66c and d; CCIR, 1966-69a]. More detailed tests, utilizing laboratory simulation, were reported in [CCIR, 1966-69b and c] and are also summarized.

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* For the purpose of this Recommendation, Recommendation 342, § 7.1.2, Annex I, should be read as: "after appropriate counts of A and Z elements . . .".

** For the purpose of this Recommendation, modulation rates of 48, 72 and 96 bauds with transmission cycles of 145 5/6, 97 2/9 and 72 11/12 ms apply respectively.

2. Summary and discussion of reported results

2.1 [CCIR, 1963-66a and b] both report on trials conducted with a system described by Keller [1963]. This system uses a ten-unit self-checking code, a synchronous mode of transmission and is capable of correcting all single errors in the text and of detecting all double errors as well as most multiple errors introduced by the transmission path.

The ten-unit code consists of the 5 elements of the International Telegraph Alphabet No. 2 followed by 5 parity check elements. The 5 parity elements are either an erect or an inverse repetition of the information elements, depending on whether the Z count in the information elements is odd or even. Errors which are detected, but cannot be corrected, are indicated by the printing of "error" symbols, usually combination 31 or 32.

Transmission over the radio circuit is at modulation rates of 62.3, 68.5 or 102 bauds for teleprinter circuits operating at modulation rates of 45.45, 50 and 75 bauds respectively. At the lower modulation rates, the system is capable of extension over the inland telegraph network using conventional 50-baud voice-frequency channels.

No special phasing signals are required, as the system is capable of fully automatic phasing during periods of traffic as well as during periods of idling.

The system reported in [CCIR, 1963-66a and b] is currently in commercial service. Results obtained from field trials with this system are summarized in Table I.

In addition to these results, [CCIR, 1963-66a] also reports that over the period of 7 August 1965 to 27 November 1965 a total number of 1099 data tapes, each containing between 1500 and 1800 characters, were transmitted from ships at sea to an office in London. Of these, 889 were accepted without need for later re-transmission (i.e. contained no errors).

It is further reported that tests between ship and shore stations with plain language messages, and ship-borne reception of broadcast services (e.g. press transmissions) were considered satisfactory, provided some measure of diversity in reception is used.

A further development of the system described above consists of element interleaving of blocks of 10 characters, providing 10 element (145 ms) error-burst correction capability.

TABLE I

Summary of results

1	2	3	4	5	6	7
Document Ref.	Trial and circuit details	Characters passed	Errors detected and corrected	Detected but uncorrected error rate	Residual uncorrected error rate	Overall error rate
[CCIR, 1963-66a]	Ship-to-shore, double-sideband transmission, single path reception	36 600	3·41 per 1000 characters	2·27 per 1000 characters	0·055 per 1000 characters	2·33 per 1000 characters
[CCIR, 1963-66a]	Ship-to-shore, single-sideband transmission, space-diversity reception					0·84 per 1000 characters
[CCIR, 1963-66b]	Ship-to-shore, double-sideband transmission, space-diversity reception(1) (2)	287 776		1·26 per 1000 characters	0·56 per 1000 characters	1·82 per 1000 characters
[CCIR, 1963-66b]	Ship-to-shore, single-sideband transmission, space-diversity reception(1)	42 952		1·42 per 1000 characters	0·54 per 1000 characters	1·96 per 1000 characters
[CCIR, 1963-66b]	Shore-to-ship, FSK transmission, single path reception	297 464		0·88 per 1000 characters	0·3 per 1000 characters	1·18 per 1000 characters
[CCIR, 1963-66b]	Shore-to-ship, FSK transmission, single path reception	54 508		1·76 per 1000 characters	0·31 per 1000 characters	2·07 per 1000 characters

(1) The distance between the two receiving antenna systems is rather small for space-diversity operation.
(2) For these trials the ship transmitter was reduced to ¼ of nominal power for technical reasons.

2.2 [CCIR, 1963-66c] proposes a single-channel error indicating system, operating at a modulation rate of 100 bauds, having to some extent capability for error correction. The system uses a constant-ratio, seven-unit error detecting code, described in [CCIR, 1963-66e] but transmits each character twice with four other characters (equivalent to 280 ms) between the repetitions. If the reception of the first transmission of a character passes the constant-ratio check, it is accepted and passed to the printer through a delay circuit. If not accepted, the reception of the repeated transmission of the character is checked, and if accepted is passed directly to the printer. If neither reception is found acceptable, a special "space" symbol is printed.

Furthermore, a third decision can be taken into account when it is not sufficiently sure whether a mark or space was received (zero-position marker). When this condition occurs, it also results in the printing of the special "space" symbol.

Transmission over the radio circuit is at a modulation rate of 100 bauds for teleprinter circuits operating at a modulation rate of 50 bauds.

Before starting the transmission of information, and in the idle time between successive messages or message blocks, the transmitting station emits idle-time signals which are also used for phasing.

This system may be viewed in either of two ways:

- as a time-diversity system with additional error detection capability. In this case, error performance (including detected but uncorrected errors) appears to be similar to the performance obtained by straight time-diversity such as reported by Lyons [1964], provided that the separation of error bursts is not less than 420 ms. The additional four bits used in the system proposed in [CCIR, 1963-66c] are used both for diversity selection and for error detection;

- as a time-spread forward error-correcting system. As such, the system is capable of correcting all single errors and most multiple errors, including error bursts of up to 280 ms, provided that the period between the occurence of errors is at least 420 ms. It is further capable of detecting most uncorrectable errors.

Systems performance measurements, utilizing laboratory simulation, have been made (see § 3.2).

2.3 The time-diversity system reported by Lyons [1964, 1965a and b] provides a burst error-correction capability for bursts up to 1.5 s, as well as having the capability of correcting most single and other multiple errors. It is particularly suitable for the reduction of errors due to time-variant distortion effects commonly experienced on HF radio circuits, such as impulsive or burst noise, sporadic interference and certain cases of selective fading due to multipath propagation.

The system utilizes two adjacent channels of a multi-channel voice-frequency frequency-shift system, each operating at a modulation rate of up to 100 bauds. One of the two channels transmits the information without delay (hereafter called the normal channel), while the other channel transmits the same information, but delayed in time by approximately 1.5 s (hereafter called the delayed channel). In addition, a parity bit is inserted after each nine information bits in the input bit stream. The information rate (bit/s) on the system is then equal to 0.9 times the modulation rate of either of the voice-frequency telegraph channels. The system is independent of input format and can be used equally well with character type transmission as with random digital input data.

Upon reception, both the normal and the delayed channel are examined for bit distortion (margin assessment) and, based on this assessment, either the normal or the delayed channel is selected as the primary channel. If, however, a parity error is found in a block in the primary channel, only that block is then taken from the other channel, provided it has no parity error.

Results obtained from a field trial of several weeks duration over a long-haul HF circuit using dual space diversity at the receiving end showed that for character error rates of approximately 1×10^{-2} on the normal channel without time diversity, the corresponding error rate of the time diversity system (measured simultaneously) was approximately 1×10^{-5}.

2.4 [CCIR, 1963-1966d] refers to four general types of forward error-correcting codes suitable for use on HF radio circuits. It further reports results from two field tests:

2.4.1 a system using a (15,10) block code (i.e. 10 information bits and 5 check bits per block), interleaved to provide 2 s burst error correction capability. This system was tested at teletype speeds over an HF link [Fritchman and Leonard, 1965], and provided an improvement in the bit error rate of about one order of magnitude when the uncorrected channel error rate was 1×10^{-2}, and two orders of magnitude when it was 1×10^{-3};

2.4.2 a system using an adaptive convolutional code (Gallager code) with maximum burst error-correction capability of 6 s. A specific feature of this system is that the error-free interval, required for burst correction (guard space), is equal to the actual length of the burst plus about 20 bits, rather than equal to a fixed interval determined by its maximum burst correction capability.

A test is reported whereby this system was compared with the use of frequency diversity. Analyzed in terms of blocks of about 3300 telegraph characters, it was found that, with the coding, over 90% of the blocks were error free, as compared with about 15% of the blocks when using diversity [Kohlenberg and Berner, 1966].

3. Systems performance measurements utilizing laboratory simulation

3.1 [CCIR, 1966-69b] presents a comparison between typical forward error correcting systems tested under simulated propagation conditions in band 7 (HF) [Law *et al.*, 1957]. The systems all accepted and delivered 50-baud start-stop teleprinter signals but used synchronous transmission in the radio path, the modulation rate of which is indicated in § 3.1.1 individually.

3.1.1 The systems tested were as follows:

System A, as described in § 2.1, with no element interleaving. Synchronous modulation rate 68.5 bauds.

System B, as system *A* but with blocks of 10 characters element-interleaved. Synchronous modulation rate 68.5 bauds.

System C. A half-rate, recurrent code similar to [Hagelbarger, 1959], but with two additional check elements per character to detect uncorrected errors and substitute error symbols, and internal dispersion giving 12 element (145 ms) error-burst correction. Synchronous modulation rate 83 bauds.

System D, as described in § 2.2 without third-decision detector (zero position marker). Synchronous modulation rate 100 bauds.

System D′, as system *D*, but with third-decision detector. Synchronous modulation rate 100 bauds.

System E. A half-rate diffuse convolutional code with threshold decoding giving 32 element (350 ms) error-burst correction [Franco and Wall, 1965; Kohlenberg and Forney, 1968]. Synchronous modulation rate 90 bauds.

Reference system. Uncoded except for the addition of one element per character for character synchronization. Synchronous modulation rate 42.3 bauds.

3.1.2 *Test conditions*

3.1.2.1 *Modulation F1B*, phase continuous, 170 Hz total frequency-shift.

3.1.2.2 *Demodulation*. Two alternative methods of demodulation were employed:

- filter-assessor with filter bandwidths of 140 Hz (3 dB);
- limiter-discriminator with predetection filter bandwidth of 180 Hz (3 dB), except for system *D′*, which had a built-in-limiter-discriminator with a predetection filter bandwidth of 500 Hz (3 dB).

3.1.2.3 *Digital test signal.* Repetitive pattern consisting of all the characters of International Telegraph Alphabet No. 2, except combination 32 (all space).

3.1.2.4 *Simulated propagation conditions.* Measurements were made with flat, Rayleigh distributed random fading and with selective fading produced by equal activity, independently-fading, two-path propagation having a path-time difference of 2 ms. Tests were made with quasi-random fading rates of 10 and 40 fades per minute. Additive Gaussian noise was used and the signal-to-noise ratio was normalized (Report 195, § 1), but with respect to the nominal data transfer rate (50 bauds) instead of to the modulation rate in order to provide a more objective evaluation of the advantages of forward error correcting coding systems.

3.1.2.5 *Character error count.* Incorrectly printed characters (i.e. undetected character errors) and printed error symbols were counted as character errors.

3.1.2.6 *Test results.* Figs. 1 to 4 represent the results of the tests for dual space diversity and for single aerial reception. System *D′* was not tested with diversity reception.

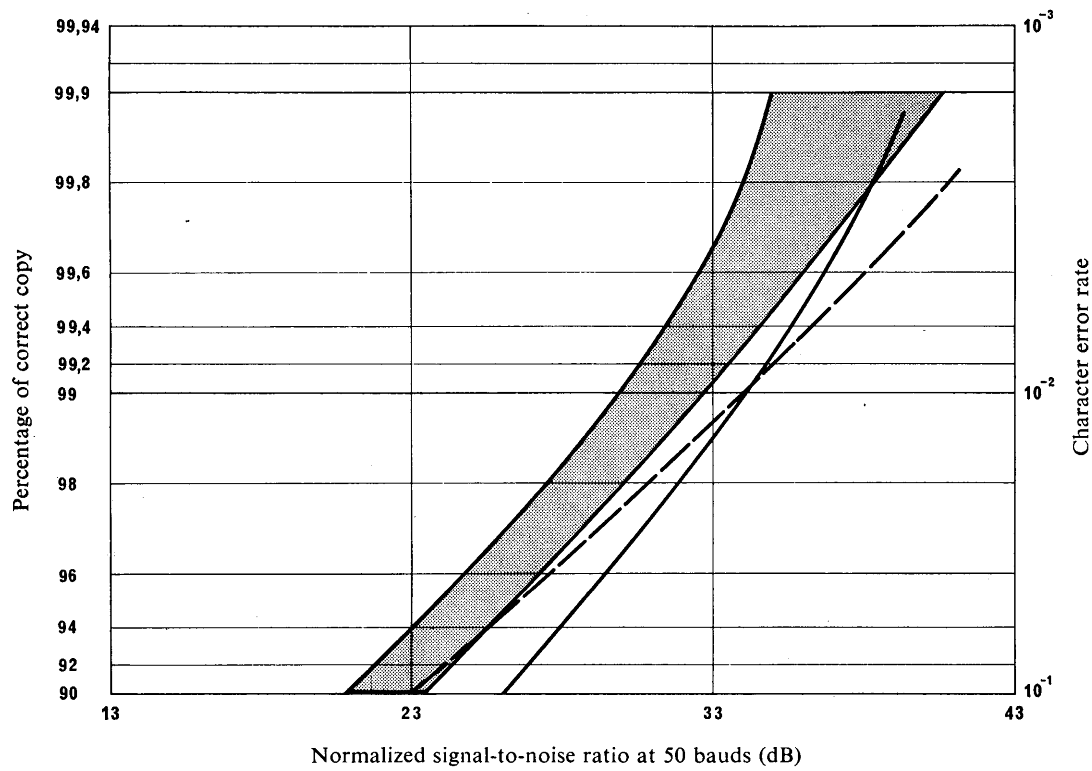

FIGURE 1 – *Comparison between forward error-correcting systems*

Fading rate: 10/min, flat
Detector: filter assessor or limiter-discriminator
Diversity: none

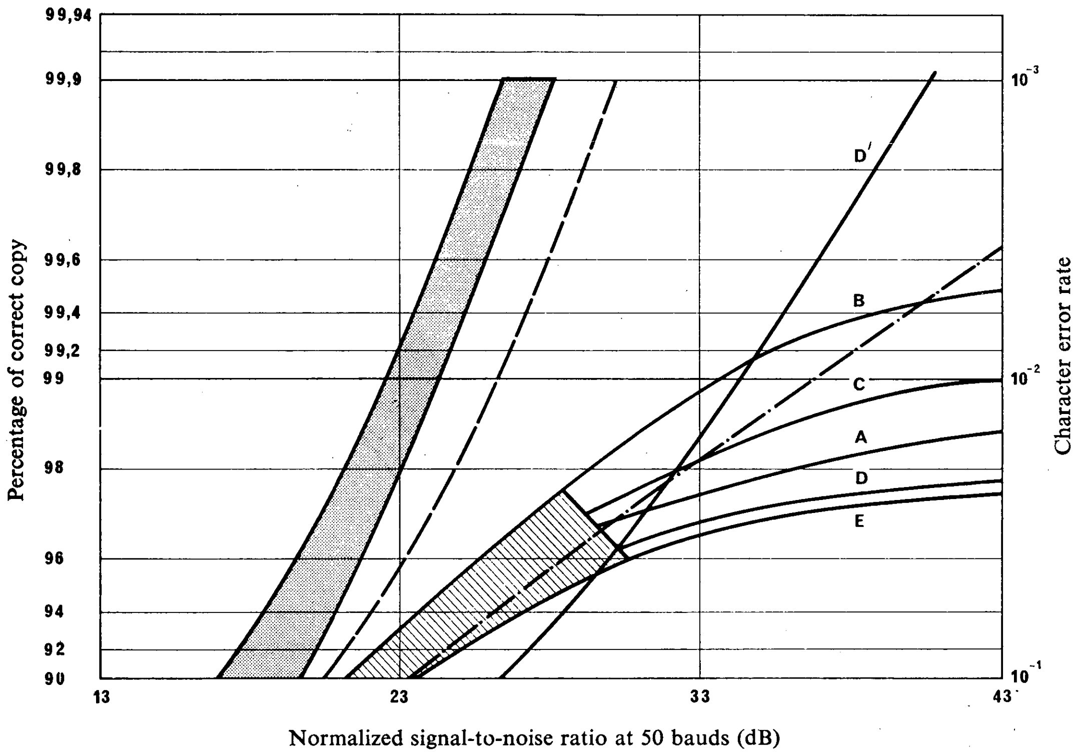

FIGURE 2 – *Comparison between forward error-correcting systems*

Fading rate: 10/min, selective, 2 ms path-time difference
Detector: filter assessor of limiter-discriminator
Diversity: none

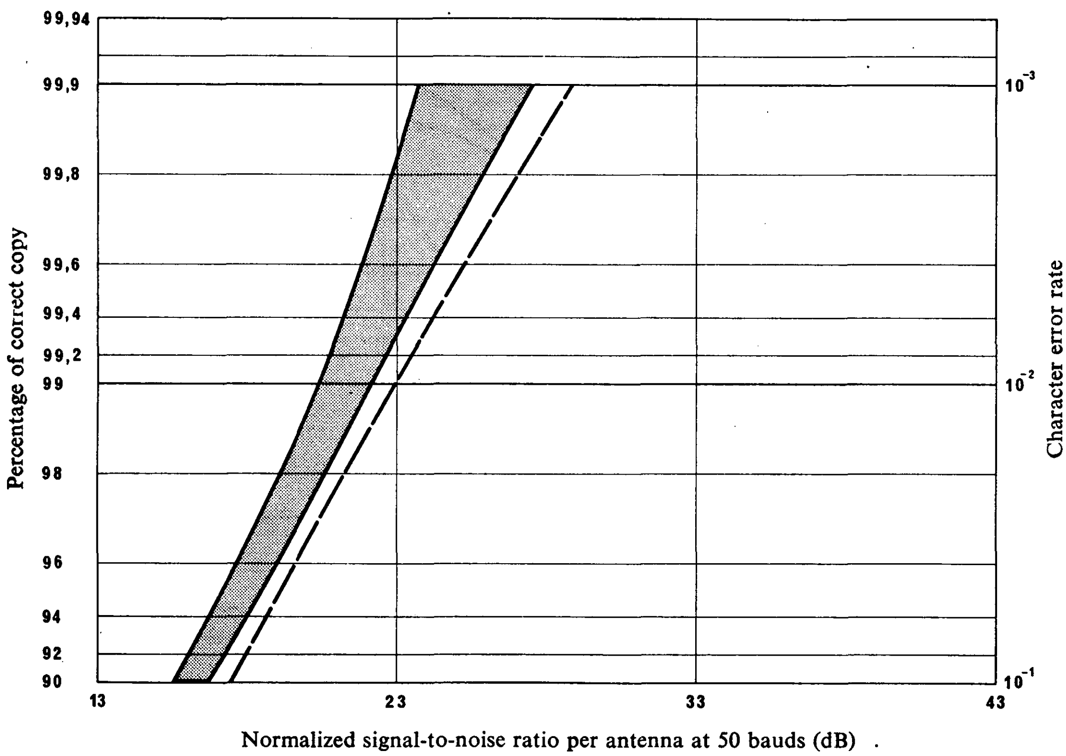

FIGURE 3 – *Comparison between forward error-correcting systems*

Fading rate: 10/min, flat
Detector: filter assessor or limiter-discriminator
Diversity: dual-spaced antennae

— — — reference system

all other systems

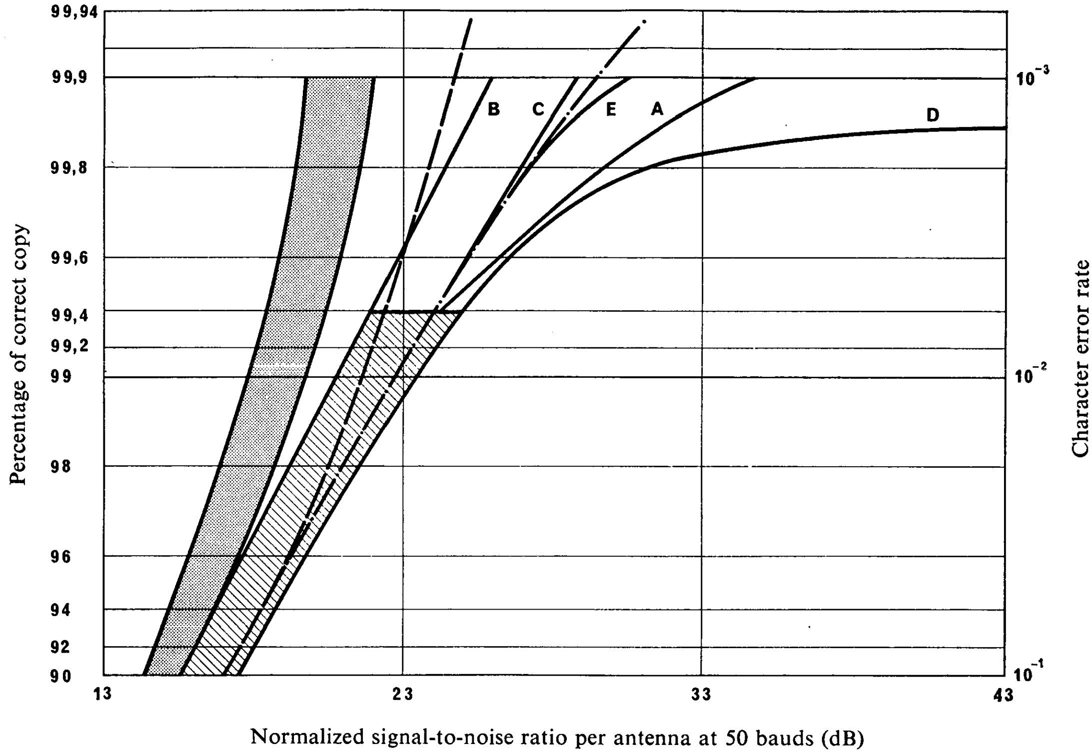

FIGURE 4 – *Comparison between forward error-correcting systems*

Fading rate: 10/min, selective, 2 ms path-time difference
Detector: filter assessor or limiter-discriminator
Diversity: dual-spaced antennae

——— reference system – filter assessor
(shaded) all other systems – filter assessor
—·—·— reference system – limiter-discriminator
(hatched) all other systems – limiter-discriminator

3.2 [CCIR, 1966-69c] presents performance measurements for two forward error-correcting systems under simulated propagation conditions in band 7 (HF) [Law *et al.*, 1957]. Both systems accepted and delivered 50-baud start-stop teleprinter signals and used synchronous transmission in the radio path.

3.2.1 *The systems tested* were as described in § 2.2, one system with and the other without third-decision detector. Synchronous modulation rate for both was 100 bauds.

3.2.2 *Test conditions*

3.2.2.1 *Modulation F1B*, phase continuous, 200 Hz total frequency-shift.

3.2.2.2 *Demodulation* limiter-discriminator with predetection filter bandwidth of 500 Hz (3 dB). The third-decision detector, when used, was adjusted to 33% of peak detector output.

3.2.2.3 *Digital test signal.* The test signal consisted of repetitive transmission of signal *R* of Report 348 (Geneva, 1974).

3.2.2.4 *Simulated propagation conditions.* Measurements were made with flat, Rayleigh distributed random fading and with selective fading produced by equal amplitude, independently phase-varying, five-path propagation with time delays of 0.5 ms between successive paths. Tests were made with quasi-random fading rates of 10, 30 and 40 fades per minute. Additive Gaussian noise was used and the signal-to-noise ratio was normalized (Report 195), to the modulation rate (100 bauds). Figs. 5 to 8 in this Report have been adjusted to a normalized S/N ratio with respect to the information transfer rate (50 bauds) to achieve conformity with § 3.1.

3.2.2.5 *Character error count.* Incorrectly printed characters (i.e. undetected character errors) and printed error symbols were counted as residual character errors (E_R). Undetected character errors were also counted separately (E_u).

3.2.2.6 *Test results.* Figs. 5 to 8 represent the results of the tests for single antenna reception.

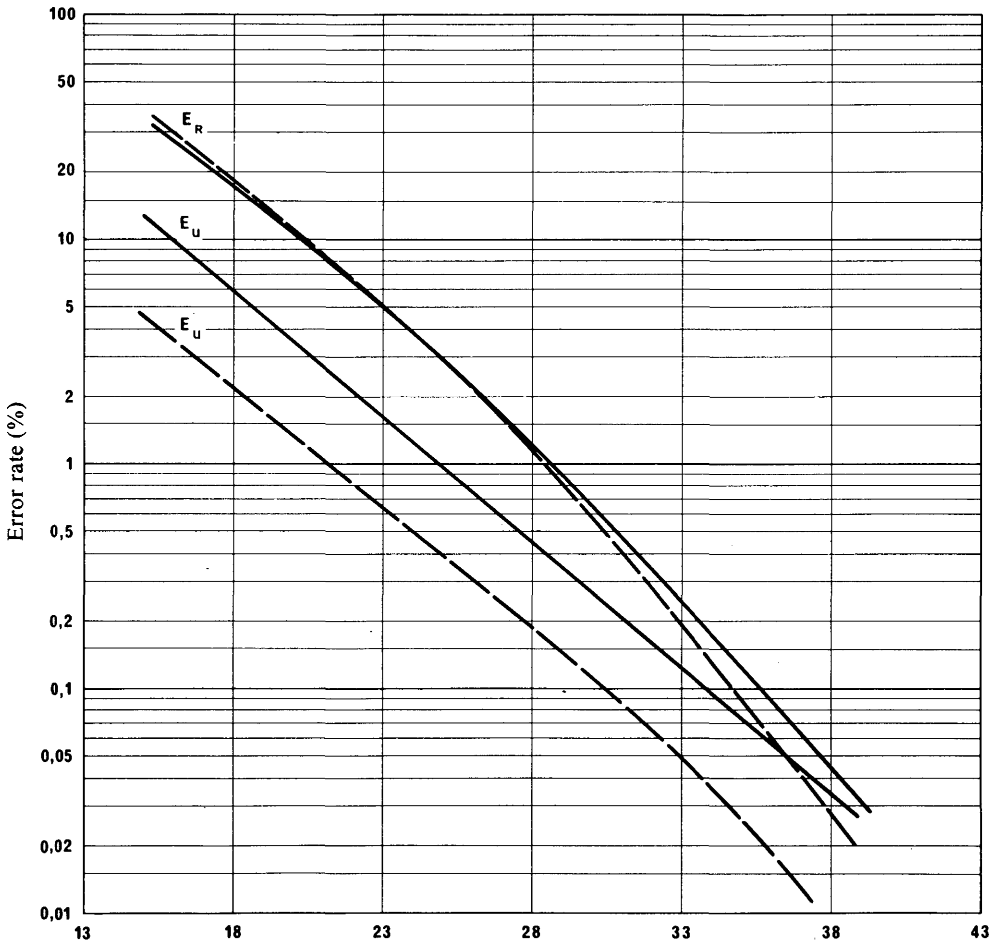

FIGURE 5 – *Residual error rate (E_R) and undetected error rate (E_u)*

Flat fading, 10 fades/minute

——————— normal detection

— — — — detection with zero-position

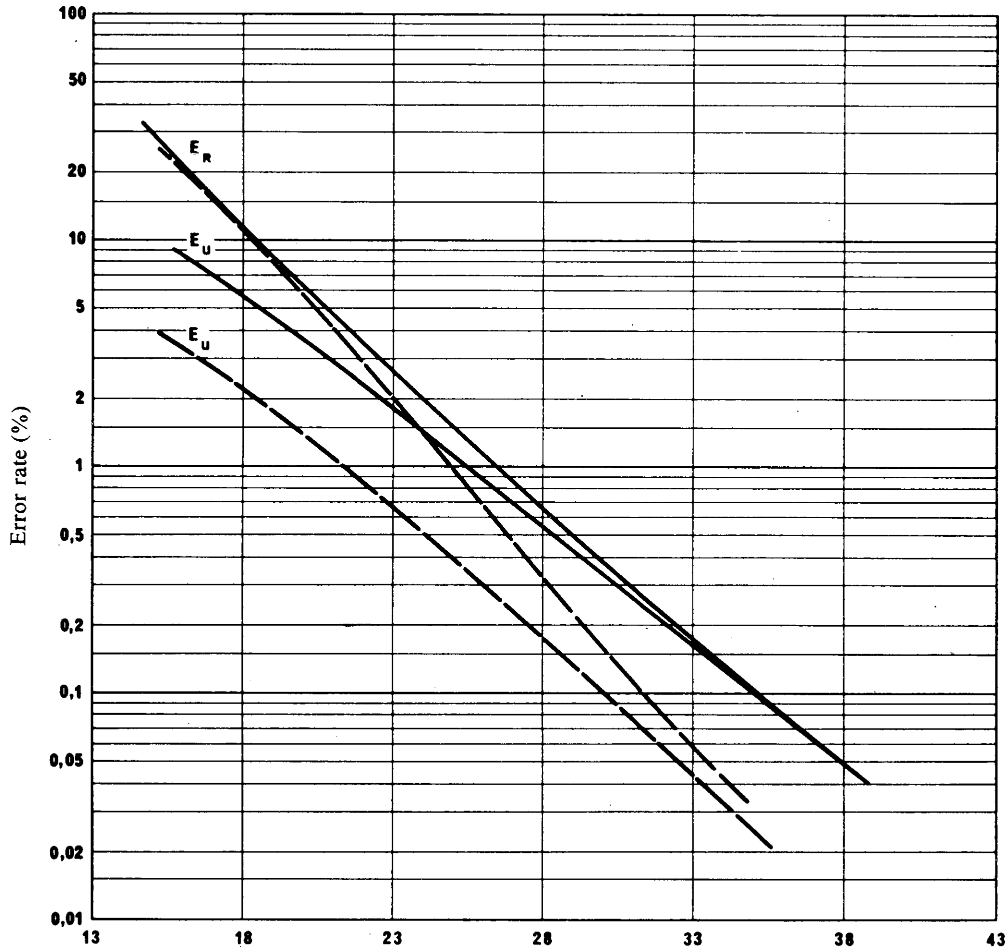

FIGURE 6 – *Residual error rate (E_R) and undetected error rate (E_u)*

Flat fading, 40 fades/minute

——— normal detection

— — — detection with zero-position

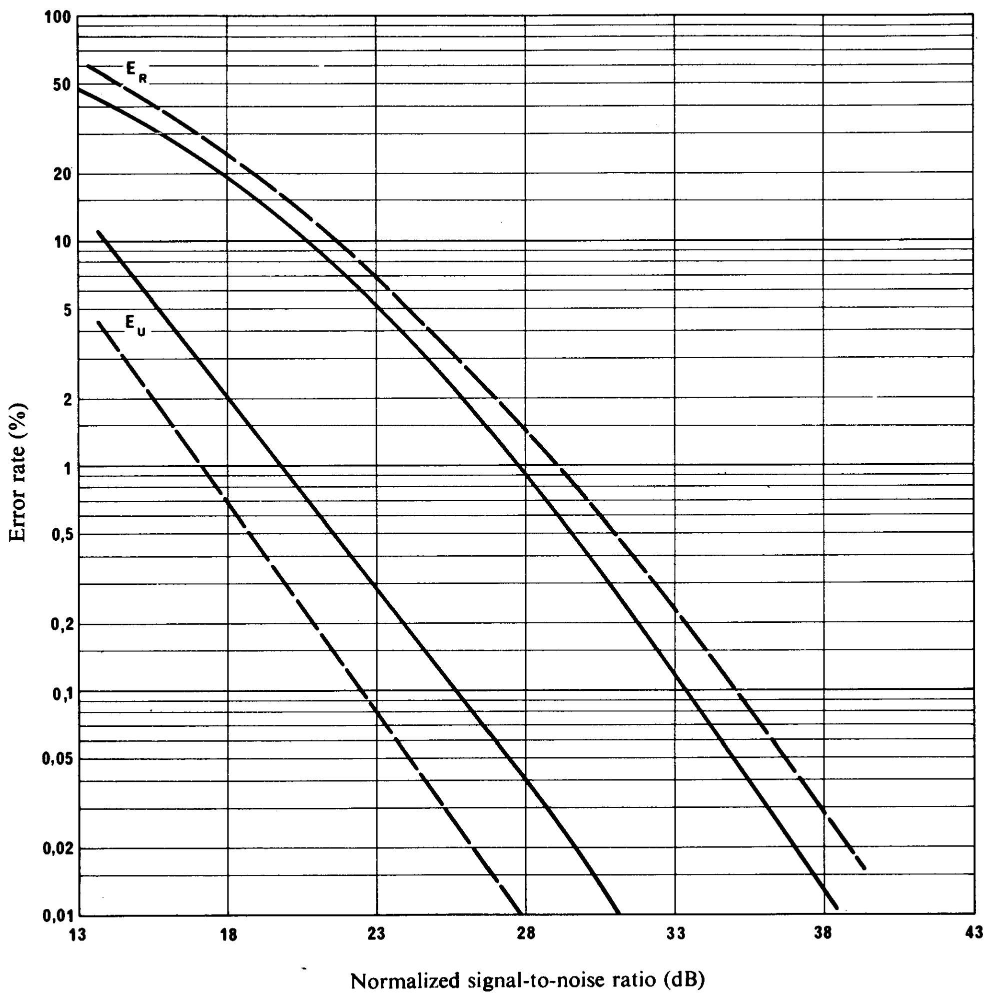

FIGURE 7 – *Residual error rate (E_R) and undetected error rate (E_u)*

Selective fading, 10 fades/minute

——— normal detection

– – – detection with zero-position

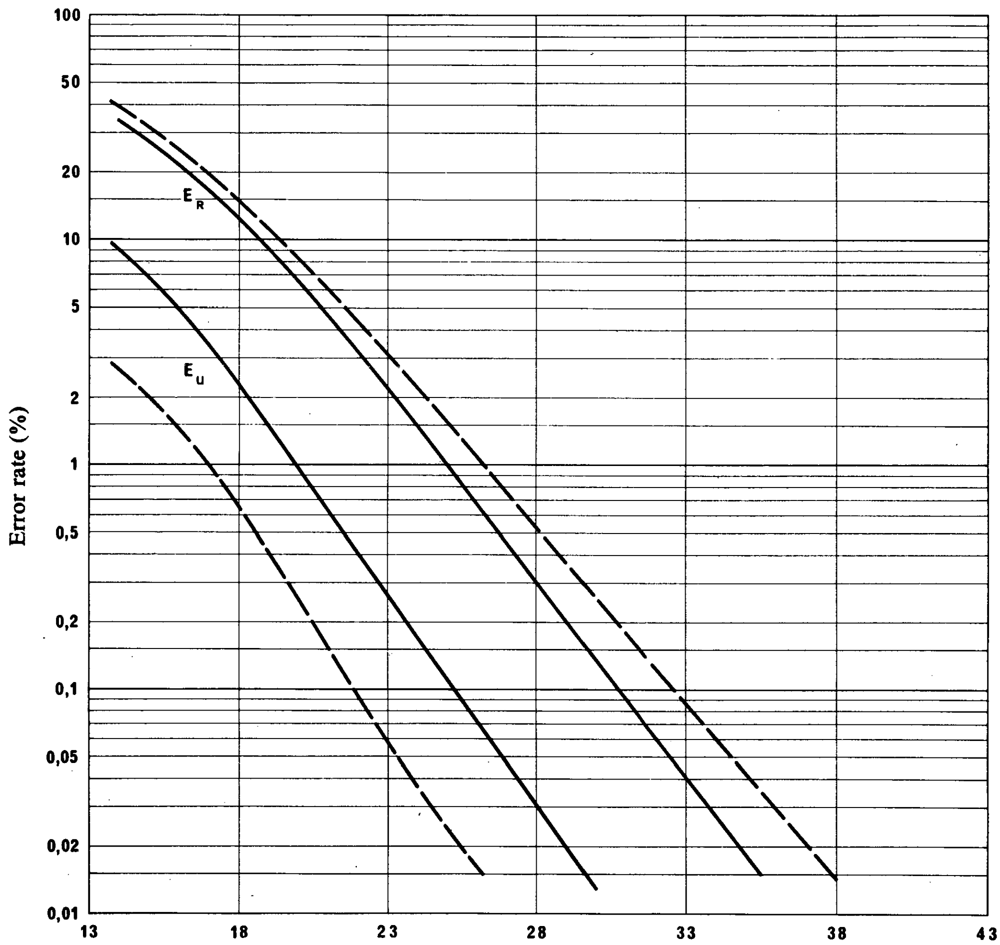

FIGURE 8 – *Residual error rate (E_R) and undetected error rate (E_u)*

Selective fading, 40 fading, 40 fades/minute

——————— normal detection

— — — — — detection with zero-position

3.3 *Discussion of results*

3.3.1 Selective fading characteristics corresponding to equal activity, independently fading, two-path propagation with a path-time difference of 2 ms and a fading rate of 10 fades/minute were chosen in the tests of § 3.1 as being representative of very unfavourable propagation conditions, and thus provide a lower bound on the performance that might be expected from the various systems tested.

The condition of flat, Rayleigh-distributed random fading with a fading rate of 10 fades/minute represents rather favourable propagation conditions, but cannot be taken as an upper bound as all the forward error-correcting systems gave a better performance with a fading rate of 40 fades/minute. This may be taken as an indication that a longer burst-error correction capability might be beneficial to cope with the lower fading rates.

3.3.2 Figs. 1 to 4 represent the results of the tests described in § 3.1. It was found that, under the particular test conditions described in § 3.1.2, the filter-assessor method of demodulation gave markedly superior results in the presence of selective fading. This can be accounted for by the distortion effects that arise from multipath propagation when using narrow predetection filter bandwidths with limiter-discriminator detection [Groves and Ridout, 1966].

With the filter-assessor method of demodulation, all forward error correction systems tested gave an improvement over the reference system, the performance of individual systems being within 1 or 2 dB of one another.

With the limiter-discriminator method of detection and under conditions of selective fading with a fade rate of 10 fades/minute, the individual performances of the different systems varied more widely. The performance of the reference system, under these conditions, was equal to or better than the performance of some of the forward error correcting systems. This may be ascribed to the lower modulation rate of the reference system, and the consequently lower distortion experienced.

With respect to the curves of system D', it must be remembered that the predetection bandwidth for this system was 500 Hz as compared to 180 Hz for all other systems with limiter-discriminator demodulation. The threshold of the third decision detector was set to approximately 50% of the peak detector output.

3.3.3 Selective fading characteristics corresponding to those produced by five equal amplitude, independently phase-varying, path components with incremental time delays of 0.5 ms were chosen in the tests of § 3.2 as being representative of fairly severe multipath conditions. Fading rates of 10, 30 and 40 fades/minute were used to evaluate the effectiveness of the forward error correcting methods, which have a fixed amount of burst error correction capability.

3.3.4 Figs. 5 to 8 represent the results of the tests described in § 3.2. Both the residual error rate (E_R) and the undetected error rate (E_u) (see§ 3.2.2.5) are shown in these figures.

Under all conditions, E_R improves with increasing fade rate, as would be expected from the fixed value of time delay between the first part and the second part of the (14 element) character.

Under flat fading conditions, E_R approaches E_u at very high S/N ratios, indicating that under these conditions most of the residual errors are undetected. Application of third decision detection shows a significant decrease in E_u for both fading rates, and thus a significant decrease in E_R at high S/N ratios.

Under selective fading conditions, E_R does not approach E_u at very high S/N ratios, and the results show that most of the residual errors are detected but uncorrected. Application of third decision detection shows again a marked decrease in E_u, but in this case a slight increase in E_R, indicating an increase in detected but uncorrected errors.

3.4 Phasing time is an important aspect of the application of forward error-correcting systems. Phasing time of the different systems under all test conditions was measured in the tests described in § 3.1. Systems D and E invariably phased in less than one second. The median times for systems A, B and C were of the order of 15 s. The phasing times observed in 99% of the tests of these three systems were less than 21, 47 and 25 s respectively. In conditions of very high error rate no system was able to achieve phase.

4. Conclusions

Performance of uncoded frequency-shift-keyed systems is, amongst others, dependent on multipath time delay spread and configuration (i.e. number and activity of individual paths), modulation index and predetection filter bandwidth in the case of limiter-discriminator detection.

For coded systems, fading rate also becomes an important factor as this has a significant influence on the time distribution of the errors.

Attention is drawn to the importance of standardizing test conditions, the parameters of ionospheric channel simulators and typical patterns of ionospheric behaviour to enable the comparison between laboratory results to be improved (see also Question 21/3).

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[1966-69]: **a.** III/9 (USA); **b.** III/81 (United Kingdom); **c.** III/91 (Netherlands).

REPORT 435

ERROR STATISTICS AND ERROR CONTROL IN DIGITAL TRANSMISSION OVER OPERATING RADIO CIRCUITS

(Question 26/3)

(1970)

1. Introduction

This Report describes some studies on error statistics in digital transmission over operating HF radio circuits. Some studies on the applicability of error control techniques are also included.

2. Error statistics

Brayer [1968] reports error-pattern data gathered from operational HF digital data transmission systems over long haul trans-equatorial paths. In one test, a four-level time differential phase-shift keying (PSK) modem with eight and sixteen tones for transmission rates of 1200 and 2400 bit/s, respectively, was used. In another test, three different types of PSK modems were used. In both tests, a sixteen-tone frequency-shift-keyed modem was used for reference purposes.

Error patterns are classified into three classes:

- relatively random patterns,
- burst-error patterns,
- systematic error patterns (periodicity).

Cumulative distributions of error-free gap length show the frequent occurrence of periodic error patterns with the period corresponding to the number of sub-channels in the modem. It appears also, that the probability of short gaps is generally much higher than what would be expected from independent error patterns.

Moyes and Taylor [1966] report error statistics collected on a 5000 km medium-latitude HF path. A binary frequency-shift keying modem (without frequency-division multiplexing) was used at a transmission rate of approximately 72 bit/s. The average bit error rate for the entire test was 4.7×10^{-4} which is normal over this path. The data showed pronounced clustering of errors.

Greim [1960] reports error statistics collected on an HF teleprinter link from Bermuda to New York. A frequency-shift keying 60 words/min circuit modem was used with a frequency shift of $\pm$ 170 Hz. The data indicated that errors were dependent and highly correlated.

Konopleva (see Report 197 and [Brayer, 1967; Brayer and Cardinale, 1967]) gives experimental results on the dependency of error rate on distance.

3. Error-control techniques

Brayer [1967] and Brayer and Cardinale [1967] report computer-simulated studies on the effectiveness of error-control techniques applied to the data they reported. The results indicate that:

- relatively random error patterns which, in general, were found to occur only at error rates of 1×10^{-4} and lower, can be corrected by applying long block codes such as the Bose-Chaudhuri (255, 123, 19) code;
- for burst type error patterns this type of code is not effective. For these patterns a relatively short block code, such as a modified Golay (24, 12, 3) code, with interleaving can be applied effectively;
- a relatively short block code with interleaving is also effective for relatively random patterns. All patterns which could be corrected by a (255, 123, 19) code could also be corrected by interleaving nine blocks of the (24, 12, 3) code;
- for periodic patterns the choice of the number of blocks to be interleaved is extremely important;
- a Massey half-rate diffuse convolutional code performed at least as well as any of the above interleaved or non-interleaved block code techniques.

Moyes and Taylor [1966] give the distribution of blocks of length n (n = 15, 21, 23, 31, 33, 35, 39, 45, 51, 63) which have m or less errors after applying interleaving of up to 32 s, as well as the same distribution without interleaving. These statistics indicate that the block code with and without interleaving improved the character error rate by approximately three and two orders of magnitude, respectively, over the raw character error rate.

Kohlenberg [1965] provides an example of the relationship between error statistics and code used. On a tropospheric circuit with burst type error statistics, a particular diffuse convolutional code gave about one order of magnitude improvement for an uncorrected channel error rate of 0.1, about two orders of magnitude for an uncorrected error rate of 0.01, while for an uncorrected error rate of 1×10^{-3} the decoded error rate was too low to be measured within the framework of the test. He points out that the use of this same code on the same channel but with a randomized error rate of 0.1 would have degraded the channel rather than improved it.

Greim [1960] analysed the teleprinter error data and concluded that:

- multiple bit-errors per character error are common, which may preclude effective operation of parity type error detection or error correction schemes;
- although more than one character error is likely to be experienced within a one-minute interval, extreme bunching (greater than eight) of character errors is unlikely.

Fontaine [1961] studied error control techniques applied to HF radio teleprinter channels based on Greim's data [1960]. The results indicate that:

- error-correcting codes are impractical for improving the reliability of a teleprinter channel; however, he did not consider interleaving of code words;
- error detecting and repeat schemes with about 10% redundancy will reduce the probability of error to a negligible amount.

Moyes [1964] reports on-the-air comparison tests at teleprinter speeds over a path from Hawaii to New Jersey. Two codes were evaluated, a non-interleaved Bose-Chaudhuri (15, 7) code, and a Wagner code. In this latter code, a single parity bit is included with each teleprinter character; in case of a parity error at the receiver, a bit-energy detector determines the least reliable bit in the character and reverses its polarity. It was found that both codes gave at least an order of magnitude improvement for an uncorrected character error rate of approximately 5×10^{-4}.

Goldberg *et al.* [1968] investigated the effectiveness of various codes on data collected on a 4000 km HF path from California to New Jersey, using a modulation rate of 75 bit/s. Results given for a specific run of approximately 60 000 bits having an uncorrected error rate of 1×10^{-3} show that:

- a Gallager type half-rate convolutional code reduced the number of errors from 61 to 4;
- a Massey type half-rate convolutional code resulted in no output errors;
- an interleaved (23, 12, 3) Golay code would have corrected all errors, with as few as 10 (the smallest number tried) blocks interleaved.

An analysis of the collected data also showed the burst nature of error patterns and the occurrence of periodic error patterns corresponding to the number of sub-channels.

4. Conclusions

All the studies reviewed here agree at the point that the observed error patterns are, in general, very different from random patterns, which would be expected with independent occurrence of binary errors. Instead, errors tend to cluster, and when the modulation technique includes frequency-division multiplexing, periodicity of error pattern may sometimes be observed.

The effectiveness of short block codes with interleaving [Moyes and Taylor, 1966; Brayer and Cardinale, 1967; Goldberg *et al.*, 1968], diffuse convolutional codes [Brayer, 1967; Goldberg *et al.*, 1968], and error detection and repeat schemes [Fontaine, 1961] appears to be well established. However, procedures to select the best technique for a particular channel and particular desired error rate have not yet been established. Comparison between the various studies is difficult as the parameters of the tests reported vary widely.

There seems to be no single statistic of error data which can be used to compare different error control schemes. For example, the statistics asked in Study Programme 18A/1, § 3 (New Delhi, 1970), are useful only to study the effectiveness of block codes without interleaving, and are of little or no help in the study of other techniques. If statistics are derived for one particular aspect of the data, some other aspects of this data will be lost. It is, therefore, recommended that the publication of raw error data be encouraged so that everyone can use the data to compare different techniques, including possible ones to be devised in the future. A rough estimate indicates that all the raw data analysed by [Brayer and Cardinale, 1967] can be printed as a computer print-out of approximately 100 pages, which is not a prohibitive amount.

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REPORT 437

OPERATIONAL USE OF THE EFFICIENCY FACTOR

(Question 1/3, Study Programme 1C/3)

(1970)

1. Introduction

With the introduction of fully automatic switching for international telex services in world-wide networks, the establishment of appropriate criteria for determining when an HF radio channel can be switched in or should be switched out of the circuit has become urgent.

[CCIR, 1966-69a] reports on a series of tests carried out during the month typical of a season, i.e. January, June and October, over HF radio channels between Tokyo and San Francisco, Manila, Brussels, Buenos Aires and Hong Kong.

[CCIR, 1966-69b] describes work carried out on circuits between Warsaw and New York in which the autocorrelation of the efficiency factor was determined for differing circuit conditions.

2. Results

2.1 A criterion that the efficiency factor is above 80% for an integration period of 20 s immediately prior to the establishment of a circuit is deemed acceptable for switching an operational radiotelegraph channel into the network. It was found that when this criterion is met the probability that the efficiency factor will remain above 80% for the next 8 minutes (average duration of a call) is 97%.

2.2 A criterion that, when the efficiency factor falls below 80% for an integration period of 60 s, an existing call should be interrupted was deemed to be inappropriate. Instead, it was found acceptable to use as a criterion that when the average value of the efficiency factor, integrated over the cumulative time period of the call, falls below 80% the call should be interrupted. Using this latter criterion, the average overcharge for a hypothetical call of 8 minutes duration for the routes Tokyo-Brussels and Tokyo-Manila was found to be 7%.

2.3 However, the auto-correlation studies show that with an observation time of 20 consecutive 20-s periods (400 s in all) the circuit conditions may only be reliably predictable for periods of as high as 200 s depending upon the stability of the circuit conditions.

2.4 It was found that the statistical properties of the time behaviour of the efficiency factor vary as a function of year, season, distance and direction of the radio circuit. For this reason, it is recommended that for any specific circuit, observations of the efficiency factor should be carried out over a period sufficiently long to permit a decision to be made as to whether or not the circuit can be used in the fully automatic switched telex network.

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RECOMMENDATION 347

CLASSIFICATION OF MULTI-CHANNEL RADIOTELEGRAPH SYSTEMS FOR LONG-RANGE CIRCUITS OPERATING AT FREQUENCIES BELOW ABOUT 30 MHz AND THE DESIGNATION OF THE CHANNELS IN THESE SYSTEMS

(Question 2/3)

(1956-1959-1963)

The CCIR,

CONSIDERING

(a) that there exists a large number of long-range multi-channel radiotelegraph systems using frequencies below about 30 MHz and that it is desirable to classify them in categories;

(b) that the lack of uniformity in the arrangement and designation of the channels in these systems, may give rise to certain difficulties when one transmitting station has to work with several receiving stations;

(c) that the increasing use of multi-channel telegraph systems makes it desirable to adopt a uniform designation of channels in such systems,

UNANIMOUSLY RECOMMENDS

1. that the systems should be classified and the different categories designated by letters, as follows:

1.1 *Time-division multiplex systems:* capital letter T (for example, synchronous systems, such as Baudot, RCA and TOR multiplex and double-current cable code);

1.2 *Frequency-division multiplex systems*

1.2.1 Systems with *constant* frequency arrangements of significant conditions: capital letter U (for example: voice-frequency multiplex with frequency-shift);

1.2.2 Systems with *variable* frequency arrangements of significant conditions: capital letter V (for example: four-frequency diplex);

1.3 *Multi-channel systems using a combination of these processes*

1.3.1 Frequency-division systems, with constant frequency arrangement, combined with a time-division multiplex system 1.3.2 Four-frequency diplex system, combined with a time-division multiplex system	combination of the above-mentioned letters (always beginning with the frequency-division letters U or V);

2. when a multi-channel telegraph signal is applied to a multi-channel telephone transmitter, the designation of the telephone channel should come first in the sequence and should be in accordance with Recommendation 348;

3. when a multi-channel telegraph signal is applied to an independent-sideband transmitter used solely for telegraphy, the designation of the sideband should come first in the sequence. The letter H should denote the upper sideband, and the letter L the lower sideband;

4. that in time-division systems, the telegraph channels should be designated by capital letters A, B, C, D, etc.; for sub-division, the sub-channels should be designated by A1, A2, A3, A4, B1, B2, B3, B4, etc.;

5. that in frequency-division systems, the telegraph channels should be designated by figures;

6. that in a combination of multi-channel processes, the telegraph channels should be designated by a letter and figure sequence.

For example:

when using a frequency-division system with constant frequency arrangement of significant conditions (letter U), and modulating the 3rd channel of this latter system with a time-division multiplex (letter T), channel B of this latter system would be indicated by U3TB;

where channel B of the time-division system is sub-divided and sub-channel 2 is in use, the designation would be U3TB2;

if the above-mentioned system is applied to channel B of an independent-sideband telephone transmitter, the corresponding designation would be BU3TB or BU3TB2;

if the above-mentioned system is applied to the upper sideband of an independent-sideband multi-channel transmitter used solely for telegraphy, the corresponding designation would be HU3TB or HU3TB2;

where additional information is required, the multiplex system may be identified by a number inserted between the letters T and B, and where two sub-channels (quarter-channels) are linked together to form a half-speed sub-channel (half-channel), each quarter-speed sub-channel component may be designated by the use of numbers separated by an oblique stroke. The full designation HU3T4B2/4 would be applicable to the arrangement shown diagrammatically by the arrows on the right of the figure below;

in established communication networks, where the sub-carrier, multiplex system, channel and sub-channel arrangements are mutually known to the station management at each end of the circuit, it shall be permissible to shorten the full designation HU3T4B2/4 above, beginning at the first letter or number which is of major significance for identification purposes. For example, in the given instance 4B2/4 will identify the specific area illustrated by the arrows to the right of Fig. 1.

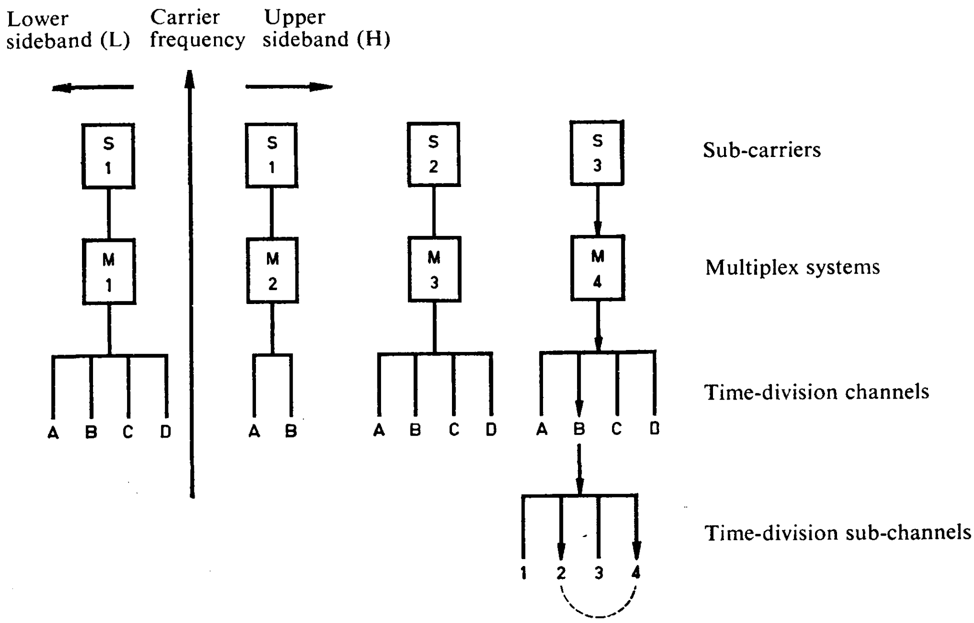

FIGURE 1 – *Multi-channel independent-sideband radiotelegraph transmitter*

Note. – Sub-carriers are numbered sequentially in both upper and lower sidebands, starting with the number 1, adjacent to the carrier (radiated or suppressed).

REPORT 863

SYNCHRONIZATION OF CHANNELS IN MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEMS USING ARQ ON LONG-RANGE RADIO CIRCUITS

(Question 2/3)

(1982)

1. Introduction

Modern radio circuits are generally designed for synchronous operation. The parameters of the synchronization channel in such circuits are an important factor in determining the channel quality. Their influence is particularly important in long-distance radio circuits using relay points.

In the U.S.S.R., a basic approach has been developed for the synchronization of channels in narrow-band, multi-channel voice-frequency telegraphy systems for long-distance radio circuits using relay points.

2. Arrangement of synchronization for channels in duplex radio circuits

2.1 Synchronous radio circuits equipped with an ARQ system use a single reference timing frequency generated at the master station for the modulation of the go and return channels. This frequency is extracted at the slave station by means of a regenerative repeater. A duplex circuit consists of two sections (one go and one return section), and a repeater is also installed at the receive side of the master station to extract the timing frequency.

Long-distance (5000-10 000 km) radio circuits may additionally use a relay point in which the bits are regenerated. Therefore, a circuit using a relay point consists of four sections with repeaters at the end of each section. Figure 1 illustrates how such a circuit is split up into sections.

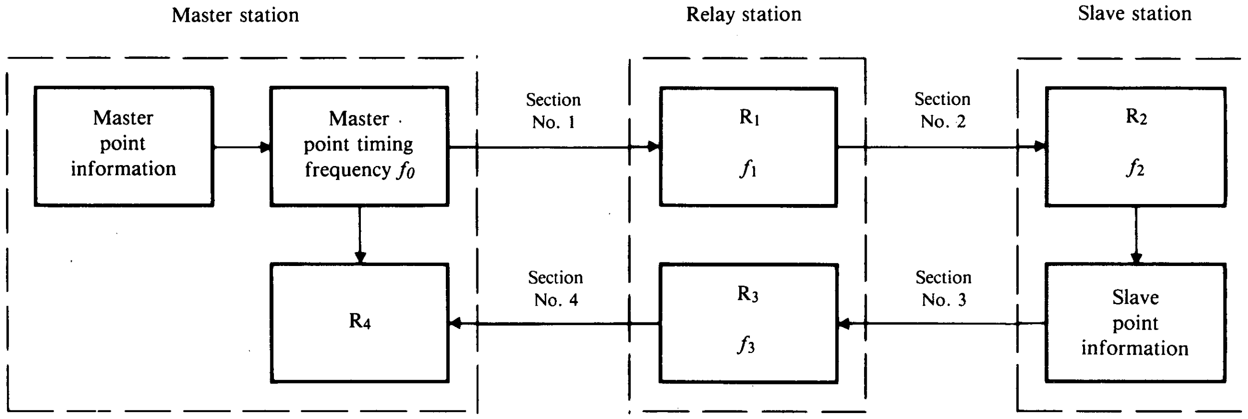

FIGURE 1 – *Division of relayed circuit into sections*

R_1, R_2, R_3, R_4: Repeaters at end of each section
f_0: Master station reference timing frequency
f_1, f_2, f_3: Timing frequencies of local generators controlled by the timing frequency f_0

2.2 Various studies [Khmelnitsky, 1978; Lobanova and Morozov, 1978] have shown that instantaneous displacements of the bit sequence on each of the sections may constitute a considerable proportion of the duration of a bit. The basic cause of these displacements is the result of interference between signals from different paths. Furthermore, the measured displacements of the bit sequence at the output of narrow-band telegraph receivers can considerably exceed the actual path time delay difference because of bit transition distortion resulting from the narrow bandwidth of the receiver [Khmelnitsky, 1975]. (These displacements will be referred to below as "shifts".) For example, at a modulation rate of 200 bauds and a path time delay difference of 0.5 ms, the maximum shift value may exceed 1.5 ms, or 3 ms at a rate of 100 bauds with the same delay difference. Figure 2 shows the values of the shifts measured at 200 bauds using an HF signal simulator.

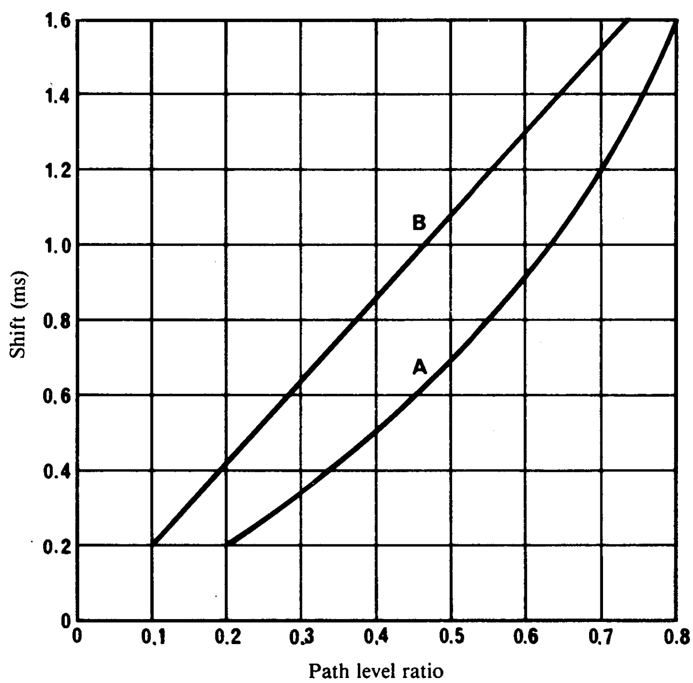

FIGURE 2 – *Shifts at 200 bauds*

A: path-time delay difference: 0.5 ms
B: path-time delay difference: 1.0 ms

The rate at which the bit position changes depends on the speed of the phase change between signals from different paths. This time is related to the fading period, and on real circuits lies within the range from fractions of a second to a few seconds. As a first approximation the increase and decrease of the shifts can be represented as shown in the example in Fig. 3. The most common rates of shift variation are around 1 ms/s.

2.3 The frequency stability of the timing reference generators is generally such that the tracking speed needed to maintain synchronism between the received and the local signals might be around 0.01 ms/s. However, with a view to enhancing channel noise immunity, the speed of tracking the shift variations in the repeaters normally is selected close to the mean rate of shift variation at the repeater input, the tracking speeds adopted being generally slightly lower than the shift variation rate. Depending on the shift variation rate and the tracking rate, the shifts appearing at the output of the repeaters in current use partly or almost wholly repeat the shifts occurring at the input. As a first approximation, we may take it that the rate of variation of the shifts transmitted by a repeater to the next section also displays a linear variation as shown in Fig. 3. Hence, at the master station receiver, shifts will appear which occur on the circuit section preceding the repeater in conjunction with the shifts transmitted by the repeaters of the preceding sections.

Since shifts may occur on each section at any time, all the shifts deriving from the various paths may be cumulative at the master station receiver. On circuits without relay points there is little likelihood that shifts of any considerable size on two sections will coincide in time. In circuits using a relay point, however, the probability of the cumulative shift being excessive becomes so great as to constitute a risk of disturbance to normal operation of the circuit.

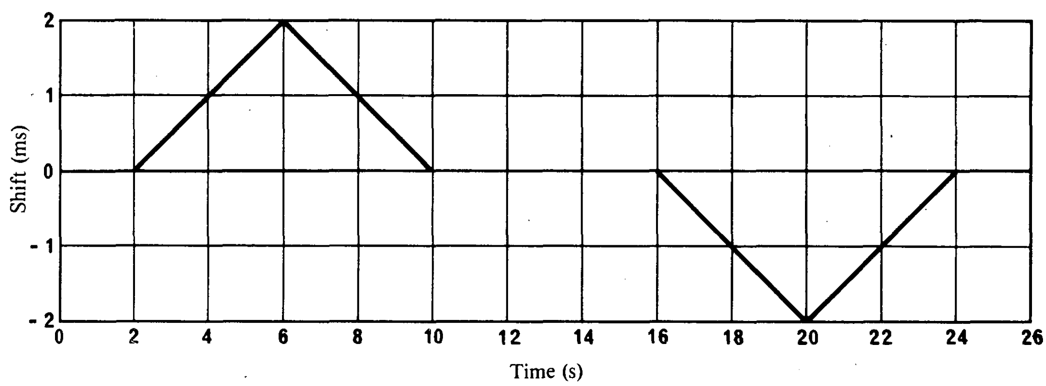

FIGURE 3 – *Shifts in an individual section*

2.4 Shifts in the received signal relative to the regenerated pulse train will not cause any noticeable (bias) distortion of the individual bits. However, when the shift reaches a value of half the bit duration, an increase (or decrease) in the total number of transmitted bits relative to received bits becomes possible. This distortion of the transmitted sequence causes a loss of frame alignment.

Figure 4 shows some possible values of shifts occurring in one section and transmitted from the preceding sections, and also the sum of these shifts. It also indicates the moment at which loss of frame alignment occurs.

2.5 To prevent shifts from being carried over from one section to another and thus to prevent the loss of frame alignment, repeater design should separate the function of input signal shift tracking from the function of altering the position of signals at the repeater output. The timing of the appearance of the bits at the repeater output depends on the speed of variation in group delay on the path and the instability of the reference frequency generators. The repeater output sequence variation rate may be of the order of 0.01 ms/s [Khmelnitsky, 1978].

It follows from the above data on the physical causes of shifts and their characteristic values that:

- the synchronization system should be designed for a tracking rate geared to the shift variation rate;
- on circuits using a relay point, summation of shifts may lead to loss of frame alignment. To prevent large shifts, repeaters should have separate tracking, one for the variation in shifts in input signals and the other for the position of the output sequence.

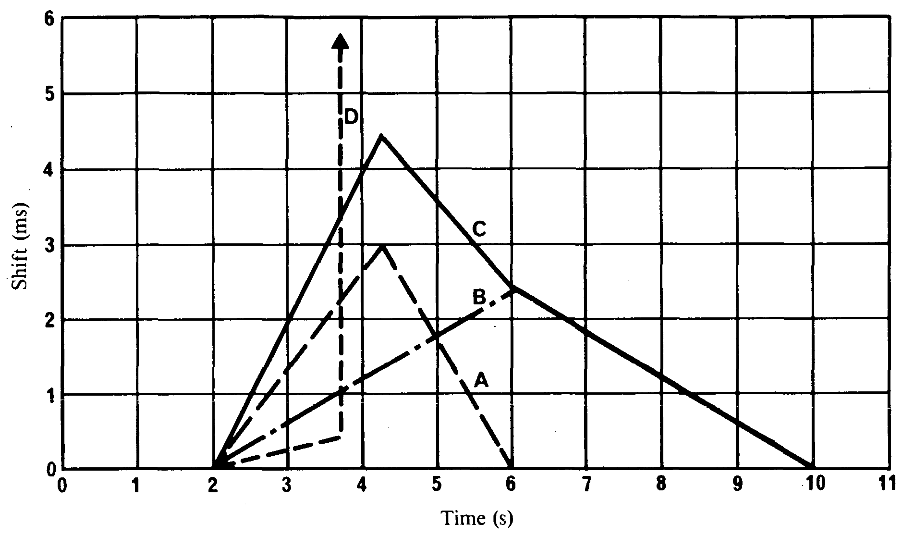

FIGURE 4 – *Shifts in the individual sections*

A: shifts in the preceding sections
B: shifts in the actual section
C: sum of shifts
D: tracking curve and moment of loss of frame alignment

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RECOMMENDATION 246-3

FREQUENCY-SHIFT KEYING *

(Question 8/3)

(1951-1953-1956-1959-1966-1970-1974)

The CCIR,

CONSIDERING

(a) that frequency-shift keying is employed in radiotelegraphy in the fixed service;

(b) that it is desirable to adapt the frequency-shift used to the modulation rate;

(c) that it is desirable to standardize the main operating characteristics of systems employing frequency-shift keying;

* For the use of frequency-shift keying in the maritime mobile service, see Appendix 38, § (c) of the Radio Regulations.

(d) that various technical factors influence the choice of operating characteristics in such systems, in particular:

- economy of bandwidth and the consequent need to control the shape of the transmitted signals,
- signal distortion due to propagation conditions,
- instability of the characteristics of certain transmitter and receiver elements (such as oscillators, filters or discriminators), this instability being one of the reasons for the relatively large shift still employed in some existing types of equipment;

(e) that for synchronous transmissions using limiter-discriminator detection, a modulation index of about 0.8 is desirable for obtaining low bit error rates (see Recommendation 436 and Report 198, Geneva, 1963) and that for asynchronous (start-stop) transmissions, a modulation index between 1 and 2 is more appropriate;

(f) that for synchronous transmissions using filter-assessor detection, a sufficiently high value of frequency-shift is desirable to take advantage of frequency diversity effects;

(g) that difficulties can arise from the use of terms "mark" and "space" on teletype circuits and also that the CCIT, at is VIIth Plenary Assembly (1953), issued Recommendation I.4 introducing new terms; these terms have been published by the ITU in the "List of Definitions of Essential Telecommunication Terms", Part I, General Terms, Telephony, Telegraphy, June 1957,

UNANIMOUSLY RECOMMENDS

1. that for frequency-shift systems working on two conditions only (i.e. single channel or time division multiplex systems) and operating between about 3 MHz and 30 MHz, the value of the frequency-shift employed should be the lowest compatible with the maximum modulation rate regularly used, the propagation conditions and the equipment stability;

2. that for services where the transmitting equipment and the receiving equipment are of sufficient high stability * and selectivity, the following values of frequency-shift in Table I are preferred for new systems:

TABLE I

Maximum modulation rate (baud)		Frequency-shift (Hz)
Synchronous	Asynchronous	
–	50	70
100	50 and 75	85
200	100	170
–	200	340

3. that for systems using filter-assessor detection (see Report 345) or where the achievement of the necessary stability or receiver selectivity is impractical, the preferred values of frequency-shift are 200 Hz, 340 Hz, 400 Hz ** and, for modulation rates above 250 baud, 500 Hz. The values of 140 Hz, 280 Hz and 560 Hz may be used provisionally, but 560 Hz should not be adopted for new systems. The value of the frequency-shift should, if possible, be maintained within ± 3% of its nominal value and, in any case, within ± 10%;

* In the absence of a Recommendation on the stability required for narrow-band frequency-shift keying a provisional value of 12 Hz may be used for the maximum permissible overall frequency error, including modulator, demodulator and translating stages at both ends of the circuit.

** The value 170 Hz is used in the maritime mobile service (see Appendix 38, § (c) of the Radio Regulations).

4.* that the following equivalence among the various terms indicating circuit condition be adopted:

(Table II is in accordance with CCITT Recommendations U.1, see Fascicle VII.1 and V.1, see Fascicle VIII.1.)

TABLE II

Frequency of emission	Circuits using teleprinter or punched tape equipment							Circuits using Morse code
	International Telegraph Alphabet No. 2				Emitted 7-unit signal (2)	Data	Telex	
Higher frequency	Space	Start	No perforation	A (1)	B	0	Free line condition	Mark
Lower frequency	Mark	Stop	Perforation	Z (1)	Y	1	Idle circuit condition	Space

(1) on a wire circuit.
(2) on a radio channel.

RECOMMENDATION 346-1

FOUR-FREQUENCY DIPLEX SYSTEMS

(Question 8/3)

(1956-1959-1963-1970)

The CCIR,

CONSIDERING

(a) that there are in use, in the fixed radiotelegraph services operating between 2 MHz and 27 MHz, four-frequency diplex (or twinplex) systems, in which each of four frequencies is used to transmit one of the four possible combinations of signals corresponding to two telegraph channels, it being understood that either one, or both of the two telegraph channels may be sub-channelled by time-division methods and that the use of such systems may be extended;

(b) that it is desirable to standardize the main characteristics of four-frequency diplex systems;

(c) that it may sometimes be necessary to employ the same radio transmitter to work with more than one receiving station;

(d) that circuit interruptions should be reduced to a minimum, by avoiding frequent changes of the spacing between adjacent frequencies and of the correspondence between the frequencies and the significant conditions of the channels;

(e) that various technical factors influence the choice of operating characteristics in such systems, in particular:

- the economy of bandwidth and the consequent need to control the shape of the transmitted signals;
- that a relatively wide spacing between adjacent frequencies may be necessary for high telegraph speeds;
- the signal distortion due to propagation conditions;
- the instability of the characteristics of certain receiver and transmitter elements such as oscillators, filters or discriminators;

* When modification of equipment is necessary, it is recognized that it may take some time before the recommendations of these paragraphs can be implemented on circuits between different Administrations.

(f) that many existing four-frequency diplex systems each use one of four values of spacing between adjacent frequencies with corresponding telegraph speeds;

(g) that it is desirable to use only one coding system, the simpler the better,

UNANIMOUSLY RECOMMENDS

1. that the following preferred values should be adopted for the spacing between adjacent frequencies:

TABLE I

Spacing between adjacent frequencies (Hz)	Nominal telegraph speed of each channel (bauds)
1000	over 300
500 (1)	200 to 300
400 (1)	100 to 200
200 (1)	200 (2)

(1) Lower telegraph speeds may be used with these spacings at present.

(2) Synchronous operation with phase-locked channels.

2. that the following system of coding be adopted:

TABLE II

Frequency of emission	Channel 1			Channel 2		
	Teleprinter	ARQ aggregate	Morse	Teleprinter	ARQ aggregate	Morse
f_4 (highest frequency)	A	B	Mark	A	B	Mark
f_3	A	B	Mark	Z	Y	Space
f_2	Z	Y	Space	A	B	Mark
f_1 (lowest frequency)	Z	Y	Space	Z	Y	Space

where f_1, f_2, f_3, f_4 designate the frequencies of the emissions, the spacings between adjacent frequencies $(f_4 - f_3)$ $(f_3 - f_2)$ $(f_2 - f_1)$ being equal,

A represents the start signal of the teleprinter,

Z represents the stop signal of the teleprinter;

Note. – When modification to equipment is required, it is recognized that it may take some time before the systems of coding indicated in this paragraph can be implemented on circuits between different administrations.

3. that the value of the frequency separation between adjacent frequencies employed should be the lowest of the preferred values compatible with the maximum telegraph speeds regularly used, the propagation conditions and the equipment stability;

4. that, when the two channels are not synchronized, it is desirable to limit the maximum rate of change of frequency to minimize the bandwidth of the emission.

RECOMMENDATION 436-2 *

ARRANGEMENT OF VOICE-FREQUENCY TELEGRAPH CHANNELS WORKING AT A MODULATION RATE OF ABOUT 100 BAUDS OVER HF RADIO CIRCUITS

(Question 2/3, Study Programme 17A/3)

(1966–1970–1978)

The CCIR,

CONSIDERING

(a) that lack of standardization in the arrangement of channels for voice-frequency multi-channel telegraph systems working over HF radio circuits can give rise to difficulties when setting up such systems;

(b) that it is necessary to use the radio-frequency spectrum to the best advantage in the interests of both spectrum economy and circuit efficiency;

(c) that frequency-shift systems are in use on many routes;

(d) that the frequency-exchange method of operation is in use on long routes suffering from severe multipath distortion;

(e) that on such systems, radiotelegraph channels which operate synchronously at a modulation rate of 96 bauds and employ automatic error correction are being increasingly used,

UNANIMOUSLY RECOMMENDS

1. that the channel arrangement shown in Table I be preferred for voice-frequency multi-channel frequency-shift systems operating at a modulation rate of approximately 100 bauds over HF radio circuits;

2. that for frequency-exchange systems, the central frequencies of Table I should be used, and should be paired in the manner found to be best suited to the propagation conditions of the route. (A typical arrangement would take alternate pairs giving 340 Hz between tones.)

Note. – Theoretical work in Japan indicates an optimum frequency-shift of 0.8 B (Hz), where B is the modulation rate in bauds. This would lead to a required minimum bandwidth (at the −3 dB points) of B (Hz). Laboratory experiments and measurements on the synchronous ARQ circuit Frankfurt-Osaka support these conclusions. For circuits which are not operating near MUF and for asynchronous circuits, some theoretical results indicate B to $2B$ as the best frequency-shift.

TABLE I – *Central frequencies of voice-frequency-shift telegraph channels with a channel separation of 170 Hz and a modulation index of about 0.8*
(Frequency-shift: ±42.5 Hz or ±40 Hz)

Channel position	Central frequency (Hz)	Channel position	Central frequency (Hz)
1	425	8	1615
2	595	9	1785
3	765	10	1955
4	935	11	2125
5	1105	12	2295
6	1275	13	2465
7	1445	14	2635
		15	2805

Note. – See CCITT Recommendation R.39 (Fascicle VII.1).

* This Recommendation cancels Report 198 (Geneva, 1963).

REPORT 347-1 *

VOICE-FREQUENCY TELEGRAPHY OVER RADIO CIRCUITS

(Study Programme 17A/3)

(1966-1978)

The principal factors determining the error rate in radiotelegraphy transmission arise from the fact that:

– radio propagation is essentially variable,
– unwanted signals caused by noise or interference appear at the receiving end.

1. As a result of variations in propagation, a complex signal is supplied to the receiver, consisting of superimposed signals from several transmission paths with differential delays of up to several milliseconds (see Report 203). As a result, the telegraph signal appearing at the output of the demodulator suffers random distortion, the limiting value of which is practically independent of the signal-to-noise ratio.

Start-stop systems are particularly vulnerable to this form of distortion, because of the risk of a loss of synchronization produced by mutilation of a start or stop element (see Report 195, Fig. 4).

2. Various Administrations have, for several years, had in service, on certain HF circuits, equipment with a channel spacing of 120 Hz, the central frequencies and frequency-shifts of which are given in Table I.

TABLE I – *Central frequencies of voice-frequency, frequency-shift telegraph channels with a channel separation of 120 Hz and a modulation index of about 1.4*
(Frequency-shift: ±35 Hz or ±30 Hz)

Channel position	Central frequency (Hz)	Channel position	Central frequency (Hz)
1	420	11	1620
2	540	12	1740
3	660	13	1860
4	780	14	1980
5	900	15	2100
6	1020	16	2220
7	1140	17	2340
8	1260	18	2460
9	1380	19	2580
10	1500	20	2700

Note. – See CCITT Recommendation R.39 (Fascicle VII.1).

3. On certain radio circuits with special characteristics (e.g. North-South links, such as Paris-Abidjan), several Administrations have since 1965 used automatic 96-baud error-correction devices associated with voice-frequency, multi-channel, frequency-shift telegraph systems with a channel spacing of 120 Hz and a frequency shift of ± 35 Hz as shown in Table I.

Circuits thus set up are used in particular for transmission of cyphered messages and they have been working satisfactorily since they came into operation. Measurements conducted by the French Administration using error correction over such a circuit during a period totalling more than 50 hours showed that values of efficiency factor were achieved in accordance with the attached curve.

This method of operation may suit quite a large number of links (e.g. Europe-West Africa links) and bearing in mind the constant search for the most rational use of the radio spectrum, it is concluded that as much information as possible should be obtained on the performance of circuits of this type, in particular concerning the undetected error rate.

* This Report combines Report 347 (Oslo, 1966) and Report 42 (New Delhi, 1970).

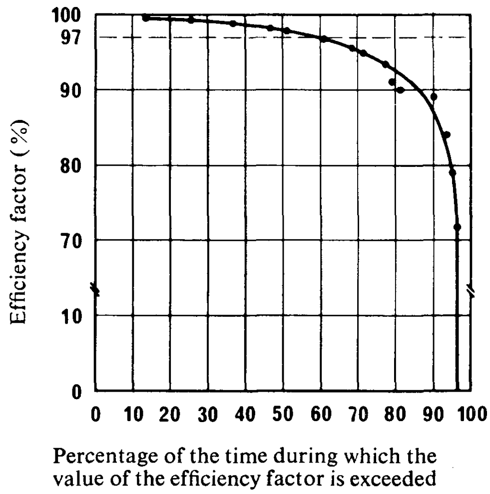

FIGURE 1 – *Distribution of efficiency factor in a 100-baud ARQ system with a 120 Hz central frequency spacing*

RECOMMENDATION 106-1

VOICE-FREQUENCY TELEGRAPHY ON RADIO CIRCUITS

(Study Programme 17A/3)

(1953–1970)

The CCIR,

CONSIDERING

(a) that, when voice-frequency equipment is used on radio circuits at frequencies lower than about 30 MHz, the quality of these circuits will, in general, be insufficient if no means of diversity reception is provided;

(b) that, in the presence of fading, space, polarization or frequency diversity gives comparable improvements in the quality of reception of telegraph signals transmitted over radio channels;

(c) that, for adequate frequency diversity, it appears necessary that the frequencies which are used in combination to obtain this diversity should differ by at least 400 Hz;

(d) that space or polarization diversity needs only half the bandwidth and less power for each telegraph channel, as compared with frequency diversity, but usually requires more equipment,

UNANIMOUSLY RECOMMENDS

1. that, when voice-frequency telegraph systems are used on radio circuits at frequencies lower than about 30 MHz, diversity reception should be used on the individual voice-frequency channels;

2. that, whenever practicable, space or, possibly, polarization diversity should be used in preference to frequency diversity;

3. that, for frequency diversity, the channel frequencies used in combination should have a separation of at least 400 Hz so that adequate diversity effects may be obtained.

REPORT 345-2 *

PERFORMANCE OF TELEGRAPH SYSTEMS ON HF RADIO CIRCUITS

(Study Programme 17A/3)

(1966–1970–1978)

1. Introduction

This Report summarizes the results of tests in which different systems of voice-frequency radiotelegraphy are compared, both in the laboratory and on real circuits. The systems treated are described briefly in § 2.

2. Description of systems

It will be convenient to refer to the various systems by means of code designations defined as follows:

2.1 *System A* is a two-tone frequency-exchange system using the method of detection described by [Allnatt *et al.*, 1957]. For modulation at 100 bauds the spacing is a multiple of 170 Hz, and is chosen according to the most likely multipath propagation time difference, the optimum in hertz being equal to half the inverse of this time difference in seconds.

2.2 *System B1* is a frequency-shift system with a channel spacing of 170 Hz [Lyons, 1960]. The normal modulation rate of each channel is 100 bauds and the frequency-shift is 80 Hz. The channel receiver comprises the conventional limiter and discriminator arrangement. When diversity reception is used, the demodulated signals produced by each branch channel receiver are weighted according to the amplitude of the input signal to each branch.

2.3 *System B2* is a frequency-shift system of the same basic form but with a channel spacing of 340 Hz and frequency-shift of 170 Hz. The channels can accept a modulation rate of up to 200 bauds.

2.4 To facilitate comparison between the systems, there is included with each set of performance curves one representing the hypothetical system mentioned in Report 195, which is based on the use of coherent detection of a non-fading signal.

2.5 *System B3* is a frequency-shift system with a channel spacing of 170 Hz [Lyons, 1960]. The modulation rate of each channel is 75 bauds and the frequency-shift is 85 Hz.

2.6 *System C1* is a time-differential phase-shift keyed system (TD-PSK) according to the principles described in [Doeltz *et al.*, 1957; Mosier and Clabaugh, 1955], in which two information bits are phase coded on each of twenty tones. All tones are keyed isochronously at a rate of 75 bauds, thus providing an aggregate data capacity of 3000 bit/s. Information in the transmitted signal resides in the relative phase of consecutive tone elements. Demodulation is accomplished with the aid of synchronously keyed matched filters, in which the gating interval is made somewhat less than the length of the transmitted symbol, so as to reduce the effects of intersymbol interference due to multipath delay spread. Sychronization of the receiver is obtained with the aid of a transmitted pilot tone.

2.7 *System C2* is a frequency-differential phase-shift keyed system (FD-PSK) according to the principles described in [De Haas, 1965; Walker, 1965], in which three information bits are phase coded on each of forty tone pairs (channels). All channels are keyed isochronously at a rate of 25 bauds, thus providing an aggregate data capacity of 3000 bit/s. In addition, twenty-two unmodulated reference tones are transmitted, spaced at regular intervals throughout the baseband, so that there are two information channels between adjacent reference tones. At the receiver, all tones are translated to a common processing frequency, the reference tones are extracted by means of narrow-band filters, and phase-demodulation is effected by cross-correlating each signal tone with a phase reference obtained by linear addition of appropriate fractions of the two references which bracket the signal tone. A delay line in the information tones path provides compensation for the delay in the narrow-band reference extraction filters. By virtue of the long transmitted symbol compared to the prevailing multipath delay, spread-inter-symbol interference is minimized. Synchronization is obtained through the use of two unused channel positions and by comparison of the phase of the beat frequencies between successive reference tones with the receiver time base.

* This Report combines Report 345 (New Delhi, 1970) and Report 346 (Oslo, 1966).

3. Tests using a fading simulator

3.1 The performance of systems *A*, *B1* and *B2* has been measured in terms of mean element error rate versus normalized signal-to-noise ratio under various conditions of fading signal with added uniform-spectrum random noise. The transmission path was provided by a fading simulator [Law *et al.*, 1957] with facilities for simulating equal-activity two-path propagation (with selected path-time difference) and dual space-diversity reception.

3.2 *Test results*

Since the application of dual space-diversity reception is quite usual for telegaphy, the performance curves for that mode only are given here in Figs. 1 to 3.

In considering these curves, it should be borne in mind that, in system *A*, the spacing of the significant frequencies was 510 Hz (i.e. three times the modular spacing); hence its optimum performance occurs when two-path propagation is present, with equal activity in both paths and a propagation time difference of about 1 ms.

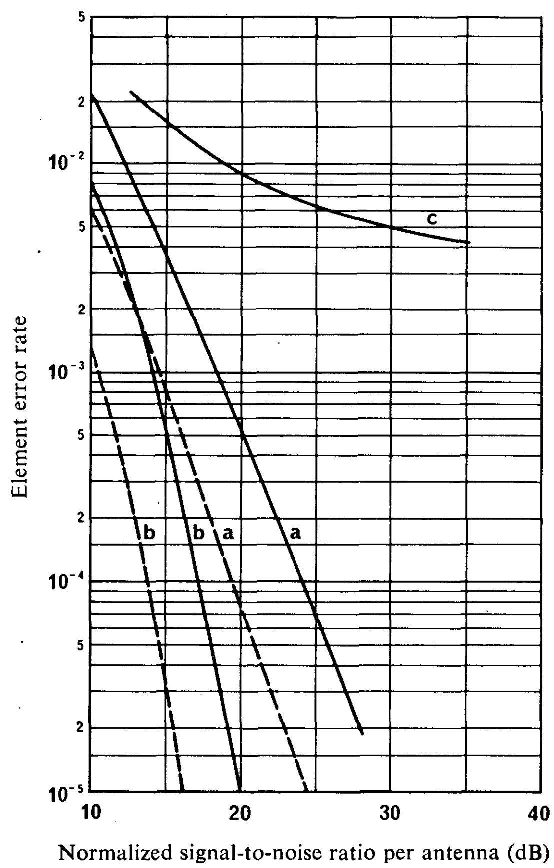

FIGURE 1 – *System A. Dual space-diversity reception*

— — — Reference system *a*: flat fading and also a path-time difference of about 2 ms

———— System *A* *b*: path-time difference 1 ms; *c*: path-time difference 4 ms

Modulation rate: 100 bauds; fading rate: 40 per min

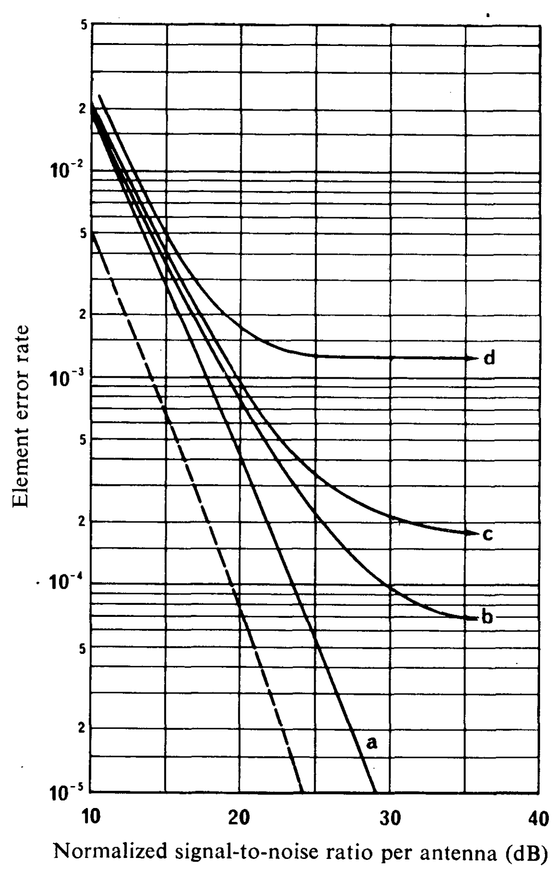

FIGURE 2 – *System B1. Dual space-diversity reception*

— — — Reference system *a*: flat fading

———— System *B1* *b*: path-time difference 0·5 ms; *c*: path-time difference 1 ms; *d*: path-time difference 2 ms

Modulation rate: 100 bauds; fading rate: 40 per min

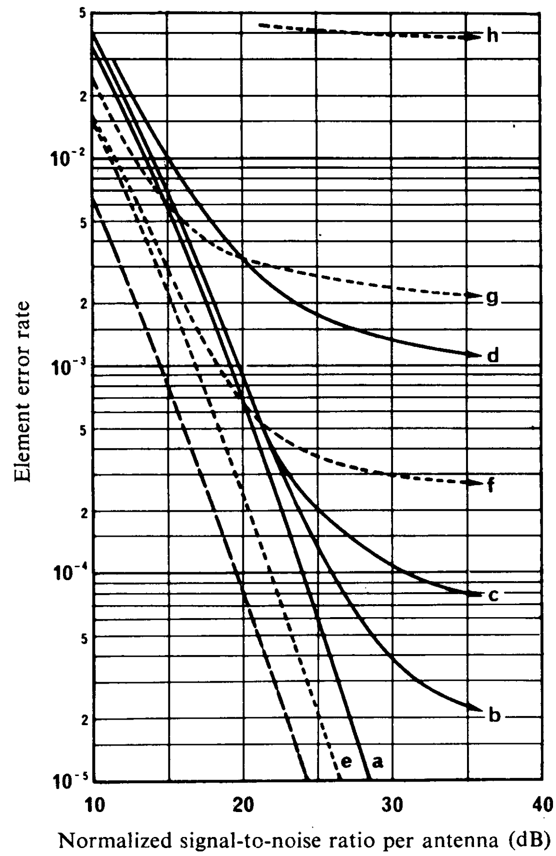

FIGURE 3 – *System B2. Dual space-diversity reception*

— — —	Reference system
———	System *B2*: modulation rate 100 bauds
----------	System *B2*: modulation rate 200 bauds

a: flat fading
b: path-time difference 0·5 ms
c: path-time difference 1 ms
d: path-time difference 2 ms
e: flat fading
f: path-time difference 0·5 ms
g: path-time difference 1 ms
h: path-time difference 2 ms

3.3 *Discussion of results*

3.3.1 *Unprotected transmission*

Assuming an acceptable mean error rate of 1 in 10^4 elements (corresponding to 1 in 2000 characters for synchronous 5-unit code transmission) and multipath propagation with effective path time differences in the range of 1 to 2 milliseconds, systems *B1* and *B2* could not produce the required performance. System *A* would require a normalized signal-to-noise ratio ranging from 17 to 24 dB according to the actual path-time difference and relative activity of the paths.

3.3.2 *Protected transmission*

When automatic error detecting and correcting systems are used on radio channels, the element error rate may be permitted to rise considerably above 1 in 10^4 before the undetected error rate approaches 1 in 2000 characters printed. An element error rate of 1 in 10^2 can be taken to define the upper limit of consideration. With similar conditions in each direction of transmission and assuming that errors occur randomly and without correlation between the two directions, this corresponds to a time-efficiency factor of 60-70%, i.e. about one-third of the circuit time is taken up by automatic retransmission for correction of errors. An element error rate of 1 in 10^3 will still produce an efficiency factor of approximately 97% with a negligible undetected character error rate. Hence the range of practical interest in element error-rate of transmission systems can be confined between the limits 1 in 10^2 to 1 in 10^3.

To illustrate the comparative performance of the systems in ARQ operation, curves of time-efficiency factor versus normalized signal-to-noise ratio, with space-diversity reception, have been derived from the element error-rate curves and are shown in Fig. 4. It has been assumed that the fading rate may be up to 20 per minute. With flat fading there are slight differences between systems *A* and *B1* but for the sake of clarity only a single curve is shown; system *B2* has been omitted since its performance at 100 bauds is not better overall than that of *B1*, and its performance at 200 bauds with a path-time difference of 2 ms would produce an inferior efficiency. From these curves it is concluded that the order of merit would be *A*, *B1* and *B2* and, if fading conditions ranging between the extremes considered are assumed, that *B1* needs approximately 3 dB better normalized signal-to-noise ratio than *A* to maintain 90% efficiency.

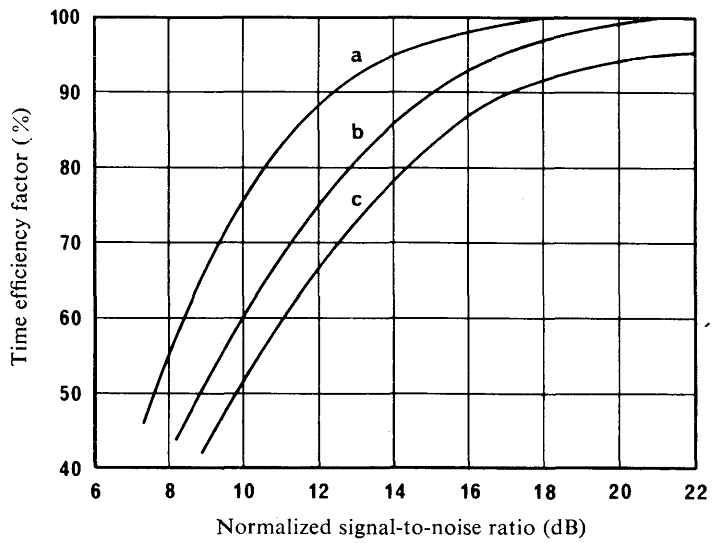

FIGURE 4 – *Time efficiency factor*

a: System *A*. Path-time difference 1 ms (optimum for frequency spacing)
b: System *A*. Flat fading and path-time difference 2 ms
System *B1*. Flat fading
c: System *B1*. Path-time difference 2 ms (in this case no frequency-diversity improvement is realized with a spacing of 510 Hz)

Modulation rate: 100 bauds

3.3.3 *Bandwidth utilization*

For a given number of channels, system *A* will require almost exactly twice the bandwidth of system *B*. Assuming that the best use is to be made of a conventional 3 kHz bandwidth, Table I shows the number of 100 baud channels which may reasonably be provided by each system and the aggregate signal-to-noise power ratio required to produce various values of time-efficiency factor.

TABLE I – *Performance of a practical fully-occupied nominal 3 kHz telephony channel*

Type of system	Number of 100-baud channels	Aggregate signal-to-noise power ratio in a 3 kHz bandwidth, to give stated efficiency (dB)		
		50 %	70 %	90 %
A	8	2 to 3	3·5 to 5·5	6·5 to 9
B1	16	6 to 7	8·5 to 10	12 to 14

3.3.4 *Error thresholds*

It will be observed from Figs. 2 and 3 that the system *B1* performance exhibits a "bottoming" effect – that is, the performance does not improve monotonically with increasing signal-to-noise ratio. This effect has been observed on real communication channels using frequency modulation. See [Aritake and Takeuchi, 1961; Groves and Ridout, 1966].

3.4 *Conclusions*

In conclusion, it is suggested that the following methods should be used to reduce error rate:

- to operate at a higher frequency, near the MUF, despite the fact that the receiving signal is not as strong as at the optimum frequency;
- to use the optimum modulation index (m = total frequency-shift in Hz modulation rate in bauds) which concentrates the distribution of higher level essential sidebands close to the centre frequency (usually $m \approx 0.8$ is recommended) for the transmission of the signal waveform;
- for high-speed transmission (more than 100 bauds), to multiplex the incoming signal into parallel low-speed signals (maximum of 100 bauds) for transmission over the radio path.

3.5 *Further tests under conditions of multipath distortion*

Results obtained from tests on two channels of system *B1*, used in frequency diversity, that were provided with signals from a fading simulator, seem to indicate that system *B1* will produce a performance comparable to system *A*, as regards both channel capacity and signal-to-noise power ratio, at least over the range of error rates of practical significance when used on protected circuits. The artificial fading used during the tests was selective fading, produced by the interference of five equally active paths, differing in propagation time from one to the other by approximately equal amounts such that an overall difference of 2 ms was achieved. The two diversity branches of the receiver were provided with signals having uncorrelated fading patterns.

4. Tests using the Singapore-Nairobi HF route

4.1 *Test arrangements*

Comparative tests of systems *A* and *B1* were carried out over periods aggregating to four weeks on a 7200 km route between Singapore and Nairobi. This route normally uses a six-channel two-tone equipment carrying a number of 96-baud ARQ aggregate signals of the Singapore to London circuit which are relayed at Nairobi. At Singapore the two lowest frequency channels of the two-tone system utilizing frequencies of 765, 935, 1105 and 1275 Hz were suppressed and four frequency-modulation channels (deviation 80 Hz) were injected into the composite signal on these frequencies.

One of the Singapore/London circuits was arranged to key both a two-tone (the component frequencies being spaced at 340 Hz) and a frequency-modulation channel so that the same information was radiated within a 3 kHz bandwidth on the two systems.

Adjacent channels on both systems were activated with different live traffic or reversal signals to simulate normal working conditions. Tone levels were adjusted so that equal peak powers were radiated by all tones as observed on a spectrum analyser.

At the Nairobi receiving station, the composite signals were received on a dual-path single-sideband receiver and fed to both the dual-diversity two-tone and FM-VFT channel equipment.

Synchronous electronic regenerators which corrected all distortion up to 48% were used on both systems. Outputs from the regenerators were connected to ARQ equipment modified to detect all incorrect 3/4 ratios of the 7-unit ARQ signals. Counters were employed to register the number of errors detected, and hourly readings were recorded. The output from the regenerator connected to the normal channel was also used to key the onward circuit to London.

Every effort to ensure a valid comparison of the two systems was made, and, in conjunction with reports from receiving station logs, radio condition reports, and distortion recorder charts, doubtful information which could have been caused by interference (QRM) was eliminated.

4.2 *Test results*

Each test run was taken over either seven or eight consecutive days and nights and the "errors detected" figures were smoothed by applying a running three-hour average for the error graphs (Fig. 5). The percentage efficiency of the circuit (Fig. 6) was estimated by the use of a curve [Croisdale, 1958] reproduced here as Fig. 7. The efficiency expected from the receiving station logs is shown in shadow-graph form; the actual efficiency of the whole Singapore-Nairobi-London ARQ circuit for the period covered is also given.

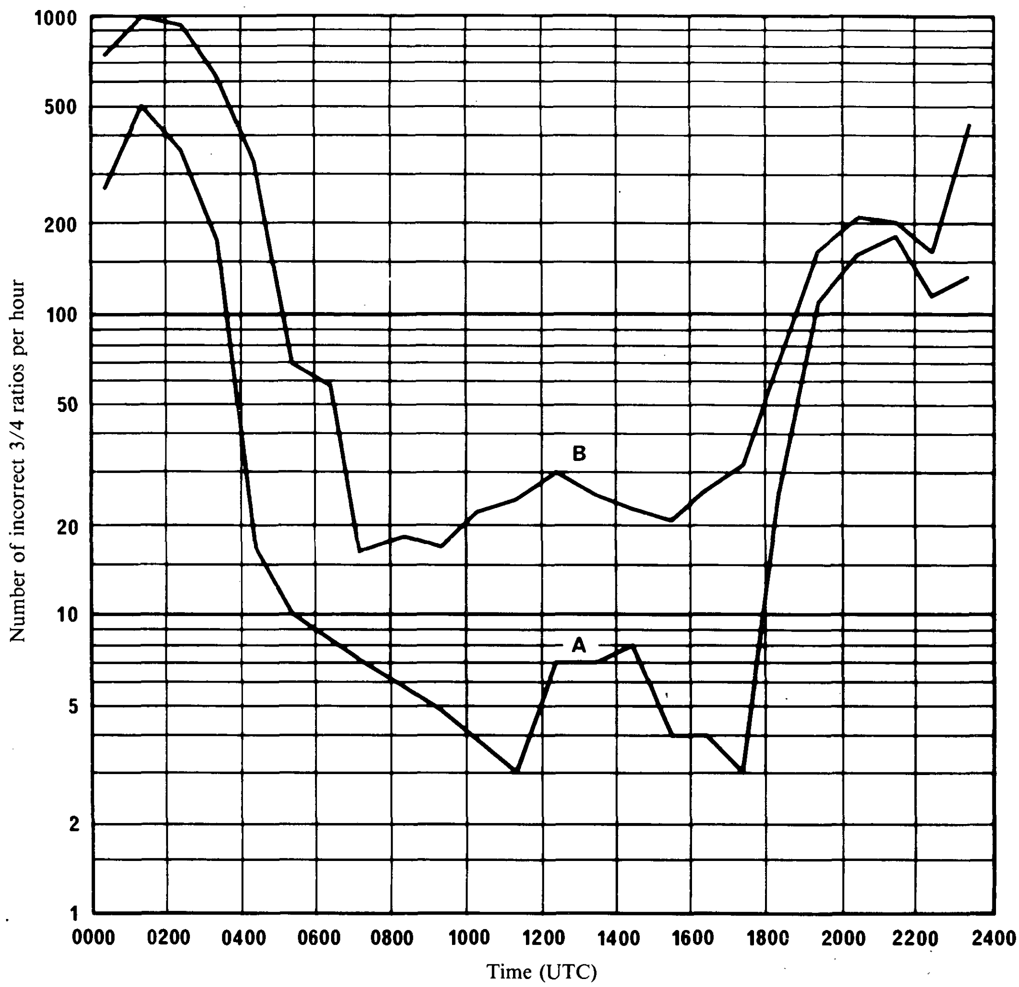

FIGURE 5 – *Typical performance curves*

Average number of errors per day over three hours on the Singapore-Nairobi telegraph system during the period 26 March-1 April, 1963

A: System *A* (two-tone)

B: System *B1* (FM)

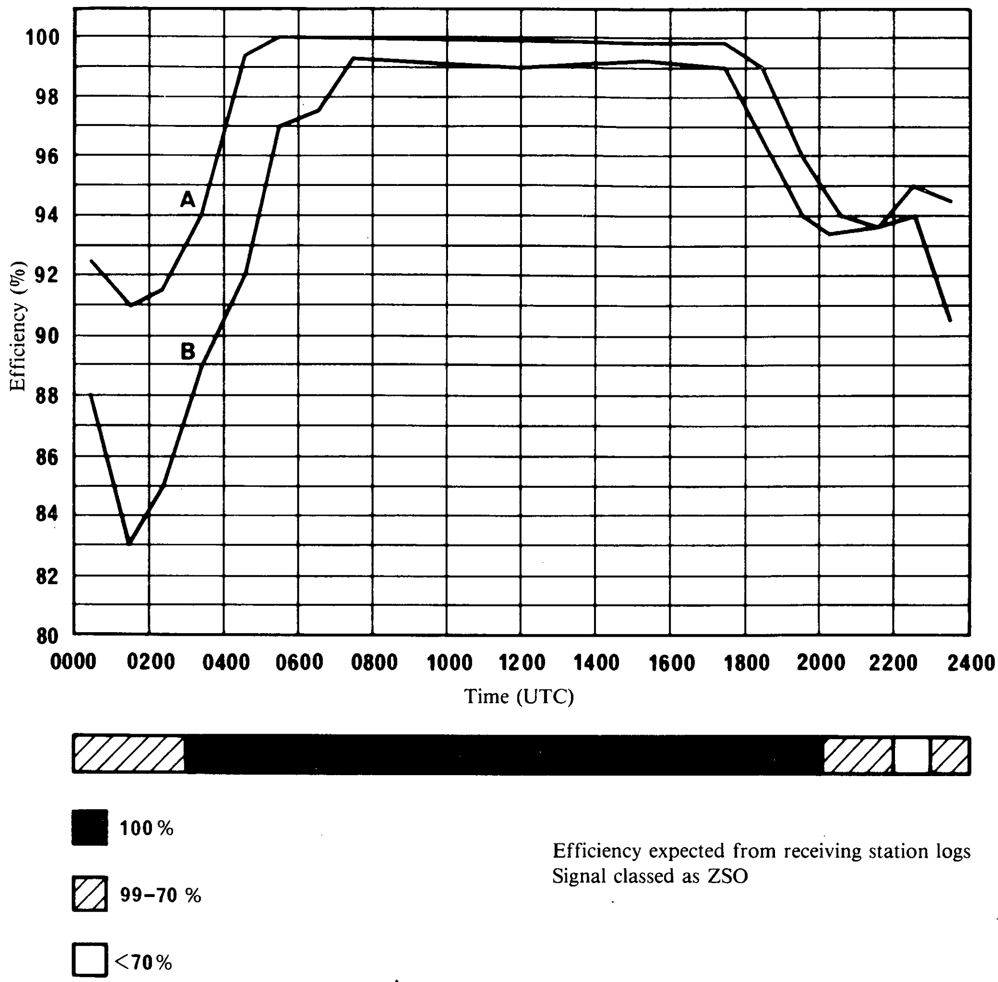

FIGURE 6 – *Estimated performance of error-corrected (in one direction only) systems (based on Fig. 5)*

Measurements of average daily efficiency factor of the overall Singapore-London circuit for the period 26 March-1 April, 1963 (average daily efficiency of overall Singapore-London circuit for this period 90 %)

A: System *A* (two-tone)

B: System *B1* (FM)

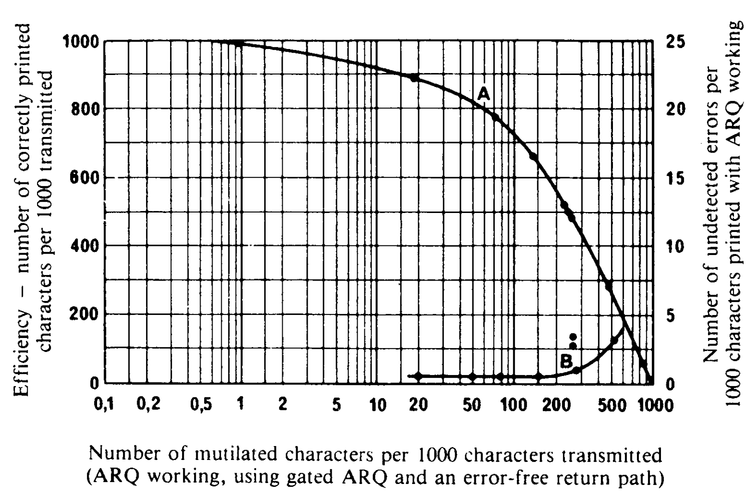

FIGURE 7

A: Efficiency of ARQ

B: ARQ undetected errors

It will be seen from Fig. 5 that, in general, the two-tone system results were always better than the frequency-modulation system results, even though the channels were of equal radiated power. If the largest possible number of channels has to be used in both cases, the level of an FM channel would be 3 dB lower than the level of a two-tone channel, for the same total peak power. During the hours of "good propagation conditions" the errors per hour on either system were very few. However, as conditions deteriorated, errors increased on both systems, but were more frequent on the frequency-modulation system than on the two-tone system.

It is of interest to note that as the efficiency of the circuits decreases, the difference between the two systems generally increases.

4.3 *Conclusions*

These tests demonstrate that under difficult radio propagation conditions the two-tone system has a higher efficiency factor than an FM-VFT system when equal power per channel is used.

However, if the major traffic load is to be carried during the hours when radio propagation conditions are not unusually difficult then the larger number of channels given by the FM-VFT system, within a 3 kHz bandwidth, is a great asset.

It should be noted that if the lower limit of Telex circuit-efficiency, adopted in CCITT Recommendation U.23 (Fascicle VII.1) were used, i.e. automatic "clearing" of these circuits whenever the efficiency falls below 80%, then a situation could arise where for appreciable periods no Telex operation would be possible if an FM-VFT system were employed, whereas satisfactory operation would be obtained by the use of the two-tone system.

5. Tests using the Pretoria-Riverhead HF link

5.1 Comparative testing of systems *B3*, *C1* and *C2* were conducted over a commercial radio circuit from Pretoria, South Africa to Riverhead, Long Island, United States of America, a great circle distance of approximately 12 700 km. The emission of the transmitter was a reduced-carrier, independent single-sideband (ISSB) signal, with a maximum of 12 kHz bandwidth consisting of four independent 3 kHz baseband slots. Both transmitter and receivers were frequency stabilized to 1 part in 10^8 per day. At the receiving terminal at Riverhead, the test signals were received in space diversity by two rhombic antennas, feeding the stabilized receiving system consisting of two receivers and two converters.

Whenever possible, two systems were run simultaneously in the two 3 kHz slots on either side of the carrier ("dual mode"), with periodic sideband switching to average out systematic channel inequalities. However, conditions of unequal QRM in the two slots often precluded this mode of operation. Under such conditions, the three systems were tested on a sequential basis, each system having an "on" period of fifteen minutes, with five-minute silent periods between successive test periods to evaluate channel noise and QRM.

To facilitate comparison of the performance of each system, the available transmitter power was maintained constant while the voice-frequency output level of each data system (drive) was set in accordance with the values computed to provide equal energy per bit. In these computations, the total composite signal powers of the PSK systems (including pilot tone and reference tone powers) were used as the basis for determining the energy per bit values.

Collateral data on the characteristics of the propagation medium were continuously monitored visually by means of two spectrum analysers and audibly by means of a loud-speaker. In addition, pen recordings were made of the a.g.c. voltages of the HF receivers. By comparing the a.g.c. level during the test run with the levels during the preceding and following five-minute off periods, a measure of received signal-plus-noise to noise ratio was available.

Manually set-up word generators were used to supply the modems at the transmitting terminal with a 52-bit binary sequence, and to detect errors at the receiving terminal. Sixteen bits of this pattern were used for sequence synchronization purposes. Bit timing for the word generators was derived from the timing clocks of the modem(s) under test.

The test circuit was operated during two 30-day test periods, which included the month of April, 1964, and the period from 15 June to 14 July, 1964.

The accumulation of test data was hampered by all the usual difficulties of HF communications. In general, data runs could be attempted for only about 16 hours out of each 24-hour period. During the hours of 0100 to 0900 UTC the circuit was not usable because of extreme QRM or lack of signal strength.

The amount of QRM experienced throughout the entire test period was a particular difficulty. Some QRM was experienced at nearly all times of the day. At times, it was possible to sidestep this type of interference by moving the radio-frequency carrier by 500 to 1000 Hz in an attempt to move away from the interfering signal.

5.2 *Test results*

Fig. 8 presents the cumulative performance curves for the three systems, representing some 100 hours of recorded data and including periods of significant QRM and severe atmospheric noise.

Fig. 9 gives scatter-diagrams showing the comparative results of parallel runs between TD-PSK/FSK and FD-PSK/FSK. These results exclude data known to contain significant QRM or known to contain moderate to severe static (exceeding 100 static bursts per run). The diagonal in a scatter diagram is the locus of points of equal performance and divides the diagram in two fields. The result of each parallel run is plotted as a point in the diagram, with ordinates corresponding to measured bit error rate of each system.

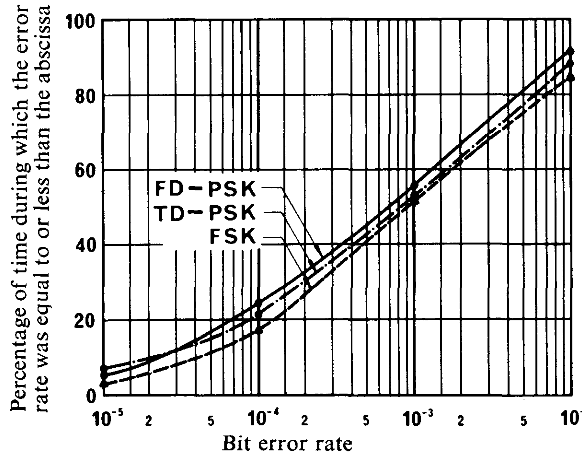

FIGURE 8 – *Cumulative performance curves*

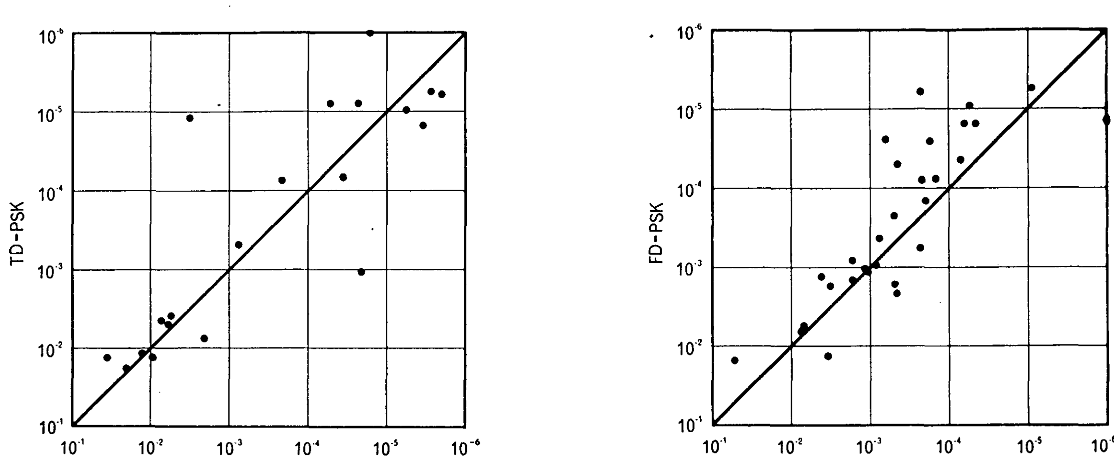

FIGURE 9 – *Scatter diagrams of error rates for parallel runs*

5.3 *Discussion of results*

The FSK system was not operated at the optimum keying speed consistent with its channel characteristics (Recommendation 436). Theoretical considerations and experimental results show that under conditions of constant energy per bit and at the optimum modulation index, the FSK system would have required 0.5 dB less signal-to-noise ratio for a given error rate. In addition, the aggregate data capacity of the FSK system used should be considered to be 1600 bit/s in a 3 kHz channel.

The results presented in Figs. 8 and 9 show that both PSK systems performed about as effectively as the particular FSK system tested. The "goodness" criterion for the type of curves of Fig. 8 is quite evident as long as the curves do not cross over. A cross-over may result from the type of time distribution of error rates, and the inclusion of sequential runs, where the amount of data, especially at the lower error rates, may not be sufficient to ensure averaging out of differences in channel conditions.

The apparent randomness of the scatter diagrams of Fig. 9 is typical of HF communications. Similar results can be obtained when comparing individual channels of a single multi-channel system.

Observed values of multipath spread were in general between 1 and 2 ms, with occasional values of up to 3 or 4 ms. The tests were conducted during a year of low sunspot activity, and larger values may therefore be expected for this circuit under conditions of higher sunspot activity. The observed values, however, are not abnormally low for many circuits, although values in excess of 4 ms may be encountered during 1% to 2% of the time (Report 203).

5.4 *Conclusions*

The limited duration of the tests preclude definite conclusions with respect to the relative performance of PSK and FSK systems for ionospheric transmissions. However, the tests demonstrated that, under conditions reasonably typical for systems of the fixed service, the four-phase PSK systems compared to a conventional two-level FSK system were capable of providing increased bandwidth efficiency without penalty in error rate, or total power, for the same amount of information transmitted.

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REPORT 19-1

VOICE-FREQUENCY TELEGRAPHY OVER HF RADIO CIRCUITS

(Study Programme 17A/3)

(1953-1966)

In principle, the voice-frequency telegraph systems described in CCITT Recommendations R.35, R.35 *bis*, R.36, R.37, R.38A and R.38B (Fascicle VII.1) are capable of being used over HF radio circuits, but the following considerations need to be borne in mind:

1. Specifications of performance in CCIR Recommendations do not normally follow the practice adopted by the CCITT.

2. The ratio between the frequency spacing and the nominal modulation rate of the channels is greater in the CCITT Recommendations than that which is currently used for FDM-FSK systems in operation over HF radio circuits. The systems listed by the CCITT would consequently be slightly less resistant to noise, but slightly more resistant to the effects of multipath propagation than the narrower channels proposed by the CCIR. Furthermore, the number of channels that can be used in a given bandwidth will be less.

3. Since the CCITT systems do not normally have to contend with fading, there may be insufficient protection by the receiving filters against inter-channel interference when the fading is frequency-selective. Also the range of levels over which the channel receiver should operate would need to be increased by at least 10 dB.

4. Systems of use over HF radio circuits should incorporate features which permit diversity reception.

Although it might appear convenient to have unified standards for line and radio systems, the divergent requirements referred to above will make this uneconomic. The characteristics of radio transmission lead to the operation of point-to-point channels with synchronous operation, and, ideally, regeneration at the radio receiving station. This is in contrast to the requirement, in landline systems, to be able to connect channels in tandem without regeneration and to transmit start-stop signals with acceptable quality.

REPORT 702

MULTI-FREQUENCY-SHIFT-KEYING TECHNIQUES FOR HF TELEGRAPHY

(Question 26/3)

(1978)

1. Principles of MFSK

The majority of telegraphy systems operate on a binary principle in which information is conveyed by selecting, in the transmitting equipment, one or other of two possible signalling conditions. In the case of FSK signalling these consist of two frequencies. The possibility of using the choice between more than two frequencies (tones) has been investigated mathematically by a number of workers [Kotelnikov, 1947; Slepian, 1963]. It has been proved that the optimum method of demodulating a signal consisting of a sequence of different tones is by "matched-filter" techniques [Schwartz *et al.*, 1966; Strong and Saliga, 1965] and that if the spacing between tones is equal to the reciprocal of the integration time of the matched filters, the system is orthogonal, i.e. with ideal synchronization there is no inter-tone interference. In practice, so long as the signalling element is much longer than the maximum multi-path propagation delay speed (e.g. 20 times) the integration time can be made more than 95% of the element length and therefore the tone spacing may conveniently be made the inverse of the element duration.

This Report will therefore discuss systems which signal by sending a sequence of equal-length tone elements of constant amplitude, each element frequency being selected from M possibilities. The frequency interval between any two tones is equal to (or may be an integral multiple of) the reciprocal of the element duration. In the demodulator the signal is applied to M matched filters in parallel and at the end of each element the filter having the highest output is identified. All filters are then rapidly discharged to zero and released for the next element. The problem of synchronization (the identification in the demodulator of the instant of transition between elements) is treated separately in § 5.

The amount of information conveyed by a single choice between M alternatives is:

$$Q = \log_2 M \qquad \text{bits} \tag{1}$$

and therefore to convey a "word" of H bits will require

$$N \geqslant H/Q \qquad \text{elements} \tag{2}$$

For any specific value of H, there is therefore a range of possible systems, from the binary case ($N = H$; $M = 2$) to ($N = 1$; $M = 2^H$). Taking, for instance, the case of $H = 10$ bits, possible values are:

TABLE I

M	2	3	4	6	11	32	1024
N	10	7	5	4	3	2	1

2. System bandwidth

If each tone element is of T seconds duration, the data rate is given by

$$C = Q/T = \frac{\log_2 M}{T} \text{ bit/s} \tag{3}$$

The frequency separation between tones is $1/T$ Hz and so the separation between the lowest and highest must be $(M - 1)/T$ Hz. The signal spectrum extends beyond this range and it is convenient to consider that the bandwidth is given by

$$B = \frac{M - 1 + G}{T} \text{ Hz} \tag{4}$$

where G/T is an allowance for transient sidebands.

A "worst-case" figure for the "occupied bandwidth" (defined as the bandwidth containing 99% of the radiated power) can be calculated by assuming that the system transmits the two extreme frequencies on alternate elements, and then using the equation for the bandwidth of an F1 emission with zero build-up time given in Report 179. On this basis a value of $G = 4$ is typical, but a value of $G = 6$ may be necessary for high values of M, or if additional tones are used for synchronising, for the "rest" condition or for "non-repeat" coding. From Equations (3) and (4) may be derived a "normalised bandwidth":

$$B_0 = \frac{B}{C} = \frac{M - 1 + G}{\log_2 M} \text{ cycles per bit} \tag{5}$$

The curves of B_0 against M are plotted in Fig. 1 for various values of G, and it can be seen that for practical cases the minimum normalised bandwidth occurs for about 4 to 10 tones, where the specific information density ($1/B_0$) can approach 0.3 bit per cycle.

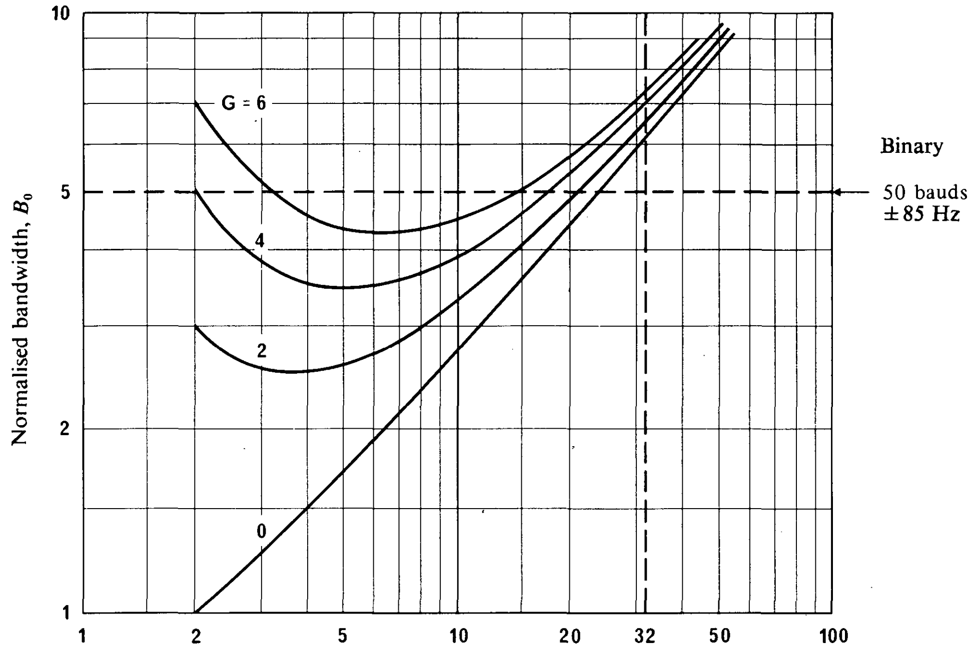

FIGURE 1 – *Normalised bandwidth*

$$B_0 = \frac{(M-1+G)}{\log_2 M} \text{ Hz/bit/s}$$

3. Signal-to-noise performance

It can be shown that the probability of element error for an ideal M-tone MFSK system with matched-filter demodulation is given by

$$p = (M-1)! \sum_{r=1}^{M-1} \frac{(-1)^{r+1}}{(r+1)!\ (M-1-r)!} \exp \frac{-rR}{r+1} \tag{6}$$

where R = signal-to-noise power ratio in one filter.

To enable the various systems in Table I to be compared, the equation must be expressed in terms of:

W signal energy per bit/noise power per unit bandwidth

$$= R/\log_2 M \tag{7}$$

and the word error rate:

$$P_w = 1 - (1 - p)^N \tag{8}$$

The combination of equations (6), (7) and (8) enables the word error rate of any of the systems to be calculated on the basis of fixed information rate and signal power.

Fig. 2 shows the performance of some of the systems and it can be seen that increase of M always causes a decrease in error rate.

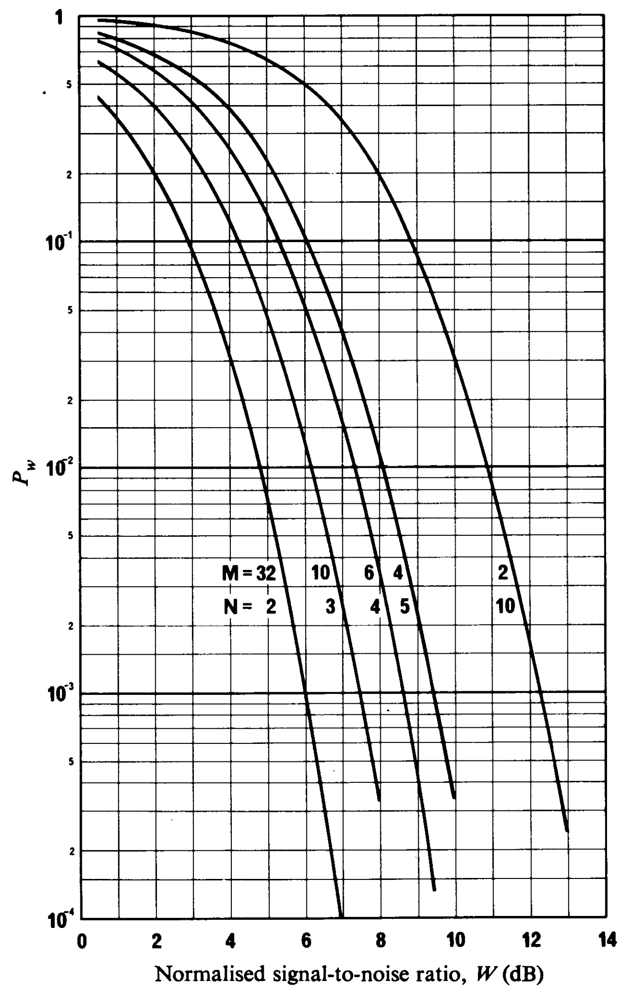

FIGURE 2 – *Word error rate for various systems*
(single path, non-fading)

Figs. 1 and 2 show that increasing the number of tones above two will give decreased errors and a decrease in bandwidth, but as M is increased above about 12, the improvement in performance is only achieved with an increase in bandwidth. Similar calculations can be carried out for Rayleigh fading conditions and diversity reception [Schemel, 1972] and these show similar tendencies.

For an ideal 32 tone system, compared with an ideal synchronous 5-unit binary system the theoretical improvement in performance is approximately as follows:

- single path: non-fading: 6.5 dB
- single path: Rayleigh fading: 8 dB
- dual diversity: Rayleigh fading: 6 dB

The measured performance of a practical MFSK system can be nearer to the ideal than with orthodox binary techniques. In comparing practical MFSK and binary systems, differences of between 6 and 12 dB may be experienced, and this has been confirmed by channel simulator measurements. In practice, this means that communication can be maintained on a steady signal which is barely audible in noise, and under fading conditions with dual diversity reception, the signal can be completely inaudible at times and the copy still remain substantially error-free.

4. Practical development

An MFSK system designed to transmit the International Telegraph Alphabet No. 2 (ITA2) code at 10 characters/sec., equivalent to 75 bauds 7.5 unit start-stop, was developed in the United Kingdom for use on a worldwide network which has stations located in large cities. The element length is 100 ms, selected from 32 tones (and a 33rd for "stand-by" condition) at 10 Hz spacing, the necessary bandwidth being 360 Hz. This system, which was introduced in 1962 and now used at 60 stations, is commonly known as Piccolo and it is convenient to use that term for referring to the developed 32-tone system.

5. Stability requirements and synchronisation

The full advantages of MFSK can be realised only in a synchronous system having a high order of frequency stability since it is quite possible to communicate at signal-to-noise ratios where AFC systems and start-stop synchronisation techniques would be ineffective. The order of frequency stability required, both of tone frequencies and character rate, is necessarily higher than with orthodox binary systems, but with the growing use of synthesizer techniques this need not introduce any serious problems.

It has been shown that tone frequency errors of 20% of tone separation do not cause serious degradation of performance but in order to give the maximum allowance for radio path effects it is suggested that the stability of synthesizer sources should be such that the maximum end-to-end frequency error due to equipment should not exceed 10% of the tone spacing. With 100 ms elements this means an overall accuracy of $\pm$ 1 Hz, or about 3×10^{-8} at 30 MHz.

The method of synchronisation of the early models of Piccolo used a low level (approx. 10%) of amplitude modulation of the signal at character rate (10 Hz). This was detected in the receiving equipment and applied to a phase-locked loop to maintain a local free-running 10 Hz oscillator source in the correct phase with reference to the incoming characters. This method has proved quite effective under noise and slow-fading conditions but under rapid "flutter" fading or severe multipath reception it can introduce systematic synchronising errors. The low frequency AM is operationally inconvenient and necessitates special attention to radio equipment, particularly the AGC characteristics of the receivers.

An improved system has been developed for later Piccolo models. The stand-by tone only is phase modulated at character rate and the modulation detected in a double phase-locked-loop circuit which has a high immunity to most ionospheric effects. While data is being transmitted the exact character rate is maintained at both terminals by high-stability sources; since synchronisation errors of $\pm$ 10% of a character duration are permissible, data should not be transmitted continuously (without re-synchronisation) for more than about $3/f$ hours, where f is the maximum expected differential character rate error in parts per million. If the same master frequency sources are used as for the RF synthesizers, this is not likely to be a serious limitation in most cases. Synchronisation is fully automatic whenever the stand-by condition is being received, and if correction is necessary it is achieved to an accuracy of better than $\pm$ 2% within 5 seconds on a good signal, or $\pm$ 4% within 10 seconds on a very poor signal.

6. Experimental evidence

Details of the performance of the system have been published [Robin *et al.*, 1963; Bayley and Ralphs, 1969; Bayley and Ralphs, 1972] and indicate that character error rates of 10^{-4} or less are maintained over long periods (without error coding of any kind) and that availabilities are considerably higher than those previously achieved with binary techniques.

An independent theoretical and practical analysis [Schemel, 1972] includes the results of a direct comparison over a radio link between Piccolo and a binary system, and error rates on the former "between one and two hundred times lower" are reported.

Tests of Piccolo on a channel simulator indicated that for non-fading signals with added Gaussian noise, the performance is within 1.5 dB of the theoretical. For Rayleigh fading signals in noise with non-diversity reception the performance is very close to the theoretical for low signal-to-noise ratios, but gives residual errors at high signal-to-noise ratios, due to the spread of the spectrum of the fading signal introducing energy into the filters adjacent to the transmitted frequency. With dual-diversity reception this anomaly is removed and the performance is within 3 dB of the ideal at all signal levels.

These measurements may be compared with similar measurements on binary modulation systems in Report 345 and binary forward error correction (FEC) systems in Report 349. Some of these comparisons have been published [Ralphs, 1971] and one conclusion was that for dual-diversity reception of flat fading signals Piccolo (without error detecting code (EDC)) may be expected to give a lower error rate than a good binary system with a modern FEC code unless the character error rate on both was less than 10^{-4}.

7. Selection of optimum parameters

The rigid relationship between element length and tone spacing means that this is the primary parameter. A long element gives a high degree of protection against multipath reception (path time delays of 10 ms having little effect on a 100 ms element), but as the element length is increased, higher RF stabilities are required, the effects of Doppler shifts become more evident and for a fixed data rate more tones are needed, so that cost and bandwidth increase. There seems to be a broad optimum for most HF circuits at about 50 to 100 ms, the longer element being preferred where multipath effects are a major factor and the necessary frequency stability is available.

The 32-tone system probably represents the maximum economic number of tones and provides the best performance in noise.

For a 5-bit character the alternative of a 6-tone system, sending two elements per character, gives the minimum bandwidth with a slight sacrifice of performance.

Intermediate values of M give a good compromise between performance and bandwidth, and it is suggested that a 10 or 12-tone system may be considered for general use, being particularly convenient for the International Telegraph Alphabet No. 5 (ITA 5) or telemetry of decimal data.

For 6 to 32 tones, with element durations of 50-100 ms, the available range of information rates (without error coding) is about 25 to 100 bit/s, and it is suggested that this is the range of optimum performance of a single-channel MFSK link and that higher rates should be obtained by frequency-division multiplexing several channels.

8. Multi-level error coding

It is essential that binary EDC or FEC coding should *not* be applied to a signal which is to be transmitted over an orthogonal multi-level system [Bell, 1973]. Instead, multi-level codes equivalent in function to the simpler binary codes can be constructed by carrying out the same arithmetical processes, but in M-level arithmetic. An example of this is the binary parity check, where a binary check digit is added to a block of information digits so as to make the Modulo-2 total of all digits equal to zero. Similarly, in a 32-tone system, each tone frequency can be allocated a "weighting" of 0 to 31, and after each block of data elements, a check element inserted to make the Modulo-32 total equal to zero. The probability of an undetected error block in such a system can be shown to be:

$$P_u = \sum_{n=1}^{N} \frac{-1}{(1-M)^{n-1}} \left[\sum_{r=0}^{n-2} (1-M)^r \right] \frac{N!}{n!\,(N-n)!} \cdot p^n \cdot (1-p)^{N-n} \qquad (9)$$

where

M: Number of tones,

N: Total number of elements in a code block,

p: Probability of element error,

r: An integer,

n: Number of element errors in the block.

This equation is plotted in Fig. 3 for $N = 11$, and $M = 2$ (binary), 10 (decimal) and 32 (Piccolo). It can be seen that for the same redundancy and element error rate, the undetected block error rate is proportional to $1/(M - 1)$ at low errors, the advantage of multi-level coding being maintained at high error densities. This can be qualitatively confirmed by noting that a random stream of binary digits will "satisfy" a binary parity check in 50% of cases, but a random stream of 32-level digits will only satisfy a Modulo-32 parity check in 3% of cases.

Some of the simpler binary FEC codes which are based on a number of independent parity checks (such as the Hamming codes) can be realised in multi-level form by similar techniques, and show similar advantages over the binary equivalents, but it should be noted that the decoding algorithms required can become very complex, requiring multi-stage decoding, and the ratio of "indicated" errors (i.e., errors detected but uncorrected) to corrected errors is often higher than with binary. This would seem to be a good subject for further investigation.

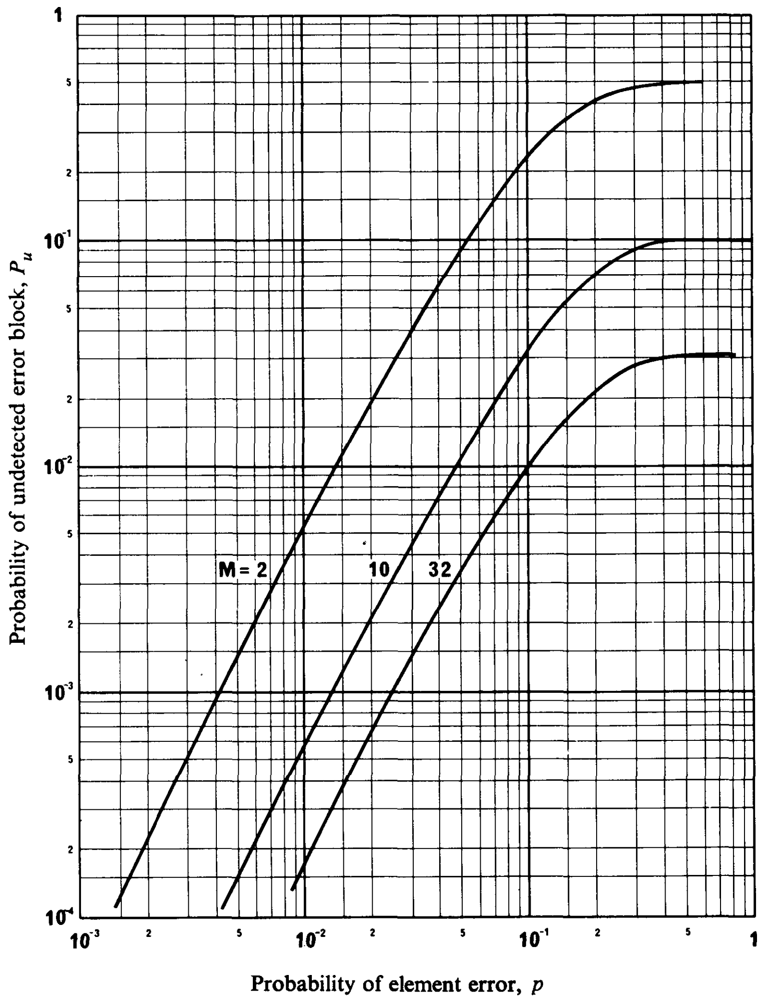

FIGURE 3 – *Multilevel parity check codes*
(11 element block, $N = 11$)

9. Conclusions

It has been shown that the use of MFSK techniques can offer improvements in HF telegraphy and telemetry, and such techniques are particularly applicable to single-channel low-speed links which must operate with high reliability on low quality signals. On such a link the error rate may be reduced by more than two orders of magnitude compared with an equivalent binary system.

The 32-tone (Piccolo) system should be considered as a practical extreme where the best possible performance has been obtained at the expense of a slight increase in bandwidth. A 10 or 12-tone system may prove to be a better compromise where a small sacrifice in performance can be accepted in return for bandwidth conservation and reduced cost.

A fully synthesized communication link with high stability sources is essential. Circuit techniques for modulation, synchronisation and demodulation have been developed and proven.

The effectiveness of error coding techniques on multi-level systems is considerably better than with binary equivalents, but more investigation is required to discover efficient FEC codes with simple decoding algorithms.

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REPORT 177-1 *

COMPRESSION OF THE RADIOTELEGRAPH SIGNAL SPECTRUM IN THE HF BANDS

(Question 28/3)

(1963-1974)

1. Introduction

The principles of bandwidth reduction have been used intuitively since the very beginning of telegraphic communication. Codes were developed to provide for the transmission of a given language in the least amount of time and bandwidth. In very limited bandwidth systems, such as transatlantic cables, use was made of three levels of amplitude and the principles of synchronous detection (regeneration) employed.

In recent years, in HF telegraphy, the trend has been toward the reduction in errors rather than the reduction of bandwidth. It is reasonable to assume that high-frequency telegraph systems will continue to use somewhat greater bandwidth than theoretically necessary (for example, the use of F1B in place of A1B emission), to overcome the unstable and noisy conditions met with in HF telegraph communication. (See [CCIR, 1962].)

2. Phase-shift-keying (PSK) systems

PSK systems using two or more levels can be used to yield a narrow-band transmission. Early systems of this type were not always successful when used in the HF band owing to the phase instability of the propagation medium at these frequencies. However, more recent PSK systems have operated quite successfully. A discussion of the principles of operation is given in Annex I. Also included is a description of one such system, which has been employed at VLF and which could be used at HF.

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* This Report has been transferred from Study Group 1 to Study Group 3 during the XIVth Plenary Assembly, Kyoto, 1978. It is also of interest to Study Group 8.

3. Digital signalling systems which employ three or more levels of amplitude, frequency-shift or phase-change

Digital signalling systems which employ three or more levels of amplitude have been investigated. It has been found that a system employing four amplitude levels has a signal-to-noise disadvantage when compared to a two-level system in the same bandwidth. While the bandwidth may be reduced for the same capacity, the higher power required, or the net reduction in signal-to-noise and disadvantages due to multipath transmission, lead to the conclusion that systems using several levels of amplitude are not particularly desirable for HF telegraphy. On the other hand, systems using four frequencies with a spacing of 800 Hz have been widely used and are successful. A somewhat similar system is now proposed using four frequencies with a spacing of only 80 Hz. Diplex keying, with 10 ms elements, is used on each channel with the two channels synchronized. A net gain of 7 dB in signal-to-noise ratio is realized by the system because of the reduction in bandwidth. With respect to phase-change systems, the previous remarks with regard to high-frequency propagation apply.

4. Coding techniques which provide either message compression or error reduction, or both

Coding techniques have been examined in great detail, particularly since the mathematical development of communication theory. The principal emphasis has been on error reduction for high-frequency telegraph systems rather than the reduction of time or bandwidth. At the present, the best system in general use seems to be the ARQ constant ratio code with feedback for error correction. Numerous techniques are being investigated to increase the volume of information transmitted over each channel, and it is expected that some of these techniques will be applied to reduce either the time of transmission or the bandwidth.

ANNEX I

Modern communication theory indicates that, in the presence of Gaussian noise, PSK is 3 dB better than FSK with coherent detection in both cases. Coherent detection is also about 1 to 2.dB superior to noncoherent detection, depending on modulation system and signal-to-noise ratio. Four-phase PSK is just as efficient as 2-phase PSK in terms of the power required per bit. However, only half the bandwidth is required.

A signal passing through a propagation medium such as HF or troposcatter experiences a smearing of the leading and trailing edges of a pulse. This is due to the arrival of the signal over two or more paths of different lengths. The difference in arrival times is referred to as multipath delay spread. This delay is usually less than 1 ms on HF paths, but delays exceeding 2 ms sometimes occur.

The means of minimizing detection problems due to multipath delay is to use relatively long pulse lengths such as 10 to 20 ms. One widely used pulse length is 13.33 ms, which corresponds to 75 pulses per second. Using 4-phase PSK permits 150 bit/s.

A further aid in avoiding the smearing at the leading and trailing edges of the pulse is to sample the pulse over a period of only 9.09 ms in the detector. Thus 4.04 ms of the received pulse is not used, so that the smeared edges are discarded. This avoids intersymbol interference due to overlapping pulses at the expense of not detecting 30% of the signal power.

The spectral density of a rectangular pulse has the shape of a $(\sin x)/x$ curve. The first nulls are separated from the centre frequency by the pulse repetition rate. A matched filter or coherent detector has detection pass-band response of the same shape. The first nulls are separated from the centre frequency by the inverse of the sample period. For the 9.09 ms sample period they are ± 110 Hz from the centre frequency.

A useful property of such a detector is that another signal can be centred on the detector spectral nulls without interference if the two signals are pulsed in synchronism. By this means, several PSK carriers can be placed close together to obtain a high bit rate in a narrow band. One popular system employs 16 PSK tones in the audio band. The tones are spaced 110 Hz starting at 935 Hz and ending at 2585 Hz. The total capacity is 2400 bit/s in an audio-frequency voice channel.

Since the transmitter and receiver carrier frequency error must be removed for phase detection, a Doppler tone is transmitted at 605 Hz for a.f.c. purposes in the modem.

SSB transmitters are employed to transmit the composite signal at HF. One essential requirement, however, is that the delay across the signal band in the transmitter and receiver sideband filters be fairly flat. A variation of less than 200 μs is satisfactory. Larger variations will reduce the tolerance to HF propagation delay spread.

The passband of suitable SSB filters must be somewhat wider than the band occupied by the tones because of the flat time delay requirement. A filter with a response of 300 to 3500 Hz can be designed to have a suitable time-delay characteristic. A filter having an upper cutoff frequency of 3000 Hz will need time delay equalization. It may be built into the filter or added externally. Thus a net bit rate of nearly 1 bit/Hz of occupied band is achieved.

It is noted that over the centre part of the band occupied by the keyed tones, the data rate is 2 × 75/110 for 1.36 bit/Hz. The keying rate could be increased to 110 pulses per second with the 110 Hz tone spacing to achieve 2 bit/Hz, which is the maximum according to the Nyquist criteria. This would also use all of the signal power, but some intersymbol interference would result from overlapping pulses due to multipath delay.

HF multipath conditions also produce frequency selective fading. When fades are sufficiently deep they will cause errors in the received bit stream. It is impracticable to use enough power at HF to have an adequate S/N ratio at the bottom of all fades. The solution is to use some form of diversity or error correction. The bandwidth of a fade during a pulse period is usually less than 1 kHz. Therefore only a few of the keyed tones will be in a fade at any one time. One common practice is to transmit the same signal on both the upper sideband and lower sideband channels. Frequency diversity techniques can be employed to make use of the stronger tone of each sideband pair. Frequency diversity, of course, occupies twice the spectrum space. This can be avoided whenever it is possible to use two receiving antennae employing either space or polarization diversity.

There are many different error detection and correction techniques that can be successfully employed. Report 196 (New Delhi, 1970) gives a good summary of these techniques which are highly relevant to minimizing the product, time × power × bandwidth, required for transmission of a given amount of information.

An example of another type of keying modulation which is useful for conserving bandwidth of a single keyed carrier (Collins Radio Company "MSK"; "MSK" stands for "minimum shift keying".), consists of two binary PSK channels on the same carrier frequency, but separated by ± 90 degrees. The pulses on each channel have the shape of a half sine wave instead of being rectangular. Each is two bit periods long. The pulses in the separate channels are staggered in time by one bit period. The result of adding the waves of these two channels is a radio-frequency wave of constant amplitude, regardless of the phase changes caused by keying. It is interesting that this emission is identical to continuous phase FSK when the difference between the mark and space frequencies is exactly one half the bit rate.

The important features of "MSK" are that its S/N performance is identical to PSK but the side-lobe energy falls off much faster, as shown in Fig. 1. Furthermore, this signal can be band-limited by filtering or pulse shape modification. This will cause some amplitude ripple, but it can be removed by amplitude-limiting. This causes a slight spreading of the band-limited signal as is also shown.

The occupied bandwidth (99% power) of unfiltered "MSK" is 1.2 times the bit rate. It has been band-limited to 1.05 bit rate in one system. Further development probably could reduce it to a bit rate of 1.0.

This emission has been employed at VLF to achieve maximum bit rates in systems severely limited in bandwidth by the transmitting antenna. This emission is now being developed for microwave data transmission at a data rate of 21.5 Mbit/s. It could be employed at other frequencies such as HF or UHF troposcatter, subject to the minimum pulse length requirements, to avoid intersymbol interference due to multipath delay spread. A bit rate of 100 bit/s would only occupy 100 to 120 Hz of bandwidth.

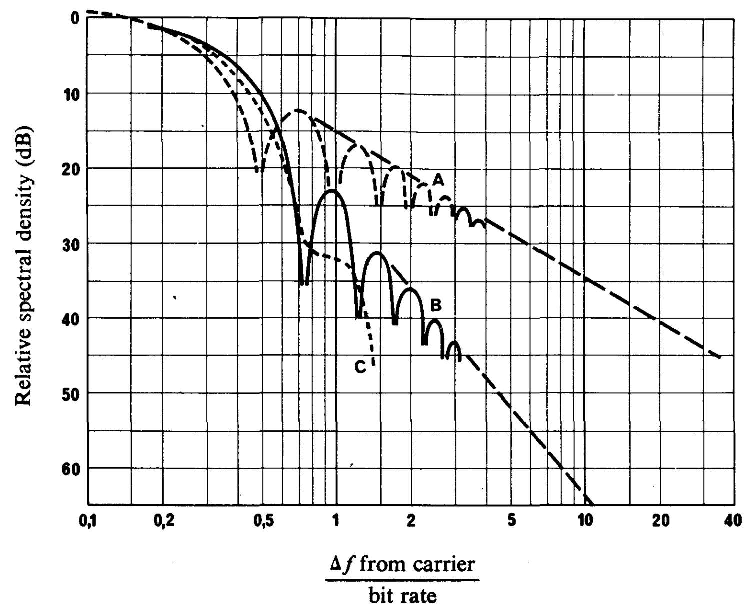

FIGURE 1 – *Relative spectral density for 4-phase PSK, MSK and MSK, filtered and amplitude-limited*

A: 4-Phase PSK B: MSK C: Band-limited MSK

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REPORT 183-3 *

USABLE SENSITIVITY OF RADIOTELEGRAPHY RECEIVERS IN THE PRESENCE OF QUASI-IMPULSIVE INTERFERENCE

(Study Programme 1A/3)

(1959-1963-1966-1970-1982)

1. Introduction

As mentioned in Recommendation 334 (Kyoto, 1978) the expression *quasi-impulsive interference* can be interpreted in different ways. In this Report, it is taken as that kind of interference which is intermediate between the two extreme cases of:

– *thermal noise*, or *white noise*, of very irregular shape and amplitude, with pulses following one another, so that their effects in the receiver are more or less overlapping;

– *true impulsive interference*, made of successive pulses, the duration of which is shorter than the time constant of the receiver, with intervals long enough to prevent their effects from overlapping.

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* This Report has been transferred from Study Group 1 and its text has been modified to deal only with those parts of interest to Study Group 3.

The two main types of quasi-impulsive interference are *atmospheric noise* and *man-made noise*, such as disturbances from switches, electric motors, radio-frequency-excited arc welders, etc. The man-made noise may, for certain periods of time, occur quasi-periodically, with fairly constant shape and amplitude. Such interference requires special methods of measurement, and the calculation of its effects on the receivers is difficult.

2. Atmospheric noise

2.1 *Measurement*

Atmospheric noise has been studied for many years. A few recent papers are listed in the Bibliography below (see also Recommendation 372, Report 322 (published separately) and Study Programme 1A/3). They show that it is possible at a given time, in a given place, on a given frequency, with a given bandwidth and a given detector and recording instrument time constant, to measure and record certain characteristic quantities:

– average power for a long time (for example, hourly) interval;
– variations of envelope amplitude and/or the time rate of these variations.

These variations can be presented in terms of amplitude distribution (for example, cumulative), and time or frequency distribution; they can also be analysed in terms of r.m.s., average, median, peak, quasi-peak, or mean logarithmic values. Calibration may be referred either to absolute field strength of intensity, or by ratio to the thermal noise level.

Numerous curves of such distributions have been given [URSI, 1957; Watt *et al.*, 1958; CCIR, 1959a; Watt and Maxwell, 1957; Harwood, 1958; Crichlow *et al.*, 1960; NBS]. One can try to approximate them by simple mathematical laws but these laws are only approximate. The important point is that, although the Rayleigh law is more or less correct for the lower levels of natural interference (which are exceeded during most of the time), it is completely wrong for strong interference, which occurs rarely or for short periods of time; the probability of "strong quasi-impulsive noise" decreases much more slowly (Fig. 1). The dynamic range of natural noise is therefore much greater than that of thermal noise. Hence, as the majority or radiocommunications require a very low error probability (e.g. 0.01% for telegraphy), they are still appreciably disturbed by rare and very strong noise, and, at such levels, the curves show * that an increase in the signal intensity has little effect – much less than with thermal noise.

Studies carried out over many years have made it possible to assess the atmospheric noise distribution over the surface of the Earth, as well as its variations with the hour of the day, season, ionospheric disturbances, etc. Changes in the distribution of amplitude, variation rate, etc., have been reported [Watt and Maxwell, 1957; Harwood, 1958] (Report 322), and further work is being continued.

2.2 *Influence of receiver bandwidth on:*

2.2.1 *Mean energy*

Studies have also been made of the variation of noise power over the frequency spectrum. In general, this variation is slow, so that the portion of the spectrum within the passband of a narrow-band receiver may be considered uniform (white noise). For wider passbands this would not hold, especially as the frequency limits for ionospheric propagation are approached.

It can be concluded that the mean energy produced in a receiver by natural noise must be proportional to the bandwidth B; the r.m.s. voltage is therefore proportional to $B^{0.5}$. This appears to be confirmed by general experience, but it does not necessarily follow that the other characteristic values, and ultimately the effect on the receiver, are also proportional to $B^{0.5}$.

2.2.2 *Mean Voltage*

A review of the observations made ([URSI, 1957], § J), shows that the mean voltage often increases more slowly with B, for example:

– according to the U.K. Administration, if $B > 0.3$ kHz: $B^{0.33}$ to $B^{0.25}$
– according to Florida University, USA: $B^{0.34}$
– according to the NBS, USA ([URSI, 1957], Fig. 20): $B^{0.42}$
– according to the NBS, the mean logarithm increases approximately with $B^{0.35}$.

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* The curves are not always drawn sufficiently far into the region of low probabilities, a fact easily explained by the difficulty of measurement, but this is also very regrettable because this region is precisely the most interesting region from the practical viewpoint.

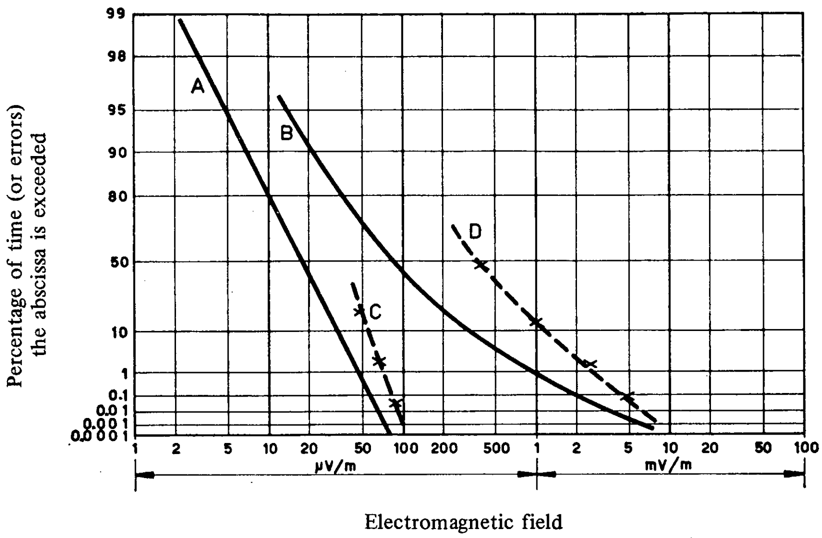

FIGURE 1 – *Comparison of thermal and atmospheric noise*

A: thermal noise envelope C: errors due to thermal noise
B: atmospheric noise envelope D: errors due to atmospheric noise

2.2.3 *Amplitude distribution*

The influence of bandwidth on amplitude distribution can be calculated [Fulton, 1957; Spaulding *et al.*, 1962].

2.2.4 *Harmful effect of noise*

Finally, the effect on the receiver may vary in accordance with quite a different law. Specifically, if there is a limiter, an increase in the pre-limiter bandwidth may decrease the harmful effect of noise because the limiter is presented with noise impulses of larger amplitude and smaller duration. After limiting, the noise energy is further reduced by restricting the bandwidth to that necessary for the transmission of the signal. The discriminator, if used, should not be the bandwidth limiting element, but should be linear over, at least, the significant bandwidth.

3. Man-made noise

3.1 *CISPR studies*

As regards *man-made noise*, it should be recalled that a great deal of study has been devoted to the problem, particularly by the CISPR. However, the point of view of that organization may differ from that of the CCIR, particularly because the CISPR:

– is primarily interested in broadcasting, and usually considers one source of interference at a time.

Nevertheless, some of the contributions submitted contain observations and conclusions of a general nature on these types of noise and the effect they produce, which may be useful in providing a reply to Question 49/1 (Geneva, 1974). The comments may be summarized as follows:

3.2 *Short pulses*

Some types of man-made intereference considered may be regarded as short pulses, more or less constant in amplitude (or at least, subject to no more than slight variations), repeated at a fairly regular rate governed by the nature of the interfering equipment.

The repetition rate, N, may be very low, e.g. a fraction of a hertz; or of the order of industrial frequencies, e.g. 50 or 60 Hz; or, again, higher than that, although rarely exceeding a few kHz; i.e. the passband of the receiver, B. The result is that the duration, T, of each interfering pulse is, in practice, usually very short compared with the interval between two pulses.

It is likewise usually assumed (this is debatable in the case of television or radar), that the duration, T, is shorter than, or equal to, the reciprocal of the bandwidth, B, of the receiver.

This being so, the disturbance produced in a receiver tuned to a frequency, f_0, can be calculated with only two parameters, i.e.

- the peak value, P, of a single frequency component of the interfering impulses at or near the frequency, f_0,
- the repetition rate, N.

It is found, for instance [CISPR, 1953a], that in a linear receiver with a gain, G, each separate pulse produces a damped oscillation with a peak amplitude, $U_{max} = G.P.B.$, reducing to half this value after a time $1/B$. This peak amplitude, U_{max}, is therefore the first factor to be measured when defining the interfering signal; if it varies, the mean value is taken.

The second characteristic parameter, i.e. the repetition rate, N, can be easily determined by direct reading, e.g., on an oscilloscope. It governs the extent of the nuisance caused in practice, in a way which varies in complexity with the nature of the signal. In telegraphy, the relation between N and P and the number of character errors can usually be calculated. The calculations may be extended to cases where there is a limiter and where the bandwidths before and after limiting are known.

3.3 *Continuous interfering signal with rapid frequency sweep*

It has been suggested [CCIR, 1959b] that the effect of a continuous wave with a rapidly varying frequency, sweeping quickly through the passband of the receiver, may be likened to a *shock* and regarded as a short interfering signal of the type dealt with in § 3.2. This phenomenon, which is liable to arise with certain machinery using high frequencies, is worthy of further study.

3.4 *Standard interference generators*

Standard interference generators can be designed – and, in fact, exist already – for providing pulses with levels and rates that are adjustable and known, or random. They have been used to simulate the effects of man-made noise [CISPR, 1953b].

3.5 *Evaluation and comparison of different interferences*

The experimental measurement conditions required for evaluating and comparing the interfering signals from various sources of disturbance can be defined, and the extent to which they can be reduced through *interference suppressors* can be measured ([CISPR, 1953a and b] and other CISPR documents).

4. Susceptibility of radiotelegraphy receivers to noise

4.1 *Elementary considerations*

Assuming that noise is a known factor, it is possible to calculate its effect upon a receiver, and, in particular, the error probability on a signal of a given type (for example, teleprinter), arriving at a fixed level. This can be done in two stages:

4.1.1 *Probability of error on an isolated element of a binary code.* It has been shown and verified that, for frequency shift reception, this probability is equal to one-half the probability of the corresponding level on the noise envelope ([Watt *et al.*, 1958], pp. 21, 24, 25 and [CCIR, 1959a]).

4.1.2 *Probability of error on a character containing a given number of binary elements.* For example, with the 5-unit code, if each "unit" is affected by the probability of error, p, and if these probabilities are independent, the probability of error on a character is ([Watt *et al.*, 1958], p. 23):

in synchronous working: $P = 1 - (1 - p)^5 \approx 5\,p$

for a start-stop system: $P = 1 - (1 - p)^{17} \approx 17\,p$

(if p is small)

A variable signal level may then be considered. It has been found [Watt *et al.*, 1958] that the lower the admissible error rate, the more troublesome the fading. In a specific instance, the useful field strength of the signal had to be multiplied by 1.6 for 10% error and by 5.0 for 0.1% error.

4.2 *Effects of rate of variation of noise and the signalling speed*

Nevertheless, the analysis has revealed another factor which is not as predictable as for thermal noise, i.e., the *variation rate*, expressed as:

- the number of times per second the envelope curve cuts the mean value;
- the individual duration probability of each noise impulse;
- the probability of a given spacing between two successive noise impulses.

The two latter intervals should be compared to the duration of the signal element.

Let us consider, for instance, the case of 3 or 4 successive noise impulses, whose individual durations (including any lengthening by the time constant of the receiver) are slightly shorter than that of a signal element.

If they arrive with a spacing sufficient to affect different characters, they will interfere with them all and give rise to 3 or 4 wrong characters. If, on the contrary, they are due to the same cause and are grouped together in the course of the duration of a character (including its synchronization), only that character will be wrong. For instance, it has been shown [Watt *et al.*, 1958] that, if two elements of the signal are systematically covered by the noise impulses, the error on characters is reduced to:

$$P = 1 - (1 - p)^7 \approx 7\,p \text{ (if } p \text{ is small)}$$

Thus the signal speed may exert an influence even if the passband of the receiver remains the same.

The analysis may be extended to different types of receiver and modulation (e.g. amplitude, frequency shift, etc.).

5. Reduction of susceptibility to noise by design of receivers

Provided the envelope of the noise impulses is discontinuous, then the interference can theoretically be attenuated to any desired level (see for example [Kotelnikov, 1956]).

Note. – A review of some methods of suppressing quasi-impulsive interference is given in [Babanov *et al.*, 1967], which also contains a bibliography of 92 publications on this subject.

Certain receiver design techniques have been found useful in reducing the effects of noise. (See [CCIR, 1965a and b]). They may be described as follows:

5.1 *Large dynamic range and fast recovery from overload*

In certain forms of man-made noise the durations of the interference pulses are very short compared with the intervals between pulses. Receivers subject to such interference may provide acceptable reception, even though the instantaneous amplitude of the pulses greatly exceeds the amplitude of the wanted signal, if care is taken in the design of the receiver to ensure linear operation over a large dynamic range of signal levels. If the pulse signals may exceed the linear dynamic range of the receiver, the design of the receiver should be such that there is a rapid recovery from overload conditions after each pulse.

5.2 *Noise limiting*

The use of noise limiters in receivers is beneficial in many cases of interference from man-made noise. Such limiters are designed to prevent the radio-frequency, intermediate frequency, audio or video signal level (resulting from the combination of wanted signal and interfering pulse) from exceeding a certain level. This level may be set just above the highest level reached in the modulation of the wanted signal. Care is taken to ensure that the noise limiter recovers immediately after each interference pulse.

5.3 *Optimum disposition of selectivity and limiting*

Effective attenuation of interference can be achieved in receivers which have the following structure: a linear preamplifier with passband considerably in excess of that required, followed by a limiter, and an amplifier with the narrowest possible passband [Shchukin, 1946].

5.4 *Noise blanking*

The system, described in § 5.3, can be improved if the limiter is switched on only during each noise pulse and if, in the absence of a noise pulse, the receiver is linear [Litvin, 1962]. The use of "interference blanking" may be also very beneficial. This technique involves the momentary switching-off of the receiver at the time of occurrence of an interference pulse [Shabalin, 1964]. The received signal preceding the interruption can be stored and kept at the output of the receiver during the time of interruption [Gorbachev and Vinogradov, 1961].

5.5 *Time diversity*

The effects of atmospheric noise have been found to have a duration of less than 1.5 s. Similarly, other forms of quasi-impulsive interference (and incidentally multipath delay distortion) have a duration of less than one second. Therefore, the application of time-diversity means to telegraph circuits, with one path delayed about two seconds, has proved to be very effective in the reduction of error-rates without the requirement of a reciprocal return circuit.

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3C b: Data transmission

Recommendations and Reports

RECOMMENDATION 456

DATA TRANSMISSION AT 1200/600 BIT/S OVER HF CIRCUITS WHEN USING MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEMS AND FREQUENCY-SHIFT KEYING

(Question 12/3)

(1970)

The CCIR,

CONSIDERING

(a) that the effects of the random variations and disturbances in the HF propagation medium, in particular the effects of multipath distortion, in general preclude the use of serial transmission of binary data at rates of 1200 or 600 bit/s;

(b) that voice-frequency multi-channel frequency-shift systems that operate synchronously at a modulation rate of approximately 100 bauds are in widespread use over HF circuits;

(c) that such systems in effect provide an aggregate capacity of up to 1500 bit/s;

(d) that such systems, therefore, are suitable, and in fact are being used for data transmission at the standard data rates of 1200 and 600 bit/s;

(e) that the presence of multiplexer and demultiplexer or of land lines in the complete circuit may introduce envelope delay distortion, this distortion being most severe for the lowest and highest channels of a multi-channel voice-frequency frequency-shift system,

UNANIMOUSLY RECOMMENDS

1. that for data transmission at binary data rates of 1200 or 600 bits/s using frequency-division multiplex frequency-shift systems, the system described in Annex I be preferred;

Note. – By agreement between Administrations, the use of systems with a different number of channels and other channel spacings and modulation rates, for data transmission at 1200/600 bit/s, is allowed.

2. that channel spacing and central frequencies of the channels of the frequency-shift system should be in accordance with Table I of Recommendation 436;

3. that channels 3 to 14 inclusive of Table I of Recommendation 436 should be used for the transmission of the data.

ANNEX I

1. Description of system

To avoid excessive multipath distortion, which would result when higher speed binary data streams are directly transmitted in serial form, the incoming-bit stream is converted into a number of relatively low-speed streams, which are transmitted simultaneously in parallel and recombined into a single serial data output at the receiving terminal.

In this way, the modulation rate of the channels transmitted over the HF circuit can be kept to an acceptable value.

A block diagram of the 1200 bit/s system is shown in Fig. 1.

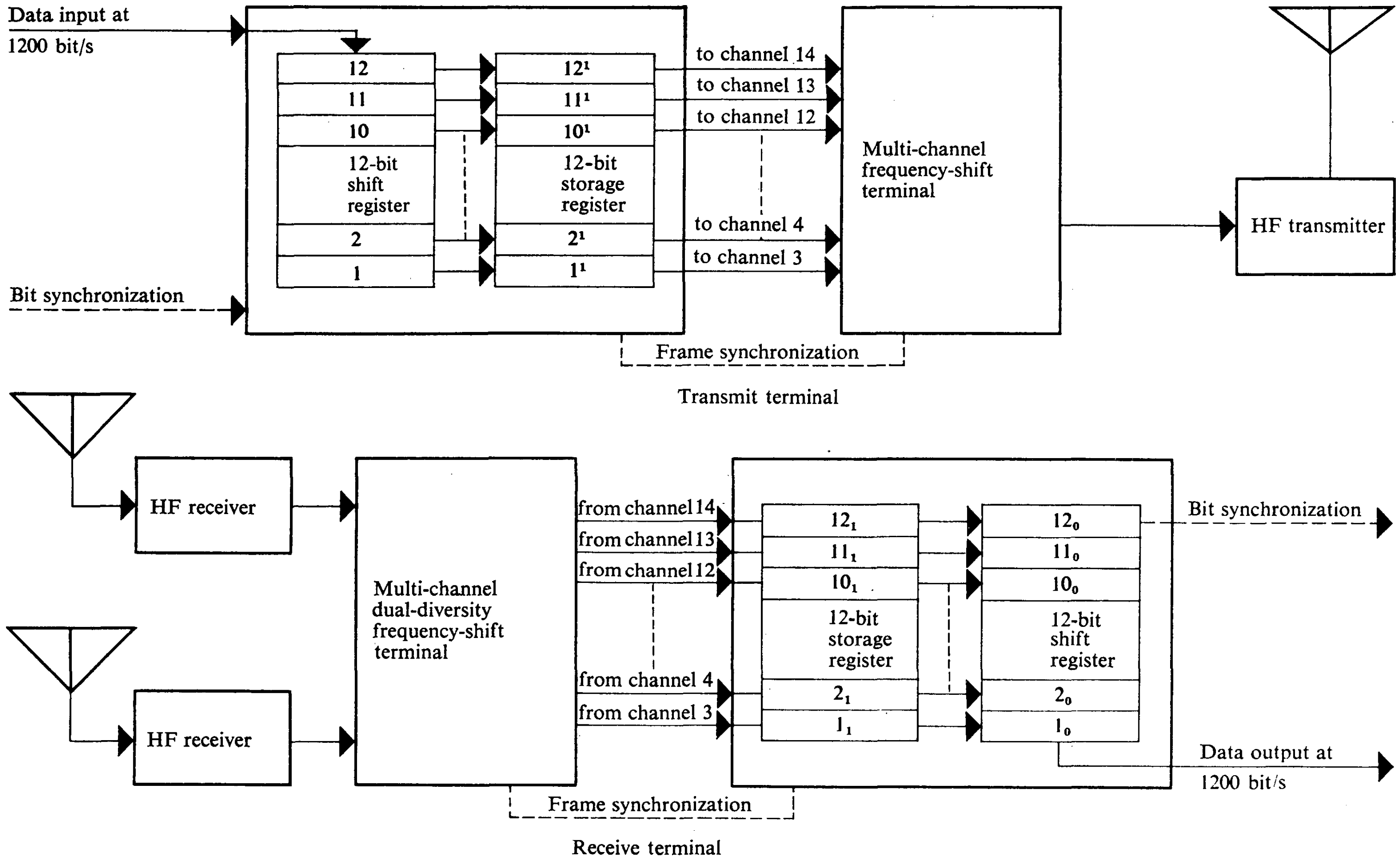

FIGURE 1 – *Data transmission system operating at 1200 bit/s*

2. Serial-to-parallel converter, transmission at 1200 bit/s

At the transmit side, the 1200 bit/s incoming-data stream is fed to a 12-bit shift register. At 12-bit intervals (i.e. at 10 ms intervals) the content of this register is transferred in parallel to a 12-bit storage register, the output of which is connected to 12 parallel channels of the multi-channel frequency-shift system.

Bit synchronization for the shift register may be:

2.1 extracted from the transitions of the data stream, provided the data stream is not expected to have excessive intervals during which no transitions occur (i.e. steady "1", or steady "0" condition);

2.2 obtained from a bit synchronizing signal from the data source, if available;

2.3 generated by an internal clock, in which case a synchronizing output is fed back to the data source.

The parallel transfer pulses are obtained from the bit synchronizing signal through a digital division process. If required, this frame synchronizing information may be transmitted over an additional channel of the frequency-shift system.

3. Channel arrangement, transmission at 1200 bit/s

The 12 channels of the frequency-shift system used for the transmission of the data information, each operating at a modulation rate of 100 bauds, shall be channels 3 to 14 inclusive of Table I of Recommendation 436; with channel 3 corresponding to the first (in time) bit of each 12-bit sequence, channel 4 to the second bit of this sequence, and so forth. The frequency spectrum occupied by these channels is that portion of the voice-frequency band which is least affected by envelope delay distortion caused by multiplexer and demultiplexer filters or by land lines which may be incorporated between the terminal sites and the HF transmitting and/or receiving sites.

4. Parallel-to-serial converter, transmission at 1200 bit/s

The parallel-to-serial converter at the receiving terminal shall be designed to perform the following functions:

4.1 to provide delay equalization for the 12 individual channels of the frequency-shift system;

4.2 to provide frame synchronization and bit synchronization by means of extracting synchronization information from the data channels (or from the additional frame synchronizing channel, if this is used);

4.3 to sample the outputs of the 12 data channels, store the sampled data in a 12-bit storage register, transfer the stored data to a 12-bit shift register once per frame interval (10 ms) and read out the data in serial form.

A bit synchronizing output terminal shall be provided for synchronization of associated data equipment which may require a separate synchronizing signal.

5. Data transmission at 600 bit/s

For data transmission at 600 bit/s the following modes of operation are optional:

5.1 the use of 6 instead of 12 channels of the frequency-shift system;

5.2 the use of 12 channels of the frequency-shift system with dualling of channels to provide in-band frequency diversity;

5.3 the use of 12 channels of the frequency-shift system and reducing the channel modulation rate from 100 bauds to 50 bauds;

5.4 the use of 12 channels of the frequency-shift system and applying binary coding techniques to provide error correction, error detection or combined error correction/detection.

The option of § 5.1 enables two independent data streams at 600 bit/s to be transmitted in a single 3 kHz voice band. The options of § 5.2 and 5.3 provide improved performance (i.e., lower error rate) with little or no additional equipment required, but at the cost of increased bandwidth. Where lowest error rate is required, the use of redundant coding (which may include time-diversity methods) of the option of § 5.4 is preferred.

REPORT 864

DATA TRANSMISSION AT 2400/1200/600/300/150/75 BIT/S OVER HF CIRCUITS USING MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPHY AND PHASE-SHIFT KEYING

(Question 12/3)

(1982)

1. Introduction

Considering the need for some data transmission systems to reach a speed of 2400 bit/s, a system based on multitone composite signals and on quadriphase modulation may be suggested.

To compensate for the unfavourable nature of the transmission medium the following techniques are available:

- various forms of dual diversity operation including separate SSB emissions or a single ISB emission;
- several levels of in-band frequency diversity;
- error detection and error correction coding combined with time interleaving;
- variable data rate to adapt the system to the channel capacity;
- introduction of guard times between frames to combat multipath propagation and group-delay distortion.

This Report describes a data transmission system based on the above principles.

2. System description

2.1 A receiving/transmitting terminal of the system consists of:

- a sender and receiver of digital information (e.g. computer);
- a modem, the primary function of which is the conversion of information from digital to analogue form compatible with the input to a radio transmitter and conversion of the analogue information at a radio receiver output into digital data compatible with the digital receiver input.

  This modem also performs various coding functions and effects diversity combination.
- RF receiving and transmitting equipment connected to antennas.

2.2 The modem generates in transmission a composite audio signal consisting of a set of 18 tones in the band 300 to 3000 Hz.

Of these tones, 16 have a spacing of 110 Hz (935 to 2585 Hz) and are modulated in DE-QPSK mode (differentially encoded – quadriphase shift keying), each at 75 bit/s thus permitting a data rate of $16 \times 75 \times 2 = 2400$ bit/s.

The tone at 605 Hz is used for the correction of end-to-end frequency errors, including any Doppler effect. The tone at 2915 Hz is utilized for system synchronization.

The dual diversity combiner can accept inputs either from two receivers operating in space, frequency or polarization diversity mode or from one receiver operating in ISB mode.

When the data rate is a sub-multiple of the transmission speed, various in-band diversity arrangements can be implemented. As an example, a data rate of 1200 bit/s provides a dual diversity (1200×2), a data rate of 600 bit/s, a quadruple diversity (600×4) and so forth, all with a transmission speed of 2400 bit/s. Utilization of the maximum possible diversity, both in-band and between independent channels, can thus be made according to the data rate selected. Provision is made for 75/150/300/600/1200 bit/s. The coding system and time interleaving with which the modem is equipped improve further the system reliability in the presence of impulsive noise and fading.

In addition to a choice of coded/uncoded operation, with selectable data rate and diversity mode, this modem also allows setting of the interleaving interval thus providing a flexible communication system as summarized in Table I.

The transmission signal consists of frames whose duration is 13.33 ms, this includes a time guard (4.2 ms) which is introduced to offset the effects of multipath propagation.

2.3 The RF equipment effects, in transmission, operations relative to channel modulation and produces an emission having suitable radio frequency and power characteristics. Reverse operations, relative to frequency conversion, are carried out in reception so as to obtain the composite audio signal to be conveyed to the modem.

The RF equipment must have the following particular characteristics:

- phase jitter: less than 5° for 10 ms time interval (100 samples);
- group-delay distortion: 500 μs in transmission, 500 μs in reception;
- intermodulation: 36 dB below peak envelope power.

TABLE I – *Data rates/modes (independently selectable for transmission and reception)*

Data rate (bit/s)	Uncoded modes			Coded modes			
	Diversity modes			Time interleaving Available time spread (transmitter and receiver)(s)	Additional diversity modes		
	In-band	Channel	Total		In-band	Channel	Total
2400 1200	– X2	X2 X2	X2 X4	0 – 12.8	–	X2	X2
600 300	X4 X8	X2 X2	X8 X16	0 – 25.6 0 – 51.2	X2 X4	X2 X2	X4 X8
150 75	X16	X2	X32	0 – 102.5 0 – 205	X8 X16	X2 X2	X16 X32

REPORT 703 *

USE OF CHANNELS WITH BANDWIDTH 300-3400 Hz IN SSB AND ISB SYSTEMS

(Question 12/3)

(1978)

1. Data transmission in HF radio links is effected at high speeds of 600 to 1200 bauds and the trend is for this to be increased to up to 2400 bauds and over. Irregular frequency response, non-linear phase response of transmission and reception paths, and multipath propagation restrict the rate and reliability of transmitted data.

Preliminary calculations show [Khmelnitski, 1972] that to have small error rates with FSK data transmission, it is necessary to widen partial channels insofar as possible. Therefore, FSK data transmission requires a radio telephone bandwidth of not less than 3100 Hz, that is 300 to 3400 Hz.

* This Report is brought to the attention of Study Group 1.

2. At the present time digital telephony, using vocoders, is increasingly used on HF radio links [Bandura *et al.*, 1970]. For this purpose, digital data transmission equipment is used. Two systems which may be of particular interest are the MS-5 (U.S.S.R.) [Zaezdnii *et al.*, 1970], which has a maximum capacity of 4800 bits/s and occupies a bandwidth of 300 to 3400 Hz, and the 20-tone Kineplex (United States) [Mosier and Clabaugh, 1958] which has a maximum capacity of 3000 bits/s and occupies a bandwidth of 300 to 3400 Hz, including guard bands of 500 Hz at the band extremities.

3. Data transmission is possible via combined channels, consisting of cable and radio links [Shvartsman *et al.*, 1970]. In this case it is advisable to use for single-sideband radio telephone links a bandwidth consistent with the CCITT recommended bandwidth of 300 to 3400 Hz (a channel with this bandwidth, 300 to 3400 Hz, was adopted for the land mobile radiotelephone service (see CCIR Recommendation 494, § 1.1.4)).

4. Conclusions

For high speed data transmission at low error rates, and also for digital telephony, it is reasonable to use SSB and ISB radio channels with a bandwidth of 300 to 3400 Hz.

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REPORT 865

IMPROVEMENT IN BIT ERROR-RATE BY THE USE OF SPREAD SPECTRUM TECHNIQUES

(Question 26/3)

(1982)

1. Introduction

This Report describes a modulator/demodulator (modem) developed in Canada [Chow, 1981] which transmits data at 300 bit/s reliably in a 3 kHz radio channel in the 3-30 MHz band in spite of multipath fading, narrowband interference and frequency offsets. It uses a narrowband spread spectrum technique instead of conventional multitone PSK or FSK.

Tests showed that its performance is significantly better than that of conventional multitone FSK modems even if the latter incorporate in-band frequency diversity.

The improvement in performance is attributed to the following characteristics:

- Spread spectrum systems are generally more resistant to narrowband interference [Dixon, 1976].
- Spread spectrum systems can be made virtually immune to the effects of selective fading and intersymbol interference caused by multipath propagation.
- The modem is relatively immune to Doppler shifts and frequency offset between the transmitter and receiver.
- The transmitted signal has an envelope of constant amplitude, which makes more efficient use of the available transmitter power.

2. System description

2.1 *Modulator*

The data at 300 bit/s is differentially encoded twice and applied to the four-phase PSK modulator (see Fig. 1). Use of a second level of differential encoding makes the system resistant to Doppler and frequency offsets. The four-phase modulator generates a signal centred on 1500 Hz and with bandwidth commensurate with the transmission rate of 150 bauds, with two bits encoded in each symbol. A further $N(N + 1)\pi/8$ phase shift (where N is the symbol number) is applied after each symbol to facilitate bit time recovery in the demodulator. The 150 baud signal is band spread by mixing it with a Barker sequence [Barker, 1958] of 13 bits. After appropriate filtering the signal is applied to the SSB radio for transmission.

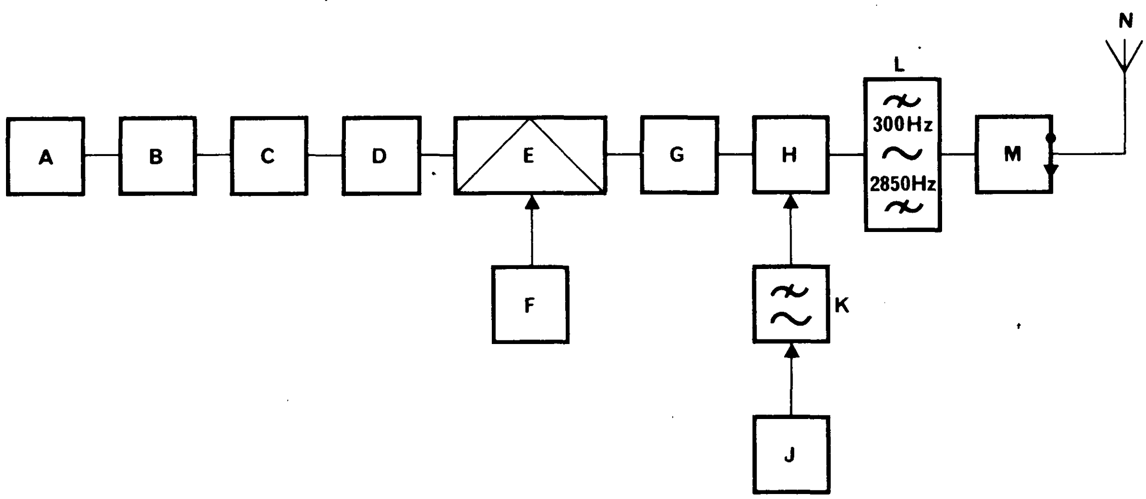

FIGURE 1 – *Modulator*

A: 300 bit/s source
B: multiplexer
C: differential encoder (first level)
D: differential encoder (second level)
E: 4-Phase modulator
F: 1500 Hz source
G: N (N + 1) π/8 phase shifter
H: mixer
J: Barker sequence generator
K: lowpass filter
L: bandpass filter 300-2850 Hz
M: SSB radio transmitter
N: antenna

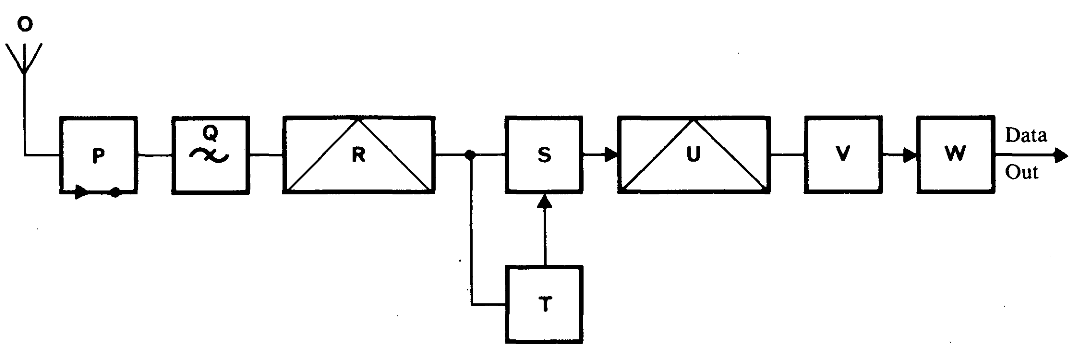

FIGURE 2 – *Demodulator*

O: antenna
P: SSB radio receiver
Q: matched filter
R: 4-Phase demodulator
S: integrate-and-dump circuit
T: bit time recovery circuit
U: differential demodulator
V: decision circuit
W: multiplexer

2.2 *Demodulator*

The receiver output is inserted into a complex passband matched filter centered at 1500 Hz, matched to the bandlimited Barker code. The filter output is a series of pulses whose envelope is the approximate ionospheric impulse response [Turin, 1960] and whose phase contains the transmitted information.

A differential demodulator extracts the phase difference information from the output of the matched filter, simultaneously removing the 1500 Hz carrier. The energy from each of the propagation paths is summed by the Integrate-and-Dump filter controlled by the bit time recovery circuit. This provides the resistance of the system to multipath.

A second differential decoder removes the constant-phase rotation caused by frequency offset and generates the input to the decision circuit, thus forming the final data output.

3. Test results

A test programme was carried out in 1980 [Chow, 1981], using two radio circuits of respectively 260 km and 560 km, on four frequencies between 3.3 MHz and 6.8 MHz. The performance of the spread spectrum modem was compared in alternate intervals each of ten minutes with an FSK modem (Recommendation 436) incorporating in-band frequency diversity. The peak RF power for both modems was equalized and the same receivers and antennas were used. Approximately 40 hours of data were gathered and analyzed, including both day and night conditions. Multipath spread of 4 ms was commonly observed. The results of the comparison tests are summarized as follows:

3.1 When the propagation conditions resulted in an FSK bit error-rate (BER) of about 10^{-4}, the spread spectrum modem improved the BER by a factor of 2.

3.2 When the propagation conditions resulted in an FSK BER of about 10^{-2}, the spread spectrum modem improved the BER by a factor of 10.

3.3 The errors using the spread spectrum system tended to be localized to time intervals associated with fading of the signal in the entire 3 kHz band and therefore appear in clusters. This would appear to favour ARQ type of error control for efficient channel utilization.

3.4 In tests in which multipath spread of 4 ms was encountered, the frequency offset tolerated by the system was about ± 100 Hz. In the absence of multipath, ± 250 Hz offset was tolerated without significant deterioration.

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DIXON, R. C. [1976] Spread Spectrum Systems. John Wiley & Sons, 7-9.

TURIN, G. L. [June,1960] An introduction to matched filters. *IRE Trans. Inf. Theory.*

3C c: Phototelegraphy (facsimile)

Recommendations and Reports

RECOMMENDATION 343-1

FACSIMILE TRANSMISSION OF METEOROLOGICAL CHARTS OVER RADIO CIRCUITS

(Question 1/3, Study Programme 1A/3)

(1956-1959-1963-1966)

The CCIR,

CONSIDERING

(a) that increasing use is being made of facsimile telegraphy for the transmission of meteorological charts for reception on direct-recording apparatus;

(b) that it is desirable to standardize certain characteristics of the radio circuits for this purpose,

UNANIMOUSLY RECOMMENDS

1. that, when frequency modulation of the sub-carrier is employed for the facsimile transmission of meteorological charts over radio circuits, the following characteristics should be used:

centre frequency	1900 Hz,
frequency corresponding to black	1500 Hz,
frequency corresponding to white	2300 Hz;

2. that, when direct frequency modulation is employed on radio circuits, the following characteristics should be used:

2.1 *HF (decametric) circuits*

centre frequency (corresponding to the assigned frequency)	f_0,
frequency corresponding to black	$f_0 - 400$ Hz,
frequency corresponding to white	$f_0 + 400$ Hz;

2.2 *LF (kilometric) circuits*

centre frequency (corresponding to the assigned frequency)	f_0,
frequency corresponding to black	$f_0 - 150$ Hz,
frequency corresponding to white	$f_0 + 150$ Hz.

RECOMMENDATION 344-2

STANDARDIZATION OF PHOTOTELEGRAPH SYSTEMS FOR USE ON COMBINED RADIO AND METALLIC CIRCUITS

(Question 1/3, Study Programme 1A/3)

(1948-1953-1956-1959-1963-1966-1970)

The CCIR,

CONSIDERING

(a) that to facilitate interworking, it is desirable to standardize the characteristics of systems employed for phototelegraph transmission over long-distance HF (decametric) circuits;

(b) that it is desirable to standardize certain characteristics of these systems in such a way as to make them equally suitable for transmission over metallic circuits;

(c) that the transmission system using direct amplitude modulation is generally unsatisfactory over HF (decametric) radio circuits, because of the intolerable fading ratio usually encountered;

(d) that the system of sub-carrier frequency modulation has proved satisfactory, but requires standardization in respect of the centre frequency and shift frequencies, taking into account the values of the picture-modulation frequencies to be transmitted;

(e) that, when a direct frequency-modulation system is employed, the terminal equipment normally used for a sub-carrier modulation system should be usable without serious modifications;

(f) that, taking into account the degree of distortion that is tolerable, the effect of multipath echoes on long-distance HF (decametric) radio circuits normally limits the maximum admissible picture-modulation frequency to approximately 600 Hz;

(g) that Recommendations M.880 (Fascicle IV.2), T.1, T.11, T.12, T.15 and T.20 (Fascicle VII.2) of the CCITT give standards for phototelegraph systems,

UNANIMOUSLY RECOMMENDS

1. that over the radio path:

1.1 the preferred method of transmission of half-tone pictures is by sub-carrier frequency modulation, of a single-sideband or independent-sideband emission with reduced carrier. The following characteristics should therefore be used:

centre frequency	1900 Hz,
frequency corresponding to white	1500 Hz,
frequency corresponding to black	2300 Hz;

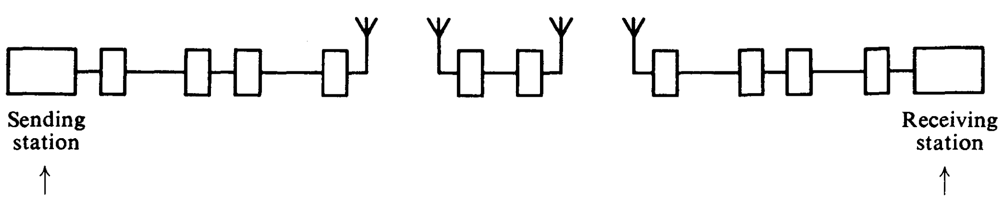
(The frequency 1500 Hz is also used for the phasing signal);

1.2 when a direct frequency-modulation system is employed, the following characteristics should be used:

centre frequency (corresponding to the assigned frequency)	f_0,
frequency corresponding to white	$f_0 - 400$ Hz,
frequency corresponding to black	$f_0 + 400$ Hz;

(The frequency $f_0 - 400$ Hz is also used for the phasing signal);

1.3 that the frequency tolerances on each of the various sections of a combined radio and metallic circuit should be no greater than those proposed by the CCITT (see [CCIR, 1963-66]) as shown in Fig. 1, which gives the composition of a very long circuit of this type:



Frequency tolerances (Hz) for short-term (1 s)

8 2 2 8 2 8 2 2

Frequency tolerances (Hz) for long-term (15 min)

16 2 2 16 2 16 2 2

FIGURE 1

If it is assumed that these deviations are distributed at random and if we take the standard deviation, we shall obtain the values 15 and 28 Hz respectively, which are not harmful for satisfactory reception, since CCITT Recommendation T.1 admits a maximum deviation of 32 Hz;

2. that, for the present, the following alternative characteristics should be used:

	a	*b*
index of cooperation	352	264
speed of rotation of drum in r.p.m.	60	90/45

(In due course, characteristic *b* will become obsolete);

3. that frequency modulation or amplitude modulation may be used in the metallic portions of the combined circuit. When conversion from amplitude modulation to frequency modulation (or vice versa) is required, the conversion should be such that the deviation of the frequency-modulated carrier varies linearly with the amplitude of the amplitude-modulated carrier.

The standards for both amplitude-modulated and frequency-modulated transmissions will be found in CCITT Recommendations T.1, T.11 and T.15.

Each Administration will decide, when the question arises, on the location of modulation converters. They may be placed either at the terminal phototelegraph station or at the control station associated with the radio station, to facilitate speech on the circuit used for phototelegraphy, if the radio channel will carry speech.

Note. – The provisions of § 2 do not imply the imposition of such standards on private users who use their own equipment for the transmission of pictures over private circuits.

REFERENCES

CCIR Documents

[1963-66]: III/3 (Annex V).

REPORT 201-2

REMOTE CONTROL SIGNALS FOR FACSIMILE TRANSMISSIONS

(Question 1/3)

(1963–1966–1970)

1. Introduction

With the rapidly increasing use of facsimile transmissions for various purposes, using continuous web (chart type) recorders, it has become desirable for the CCITT to set up standards for the remote control signals to be employed for the connection, starting, phasing, speed control, stopping, etc. of a facsimile transmission.

2. Remote control signals for the meteorological facsimile service

The World Meteorological Organization, in collaboration with the CCITT, has established a set of standards, including control signals for use over the leased weather network (see CCIR Recommendation 343).

3. Remote control signals for the subscribers' facsimile service

The CCITT proposals for the remote control of subscribers' apparatus for the transmission of business documents are given in CCITT Recommendation T.30 (Fascicle VII.2).

4. Conclusions

These documents make known to the CCIR proposals for the standardization of remote control signals. The CCIR will study them to determine whether these signals are acceptable and applicable on radio circuits.

REPORT 352

USE OF PRE-EMPHASIS AND DE-EMPHASIS FOR PHOTOTELEGRAPH TRANSMISSION OVER HF RADIO CIRCUITS

(Question 1/3, Study Programme 1A/3)

(1966)

1. Introduction

The relationship between the picture density and the degree of modulation at present used, concentrates the deterioration produced by noise at the darker end of the density range, whereas a linear relationship over the whole graduation range of picture density would distribute the effects of noise and so improve the picture quality. A further advantage would be to make the effect of frequency errors in transmission less noticeable.

To keep this relationship, a technique was introduced in [CCIR, 1963-66] which is described below.

2. Description of technique

The output of the photocell is proportional to the intensity of the reflected luminous flux, while the density of a picture is inversely proportional to the logarithm of the reflected flux.

The quality of the picture may be improved considerably when the signal is transmitted through a pre-emphasis network with a logarithmic characteristic, and received through a de-emphasis network with the inverse characteristic.

REFERENCES

CCIR Documents

[1963-66]: III/31 (Japan).

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QUESTIONS AND STUDY PROGRAMMES, RESOLUTIONS, OPINIONS AND DECISIONS

QUESTION 1/3

FACTORS AFFECTING THE QUALITY OF PERFORMANCE OF COMPLETE SYSTEMS OF THE FIXED SERVICE

(1948-1966)

The CCIR

UNANIMOUSLY DECIDES that the following question should be studied:

what are the technical factors affecting the quality of performance of complete systems of the fixed service?

Note. – See Reports 195, 197, 200, 327, 352, 355, 436, 550, 704, 855, 856, Recommendations 201, 203, 240, 338, 339, 343, 344, 345, 349, 454 and Decision 45.

STUDY PROGRAMME 1A-3/3

SIGNAL-TO-NOISE RATIOS AND PROTECTION RATIOS; BANDWIDTH, ADJACENT CHANNEL SPACING AND FREQUENCY STABILITY

(1959-1966-1970-1974-1982)

The CCIR,

CONSIDERING

(a) that the conditions for satisfactory performance of a system must take account of the need to receive signals propagated via the ionosphere, which are subject to fading and multipath effects and are accompanied by radio noise and interference;

(b) that studies requiring signal-to-noise ratios and protection ratios are closely related and that determination of necessary adjacent channel spacings requires, in addition, consideration of frequency stability and bandwidth of the systems;

(c) that there are a number of different techniques and systems in use in the radiotelegraph and radiotelephone services and, while it is essential to consider the most advanced state of the radio art, it is also necessary to give special study to conventional systems, either affecting integration of landline and radio services, or of concern to the IFRB;

(d) that the WARC-79, in its Recommendation No. 64, invites the CCIR to continue to study the protection ratios, the signal-to-noise ratios and the fading allowances and, in its Recommendation No. 60, urges the CCIR to expedite all phases of the programme of studies which will assist the IFRB in the further refinement of its Technical Standards,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. Classes of emission

The studies concern the following classes of emission in regular use in the fixed service but should also give due regard to new techniques and systems, including those under development, for application to the fixed service:

1.1 *Radiotelephony*

Classes of emission: A3E, R3E, B8E, J3E, H3E, F3E (above 30 MHz only, with reference to ionospheric-scatter applications).

1.2 *Radiotelegraphy*

1.2.1 Classes of emission: A1B, A2B, A7B, F1B, F7B.

1.2.2 Modulation rates:

- A1B, A2B, machine telegraphy: 50 and 120 bauds;
- A7B multi-channel VF telegraphy: 50 to 200 bauds per channel;
- F1B: 50 to 600 bauds.

1.2.3 Codes:

- 5-unit start-stop;
- synchronous error-detecting and correcting systems using two-condition signalling codes other than the International Telegraph Alphabet No. 2;
- other systems.

1.3 *Facsimile, phototelegraphy*

Classes of emission: R3C, F3C.

2. Minimum conditions required for satisfactory service

2.1 *Acceptable criteria and values for:*

2.1.1 intelligibility over radiotelephone circuits, for the various grades:

- just usable, operator-to-operator (order wire),
- marginally commercial,
- good commercial;

2.1.2 the quality of radiotelegraph circuits (telegraph distortion; character error rate; efficiency factor for ARQ circuits);

2.1.3 legibility of copy over facsimile (phototelegraphy) circuits;

- the maximum duration and percentage of the time during which performance inferior to the standard values can be tolerated.

2.2 *Performance of the system as a function of:*

2.2.1 signal-to-noise ratios and co-channel protection ratios;

2.2.2 required signal-to-noise ratios and co-channel protection ratios for the acceptable standard values of intelligibility, error rate (efficiency factor on ARQ circuits), or legibility for the various services * and of the frequency of operation; considering:

2.2.2.1 signal fading, taking account not only of the amplitude distribution, but also of the autocorrelation function and the distribution of duration of the fades;

2.2.2.2 diversity (space, frequency or time) techniques: noise reducers, coding including the use of error-correcting codes or ARQ, use of more than two signalling conditions and optimum modulation and detection techniques;

Note. – It would be useful to compare the systems using the various telegraph codes, including those of § 1.2.3, in terms of undetected or uncorrected error rate for a given power and signalling speed, in words per minute, and operating under the same conditions. A 5-unit start-stop system may be used as the reference system by regarding each mutilated character as an error only. It is provisionally suggested that the ratio of error rates should be expressed for two-circuit conditions only; namely, when the system under test is subjected to an average of one undetected or uncorrected error per 1000 characters, and per 10 000 characters.

2.2.2.3 multipath effects;

2.2.2.4 interference effects of the predominant sources of radio noise such as atmospheric, or man-made noise:

- as described by the waveform and amplitude distribution of the instantaneous values of the noise;
- the effects as actually received, taking account of the method of detection, and of filtering prior to and following detection;

2.2.2.5 interference effects of co-channel signals representing the various classes of emission, taking account of the spectral and statistical (fading) characteristics of the interfering signal;

* For radiotelephone services, the signal-to-noise ratio required in the audio band must be specified, and from this the signal-to-noise ratio required in the radio-frequency band is established.

2.2.2.6 monthly mean signal-to-noise ratios and co-channel protection ratios, required for circuits of various lengths and directions, to meet the acceptable standard values of circuit performance (§ 2.1) during the specified percentage of the time, taking into account:

- the distribution within an hour of the mean values of the short-term (fading) distributions of signals and noise;
- the distribution, within a month or season, for a given hour of the hourly mean values of the signal strengths and atmospheric noise levels (Report 322, published separately);

2.2.2.7 the total fading allowance derived from the day-to-day intensity fluctuations of signals and noise and short-term fading of signals.

Note. – The monthly mean values of atmospheric noise for various time blocks, and information on the distribution of values within the month, is given in Report 322; with regard to monthly mean values of signal strength, and distribution of hourly values within the month, Report 252-2 + supplement (published separately) gives a method for computation.

This study is intended to lead to revisions or replacement of Recommendations 240-2 (Kyoto, 1978) and 339-3 (Geneva, 1974).

2.3 Minimum bandwidth required for satisfactory transmission and reception of the intelligence in a complete system.

2.4 Overall frequency stability of a complete system, and the parts of a system, required for satisfactory transmission and reception of information, with particular reference to the performance criteria of frequency synthesizers.

3. Determination of adjacent channel protection ratios, and required frequency separations between various classes of emission, considering:

3.1 the use of effective receiving band-pass filters no wider than necessary for satisfactory reception (see § 2.3 above, and Recommendations 237 (New Delhi, 1970), 330 (Geneva, 1963) and 331);

3.2 the dynamic range of the receiver input circuits;

3.3 the bandwidth occupied by the interfering signal;

3.4 the spectral distribution of the interfering signal in relation to the receiver bandwidth;

3.5 the frequency tolerance and stability of the wanted and unwanted signals;

3.6 the studies of § 2.2 above relating to co-channel protection ratios.

Note 1. – The result of this study should be presented in the form indicated in the Table annexed to Recommendation 240.

Note 2. – See Reports 183, 195, 197, 200, 203, 352, 436, 550, 704, 856 and Recommendations 240, 338, 339, 343, 344, 345, 349 and Decision 45.

STUDY PROGRAMME 1B/3

USE OF PILOT CARRIER IN SINGLE- AND INDEPENDENT-SIDEBAND SYSTEMS

(1970)

The CCIR,

CONSIDERING

(a) that single-sideband and independent-sideband radio systems in the fixed service commonly use a reduced level pilot carrier for controlling the gain and frequency tracking of the receiver;

(b) that a pilot carrier level of −26 dB relative to peak envelope power has been widely used on independent-sideband radiotelephone systems;

(c) that the level of pilot carrier used by other types of system, such as radiotelephony using a frequency-modulated control channel and frequency-division multiplex telegraph systems, is governed by different considerations from those applying to conventional radiotelephony;

(d) that advances in technique in the design of transmitters and receivers, including the application of automatic methods of operation, render a reappraisal of current practice desirable;

(e) that in the interest of operational simplicity a standard level of pilot carrier common to all types of system may prove desirable;

(f) that improvements in the frequency stability of carrier generating sources make it possible to consider dispensing with the frequency control functions of the pilot carrier in certain cases;

(g) that the general aim is to ensure that circuit failure due to contamination of the pilot carrier channel by noise at the receiver does not occur whilst the signal in the communication channel is otherwise commercial,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the levels of the pilot carrier for the various systems which will lead to the most efficient communication, bearing in mind the current state of development in transmitting and receiving equipment;

2. consideration of the advantages which would result from the use of a standard level for all systems using a pilot carrier;

3. determination in what cases and under what circumstances a pilot carrier could be dispensed with.

Note. – See Recommendation 454.

STUDY PROGRAMME 1C/3

EFFICIENCY FACTOR AND TELEGRAPH DISTORTION ON ARQ CIRCUITS

(1970)

The CCIR,

CONSIDERING

(a) that the efficiency factor as defined in the "List of Definitions of Essential Telecommunication Terms" (Part I, 1961, No. 33.23; see also Recommendation 345) is very useful for defining and determining the quality of a communication circuit using error correction by automatic repetition;

(b) that the value of the efficiency factor of an ARQ circuit depends on the telegraph distortion in both directions of the radio circuit;

(c) that a continuous measurement of the efficiency factor is required by the CCITT for radiotelegraph circuits incorporating ARQ equipment, and operating in the fully automatic telex network (see Recommendation U.23, CCITT, Fascicle VII.1),

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the way in which measurements of the efficiency factor may be used to analyse and predict the performance of systems with error correction by automatic repetition, especially at the commencement and finish of the operating period using one frequency;

2. the way in which the efficiency factor depends on the telegraph distortion measured at the incoming end (receiver) of the ARQ terminals at either end.

Note 1. – Measurements should preferably be carried out in successive periods of 20 seconds for detailed analysis and over a number of such periods for long-period evaluation.

Note 2. – Attention is especially drawn to § 9 of Recommendation U.23 of the CCITT with regard to the monitoring of ARQ circuits, which reads:

"9. *Precautions to be taken before incorporating circuits with ARQ equipment in automatic switching networks*

In spite of these precautions, fully-automatic operation on a radiotelegraph circuit incorporating ARQ equipment can be considered only if this circuit possesses adequate stability.

Before incorporating a circuit with ARQ equipment in the fully-automatic switching network, the Administrations must carry out extended trials. These trials should be made under normal traffic conditions, over a minimum period of three consecutive hours chosen from the busy period (or periods), when heavy traffic is foreseen to occur on the route under consideration (allowing for the traffic, whether terminal or transit, that prevails on the route according to the season). The condition that must be fulfilled before a circuit can be accepted for use in the fully-automatic network is that its mean efficiency factor, measured over periods of 20 consecutive seconds each, shall not fall below 80% for more than 10% of the total time involved in the measurements. The measurements must be repeated as often as will be necessary for the Administration to have an assessment of the suitability of the circuit.

The attention of Administrations is drawn to the fact that, before offering fully-automatic transit working on a radio route incorporating ARQ equipment, the grade of service on the route under consideration must be in accordance with that proposed in Recommendation F.68, [2], i.e. only one call lost in 50.

If these conditions are not complied with, it would be better to retain semi-automatic operation.

Reference

[2] CCITT Recommendation *Establishment of the automatic intercontinental telex network*, Vol. II, Fascicle II.4, Rec. F.68."

Note 3. – See Report 437.

QUESTION 2-2/3

ARRANGEMENT OF CHANNELS IN MULTI-CHANNEL SYSTEMS FOR LONG-RANGE RADIO CIRCUITS

(1953–1978–1982)

The CCIR,

CONSIDERING

(a) that there is a need to define the arrangement and designation of the channels in multi-channel systems, for long-range radio circuits operating at frequencies below about 30 MHz;

(b) that many such systems are in use,

UNANIMOUSLY DECIDES that the following question should be studied:

what is the best way of arranging and designating telephone channels with respect to the carrier frequency and telegraph channels within telephone channels in multi-channel systems for long-range radio circuits, operating at frequencies below about 30 MHz?

Note. – See Report 863 and Recommendations 347, 348 and 436.

QUESTION 3/3

DIRECTIVITY OF ANTENNAS AT GREAT DISTANCES

(1948–1951–1953)

The CCIR

UNANIMOUSLY DECIDES that the following question should be studied:

what are the experimental studies, by Administrations and various organizations, of the directivity of antennas realized at great distances (taking full advantage of existing transmissions), by any suitable method, for example, by use of mechanically or electrically steered antennas?

Note. – See Reports 106 and 107.

STUDY PROGRAMME 3A-3/3 *

IMPROVEMENT OBTAINABLE FROM THE USE OF DIRECTIONAL ANTENNAS

(1953-1956-1959-1970-1974-1978)

The CCIR,

CONSIDERING

(a) that Study Programme 1A/3 requires knowledge of the improvement in the signal-to-interference ratio that can be obtained by the use of directional antennas on long-distance circuits;

(b) that the performance of a system under fading conditions may also be improved by the use of appropriate directional antennas;

(c) that it is important to know the discrimination given by directional antennas for various ranges and directions of both the wanted and the interfering stations;

(d) that it appears practicable to obtain some reduction of interference by using a null method at the receiver;

(e) that it is important to know the antenna directivity under various environmental conditions such as ice and snow,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the signal power gain in the main lobe provided by practical directional antennas used under actual propagation conditions, relative to a half-wave horizontal dipole at the height of the centre of the directional antenna (the median values of the gain can also be expressed relative to the isotropic antenna); the median value and cumulative distribution with time of the values of gain during short periods (as, for example, less than an hour), should be observed; observing periods should be suitably distributed and the data studied on a statistical basis, so as to show dependence of results on time of day and season for normal propagation conditions, and the effect of especially critical propagation conditions such as encountered near time of sunrise and sunset, and at times of failure of the operating frequency near the MUF, and at times of ionospheric disturbances;

2. determination of the signal power gain in directions outside the main lobe and/or values of discrimination provided by the antenna between the wanted and interfering signals. The data should include the variations with time, referred to in § 1, and should specify the directions of the wanted and interfering signals;

3. the effect of the antenna directivity pattern (antenna diagram) in reducing multipath distortion;

4. the effects of the antenna height in increasing the number of hours of useful transmission and in the reduction of interference;

5. the usefulness of a null method of minimizing the interference. The data required to evaluate the usefulness might consist of:

5.1 logs of commercial receiving stations, showing outages due solely to interference and the relative azimuth bearing of interfering stations,

5.2 experimental data on the use of directional antenna systems and antennas with adjustable directions of null, under conditions where interference is experienced;

6. the effects of the environmental conditions such as ice and snow on the directivity of the antenna.

Note. – See Report 106.

* This Study Programme and the texts related to it in this Volume have been brought to the attention of Study Group 6.

STUDY PROGRAMME 3B/3

DIRECTIVITY OF ANTENNAS FOR THE FIXED SERVICE USING IONOSPHERIC-SCATTER PROPAGATION

(1959)

The CCIR,

CONSIDERING

(a) that systems are at present in service using ionospheric-scatter propagation, at frequencies above 30 MHz and that extension of use of this mode of propagation may be expected in the international fixed service;

(b) that it is desirable to establish the preferred characteristics of such systems needed to facilitate their international connection, and that it is particularly important to have similar or matched directivity of the antennas at opposite terminals of the circuit;

(c) that antenna directivity, including the characteristics of radiation pattern, gain, beamwidth and direction of the main lobe or lobes, significantly affects transmission loss and the possibility of occurrence of multipath propagation and interference to and from other services,

UNANIMOUSLY DECIDES that the following studies should be carried out:

studies of the desirable characteristics of the directivity of transmitting and receiving antennas for the international fixed service, using ionospheric-scatter propagation above 30 MHz, including gain, beamwidth and direction of the main lobe or lobes, and tolerances for the radiation pattern outside the main lobe, taking into account:

- dependence on propagation characteristics of the scattering medium, including dependence on scattering angle, size and inhomogeneity of the scattering region;
- effects of meteoric ionization, and the techniques of beam slewing and beam splitting, and how these may depend on season and time of day;
- operating frequency;
- diversity;
- polarization;
- multipath propagation, in relation to the modulation technique used;
- interference to and from other services.

Note. – See Report 107.

QUESTION 4/3

RADIO SYSTEMS EMPLOYING IONOSPHERIC-SCATTER PROPAGATION

(1956)

The CCIR,

CONSIDERING

(a) that experiments have already shown the possibility of utilizing frequencies above 27.5 MHz for transmission by ionospheric-scatter propagation to distances well beyond the horizon;

(b) that systems using this mode of propagation are already in service;

(c) that it is desirable to determine the preferred characteristics of such systems needed to facilitate their international connection;

(d) that the frequency bands, which might be used for such systems, are already intensively used by other services,

UNANIMOUSLY DECIDES that the following question should be studied:

1. how do the propagation characteristics, relevant to the exploitation of systems employing ionospheric-scatter propagation, vary with frequency;

2. to what extent are systems employing this mode of propagation liable to interfere with each other and with other services operating on the same or neighbouring frequencies;

3. what are the radio-frequency and baseband characteristics of such systems, which it is essential to specify for the transmission of telephony or telegraphy to enable two systems to be interconnected, and what values should be specified?

Note. – See Report 109.

QUESTION 7-1/3 *

INFLUENCE OF FREQUENCY DEVIATIONS ASSOCIATED WITH PASSAGE THROUGH THE IONOSPHERE ON HF RADIOCOMMUNICATIONS

(1956-1959-1966-1978)

The CCIR,

CONSIDERING

(a) that Recommendation 246 (§ 3) recommends that, for frequency-shift systems working on two conditions only and operating between 3 and 30 MHz, the values of frequency-shift should be 200, 400, and for modulation rates above 250 bauds, 500 Hz;

(b) that preferred values for the channel spacing and frequency-shifts of multi-channel voice-frequency telegraph systems for use on HF radio circuits are given in Recommendation 436;

(c) that study of frequency deviations, associated with passage through the ionosphere, has shown that the resultant frequency variations may reach values of a few hertz while instantaneous deviations may reach much higher values (see Report 111 and Annex I to Recommendation 349),

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the statistical distributions of frequency deviation associated with passage through the ionosphere in magnitude, duration and frequency of occurrence;

2. what minimum value of frequency-shift is required for frequency-shift systems operating by HF ionospheric propagation, to take into account:

- the frequency stability of the equipment (see Recommendation 349);
- the frequency deviations referred to in § 1?

Note. – See Report 111.

QUESTION 8/3

FREQUENCY-SHIFT KEYING

(1948-1959)

The CCIR,

CONSIDERING

(a) that frequency-shift keying is employed in radiotelegraphy for the fixed services and it has also been extended to the mobile services;

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* This Question and the texts related to it in this Volume have been brought to the attention of Study Group 6.

(b) that it is desirable to standardize the main operating characteristics of systems employing frequency-shift keying;

(c) that various technical factors influence the choice of operating characteristics in such systems, in particular:

c.a the overlap of marking and spacing signals due to multipath propagation (in this respect a small shift is preferable);

c.b the possible advantage of frequency diversity for reception (an advantage which increases with shift);

c.c economy of bandwidth and the consequent necessity for controlling the shape of the transmitted signals;

c.d instability of frequency, which is one reason for the relatively large shift employed in many existing equipments;

c.e the choice of receiving systems, whether with separate filters or with frequency discriminator,

UNANIMOUSLY DECIDES that the following question should be studied:

1. fixation of one or more standard values of shift for fixed and mobile services in the various frequency bands, having regard to the various factors, in particular:

- the frequency spectrum resulting from the keying operation;
- the degree of frequency diversity desired;
- economy of bandwidth;
- instability of frequencies;

2. compilation of a standard terminology regarding the characteristics of systems employing frequency-shift keying.

Note. – See Recommendations 246 and 346.

QUESTION 12-1/3

CHARACTERISTICS REQUIRED FOR SINGLE-SIDEBAND AND INDEPENDENT-SIDEBAND SYSTEMS USED FOR HIGH-SPEED DATA TRANSMISSION OVER HF RADIO CIRCUITS

(1966–1978)

The CCIR,

CONSIDERING

(a) that an increasing demand is noted for high-speed data transmission over HF radio circuits and further increase in such demand may be expected;

(b) that recent developments are leading to systems having greatly improved bandwidth efficiency, i.e. a larger capacity in bits per second per unit bandwidth;

(c) that it is desirable that the effects of the random variations and disturbances in the propagation medium be the ultimate factors governing the performance obtainable with such systems;

(d) that the characteristics of a "3 kHz channel" have largely been evolved from the use of such a channel for telephony,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the permissible limits of amplitude, phase and delay distortion on HF radio circuits intended for high-speed data transmission (e.g. 2400 bit/s and above), excluding *a priori* effects due to the radio propagation medium;

2. are these limits likely to be exceeded in HF systems of the fixed service currently available;

3. what is the possibility of using for data transmission two telephone channel bandwidths, namely 250 to 3000 Hz (Recommendation 348) and 300 to 3400 Hz (CCITT), and how should they be arranged with respect to the carrier;

4. in evaluating high-speed data transmission systems, what statistical parameters should be used to describe the radio propagation medium and what values should be considered?

Note. – See Reports 703, 864 and Recommendation 456.

QUESTION 13-2/3

IMPROVEMENTS IN THE PERFORMANCE AND EFFICIENCY OF HF RADIOTELEPHONE CIRCUITS

(1966–1974–1982)

The CCIR,

CONSIDERING

(a) that there is a need to improve the quality of transmission of HF radiotelephone circuits;

(b) that the use of diversity techniques may offer the prospect of such improvements;

(c) that other methods of improvement, for example, the adaptation of compandor principles, might become available;

(d) that the efficiency of HF radiotelephone circuits can be enhanced by converting from manual to semi-automatic operation;

(e) that these techniques might be used either separately or in combination;

(f) that Recommendation No. 65 of WARC-79 invites studies of new and developing techniques which are making practicable improved spectrum sharing and band utilization schemes,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the various methods whereby diversity can be obtained on HF radiotelephone circuits;

2. what other methods including new developments, are available for obtaining such improvements;

3. what devices are most suitable for semi-automatic operation on HF radiotelephone circuits;

4. what improvement in performance and efficiency can be expected with these methods?

Note. – See Reports 354, 355, 434, 701 and 862 and Recommendations 335, 336, 455 and 480.

QUESTION 14/3

AUTOMATICALLY CONTROLLED RADIO SYSTEMS IN THE HF FIXED SERVICE

(1966)

The CCIR,

CONSIDERING

(a) that successful development of fully automatic transmitting and receiving terminals may offer important improvements in efficiency, reliability and economy of operation in the fixed service;

(b) that certain features of automatic control may require cooperation and exchange of information between transmitters and receivers as, for example, for change of frequency and power,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what features of automatically controlled radio systems in the HF fixed service require cooperation between Administrations;

2. what are the preferred methods of exchanging and utilizing such information?

Note. – See Report 551.

STUDY PROGRAMME 17A-2/3 *

VOICE-FREQUENCY TELEGRAPHY ON RADIO CIRCUITS

(1951-1953-1959-1966-1970-1982)

The CCIR,

CONSIDERING

(a) that different methods are now in use for voice-frequency telegraphy on radio circuits operating below 30 MHz subject to fading, noise and interference:

– either using equipment normally designed for landline working and suitably adapted for radio;
– or using equipment especially designed for radio working;

(b) that studies carried out so far show that it is impossible to compare transmission systems in which the two significant conditions of modulation are obtained either by the frequency exchange method or by the method of frequency-shift of a single voice-frequency oscillator, without taking into account all the properties of the equipment and of the propagation medium;

(c) that experience in reception of voice-frequency telegraphy over radio circuits has shown that frequency-modulated voice-frequency telegraph equipment for use on radio circuits may differ substantially from voice-frequency landline equipment; this equipment may, therefore, have to be designed and constructed with their special purpose in mind,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. comparisons of the different systems used to transmit and receive voice-frequency telegraphy on radio circuits subject to the effects of fading, multipath propagation, noise and interference, with a view to standardizing their characteristics, taking into account the following techniques and factors;

– frequency-shift keying of one voice-frequency oscillator,
– transmitting the two significant conditions of modulation by the two-tone method,
– other modulation systems, e.g., phase-modulation systems, or systems of modulation employing more than two significant conditions of modulation,
– reception by discriminator or separate filters,
– synchronous operation,
– signal regeneration,
– use of relay points for long range circuits;

2. influence of the modulation index (frequency-shift (hertz)/modulation rate (bauds)), the channel spacing and the parameters of the regenerators on the error rate.

Note. – See Reports 19, 345, 347 and Recommendations 106, 436.

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* This Study Programme does not derive from any Question under study.

STUDY PROGRAMME 20A/3 *

OPERATIONAL IONOSPHERIC SOUNDING AT OBLIQUE INCIDENCE

(1965-1966)

The CCIR,

CONSIDERING

(a) that sounding of the ionosphere at oblique incidence has proved to be an effective method for observing the behaviour of HF radio waves propagated via the ionosphere;

(b) that the information obtained from oblique incidence sounding may be used to improve the performance of some long-distance radio circuits;

(c) that such sounding carried out as an operational procedure may give rise to harmful interference, particularly if used indiscriminately;

(d) that with increasing use difficulty may be experienced in identifying emissions from particular sounders,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the methods by which the information obtained from sounding of the ionosphere at oblique incidence (see Study Progamme 27B/6) could be used to improve the operational efficiency of long-distance radio circuits;

2. the limitations, if any, in such characteristics as emitted power and number of simultaneous emissions that are desirable to avoid harmful interference;

3. the measures necessary to enable such emissions to be identified;

4. the preferred characteristics of the equipment used for operational ionospheric sounding that will promote effective cooperation between the greatest number of users.

Note. – See Report 357.

QUESTION 21/3

HF IONOSPHERIC CHANNEL SIMULATORS **

(1970)

The CCIR,

CONSIDERING

(a) that on circuits operating in band 7 (HF), the distortion caused by multipath effects, manifested by selective fading and time-variant frequency spread and delay distortion, degrades the quality of the received signals;

(b) that the type of multipath effect encountered differs appreciably depending on the length of the radio circuit, its global routing and the frequency used for transmission, and thus gives rise to a wide range of distortion and fading patterns;

(c) that for a particular system of transmission, the performance of a radio circuit may differ appreciably with differing types of distortion and fading;

(d) that fading simulators or ionospheric channel simulators have been constructed by various laboratories and are useful instruments to study system performance;

(e) that it is essential for the time-variant distortion and fading patterns generated in the simulator to be representative for the patterns actually encountered on such radio paths;

* This Study Programme does not derive from any Question under study.

** This Question has been brought to the attention of Study Group 6.

(f) that it is desirable for such a simulator to take account of atmospheric and man-made noise characteristics, and to facilitate study of interference between signals,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what patterns of fading, time-variant frequency spread and delay distortion should be considered as giving markedly differing types of circuit performance;

2. how should these patterns, and the parameters of a model of HF ionospheric transmission, be specified so as to assure fully representative laboratory simulation of various transmission conditions in band 7;

3. how should atmospheric and man-made noise be represented, and how can a simulator be used to study interference between signals?

Note. – See Report 549 and Recommendation 520.

QUESTION 22/3 *

TRANSPORTABLE FIXED SERVICE RADIOCOMMUNICATION EQUIPMENT FOR RELIEF OPERATIONS

(1972)

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 WARC-79 has adopted Recommendation No. 1,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics and frequency bands for transportable fixed service equipment, operating at frequencies below approximately 30 MHz, for the provision of relief telecommunications when:

– the equipment is used in liaison with a transportable earth station;
– only terrestrial relief telecommunication facilities are involved?

QUESTION 23/3 **

USE OF COMMON-FREQUENCY SYSTEMS ON RADIOTELEPHONE CIRCUITS

(1963-1966-1970-1974)

The CCIR,

CONSIDERING

(a) that relief of the present congestion of the HF (decametric) band is a matter of urgency;

(b) that, in certain cases, the use of the same carrier frequency in both directions of a radiotelephone circuit (in combination with techniques that prevent simultaneous transmission in both directions) may result in important economies in spectrum utilization on a radiotelephone circuit,

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* See also Questions 22/4, 22/8 and 20/9.

** This Question replaces Question 19/1 (New Delhi, 1970) and is identical with that text.

UNANIMOUSLY DECIDES that the following question should be studied:

1. in which cases does the use of the same frequency in both directions of transmission result in more effective sharing of frequencies;

2. in such cases:

2.1 what are the characteristics to be specified for radiotelephone systems using the principles of common-frequency operation;

2.2 what should be the minimum difference in level at the input to the receiver, between the received signal from the distant station and signals from the nearby transmitting station, to avoid interference between the wanted signal and that from the nearby transmitter operating on the same frequency;

2.3 to what extent will the use of transmitting and receiving antennas with different transmission characteristics reduce the possibilities of application of this technique;

2.4 to what extent will the possibilities of application of this technique be reduced by the presence of different noise levels at the receiving locations;

2.5 what other factors should be taken into account when planning such systems, for example:

- non-linearities in the transmitting and receiving equipment,
- carrier-filter bandwidth,
- frequency stability of the equipment?

Note. – See Report 353.

QUESTION 24-2/3 *

REMOTELY CONTROLLED HF RECEIVING AND TRANSMITTING STATIONS

(1974–1978–1982)

The CCIR,

CONSIDERING

(a) that HF receiving stations should be sited in locations practically free of man-made noise;

(b) that there exists a general trend to encourage automation and so to reduce the technical personnel required;

(c) that reduction of the interference level and introduction of automation could result in a better operation of the receiving stations and so could improve the quality and reliability of HF communications;

(d) that several Administrations are studying the problems involved in applying remote control to HF receiving and transmitting stations and are encountering certain difficulties,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the problems raised by the remote control of HF receiving and transmitting stations;

2. what are the special characteristics of HF receivers and transmitters designed to be installed in remote-controlled stations;

3. what are the required characteristics of the controlling system, taking into account reliability of control and economy of circuits and equipment?

Note. – See Reports 329, 705, 857 and 858.

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* This Question replaces Question 12/1 (New Delhi, 1970) and Question 24/8 (Geneva, 1974).

QUESTION 25/3 *

AUTOMATIC CONTROL OF THE OUTPUT POWER OF HF TRANSMITTERS IN THE FIXED SERVICE

(1974)

The CCIR,

CONSIDERING

(a) Recommendation 38 of the "ITU Panel of Experts" in its Final Report, Geneva, 1963;

(b) that No. 1804 of the Radio Regulations requires that all stations shall radiate only as much power as is necessary to ensure a satisfactory service;

(c) that nevertheless, for a considerable part of the time, stations using frequencies in the bands between 4 and 27.5 MHz radiate powers considerably in excess of those necessary to ensure a satisfactory service;

(d) that manually operated methods of adjusting the power of transmitters are not fully adequate to meet No. 1804 of the Radio Regulations;

(e) that the use of automatic control of the output power of transmitters would assist in reducing the congestion in the HF spectrum,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the most suitable methods for automatically controlling the output power of radio transmitters of the HF fixed service to ensure, as far as practicable, that the radiated power is no greater than is necessary to ensure a satisfactory service, taking into account the distances of reception points and the existing conditions of propagation?

QUESTION 26-1/3

IMPROVEMENTS IN THE PERFORMANCE OF HF RADIOTELEGRAPH CIRCUITS

(1976-1978)

The CCIR,

CONSIDERING

(a) that several systems for the transmission of telegraph and data signals over HF radio circuits have been devised;

(b) that further improvements in these systems could benefit spectrum utilization and/or reduce error rates;

(c) that the use of digital techniques for data and speech transmission is increasing,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what improvements can be made to HF radiotelegraph systems;

2. what new techniques could be employed which offer advantages over existing techniques?

Note. – See Reports 349, 435, 702, 865 and Recommendations 342, 518, 519.

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* This Question, together with Question 25/8 (Geneva, 1974), replaces Question 21/1 (New Delhi, 1970).

QUESTION 27/3 *

COMPRESSION OF THE RADIOTELEPHONE SIGNAL SPECTRUM IN THE HF BANDS

(1961)

THE INTERNATIONAL FREQUENCY REGISTRATION BOARD,

IN VIEW OF

the request of the PANEL OF EXPERTS in Section II of Part D of its Interim Report, after considering:

(a) the congestion in the bands between 4 and 27.5 MHz;

(b) the need to adopt new methods for the solution of the frequency problems with which Administrations are confronted in the use of those bands;

(c) the work accomplished in the field of communication theory;

(d) the need to know what practical experience has been acquired in the matter of compressing the spectrum occupied by HF radiotelephone signals for the Panel's second session;

AND IN VIEW OF

No. 308 of the International Telecommunication Convention, Málaga-Torremolinos, 1973,

DECIDES to submit the following urgent question to the CCIR:

1. what, in practice, can be done to reduce the spectrum space occupied by HF radiotelephone signals;

2. what experience has been acquired in so doing; for example, what degradation of intelligibility or ability to converse accompanies the use of spectrum-reducing techniques?

Note. – See Reports 176 and 862.

QUESTION 28/3 **

COMPRESSION OF THE RADIOTELEGRAPH SIGNAL SPECTRUM IN THE HF BANDS

(1961)

THE INTERNATIONAL FREQUENCY REGISTRATION BOARD,

IN VIEW OF

the request of the PANEL OF EXPERTS in Section II of Part D of its Interim Report, after considering;

(a) the congestion in the bands between 4 and 27.5 MHz;

(b) the need to adopt new methods for the solution of the frequency problems with which Administrations are confronted in the use of those bands;

(c) the work accomplished in the field of communication theory;

(d) the need to know what practical experience has been acquired in the matter of compressing the time-bandwidth product of HF radiotelegraph (or other digital) signals for the Panel's second session;

AND IN VIEW OF

No. 308 of the International Telecommunication Convention, Málaga-Torremolinos, 1973,

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* This Question replaces Question 2/1 (1961) and is identical with that text. Transferred from Study Group 1 to Study Group 3 during the XIVth Plenary Assembly, Kyoto, 1978.

** This Question replaces Question 3/1 (1961) and is identical with that text. Transferred from Study Group 1 to Study Group 3 during the XIVth Plenary Assembly, Kyoto, 1978.

DECIDES to submit the following urgent question to the CCIR:

what are the advantages, limitations and practical experience with:

1. phase-change signalling systems;

2. digital signalling systems which employ three or more states of amplitude, frequency-shift or phase change;

3. coding techniques which provide either message compression or error reduction, or both?

Note. – See Report 177.

QUESTION 29/3 *

USE OF DIRECTIONAL ANTENNAS IN THE BANDS 4 TO 27.5 MHz

Limitation of radiation outside the direction necessary for the service

(1963-1970)

THE INTERNATIONAL FREQUENCY REGISTRATION BOARD,

IN VIEW OF

the request of the PANEL OF EXPERTS in Recommendation No. 38 of its Final Report, Geneva, 1963,

CONSIDERING

(a) that there is serious congestion in the frequency bands between 4 and 27.5 MHz;

(b) that there is a need to adopt methods and regulations for the solution of the frequency problems with which Administrations are confronted in the use of these bands;

(c) that occupation of the radio-frequency spectrum is represented, not only in time and bandwidth, but also in the spatial distribution of the radiated power;

(d) that this latter distribution can be effectively controlled by the use of directional antennas;

(e) that the intent of Articles 5 and 18 of the Radio Regulations, would seem to justify further explicit requirements for the use of directional antennas in the bands between 4 and 27.5 MHz, as well as for quantitative limitation of the intensity of radiation in directions other than that required for the service;

AND IN VIEW OF

No. 308 of the International Telecommunication Convention, Málaga-Torremolinos, 1973,

DECIDES to submit the following urgent question to the CCIR:

what are reasonable standards for the directivity of antennas in the various types of radio services, and for various distances, in the bands between 4 and 27.5 MHz, including the width of the main beam and the allowable intensity of radiation (effective radiated power) in directions of azimuth outside the main beam (such standards should reflect due regard for practical considerations of construction and cost)?

Note. – See Report 356 and Recommendation 162.

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* This Question replaces Question 20/1 (New Delhi, 1970) and is identical with the text. Transferred from Study Group 1 to Study Group 3 during the XIVth Plenary Assembly, Kyoto, 1978.

QUESTION 30/3

FREQUENCY TOLERANCE OF TRANSMITTERS FOR THE FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz

(1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 69 of WARC-79;

(b) that Appendix 7 to the Radio Regulations specifies the frequency tolerances for transmitters;

(c) that the principal objective of Appendix 7 has been the reduction of frequency space required per channel by means of the tightening of frequency tolerances;

(d) that it will be of considerable assistance to Administrations, in the future planning of services and provision of equipment, to know those frequency tolerances which can be considered to be the ultimate useful minimum value for stations when using existing techniques and methods of operation;

(e) that Recommendations from CCIR on the matter of frequency tolerances may be of assistance to future Administrative Radio Conferences,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the desirable frequency tolerances of transmitters with a view to the reduction of the amount of spectrum required for the fixed service below 30 MHz;

2. where it would not be necessary to make these tolerances more stringent under currently known conditions of operation, whether or not in certain cases it is possible to predict ultimate values of tolerances, and to recommend what these tolerance values might be;

3. which, if any, of the tolerances specified in Appendix 7 have already attained these ultimate values?

Note. – See Report 181.

QUESTION 31/3

PROTECTION OF RADIO STATIONS AGAINST LIGHTNING AND OTHER ELECTROMAGNETIC DISTURBANCES

(1982)

The CCIR,

CONSIDERING

(a) that the WARC-79, in Resolution No. 64, invited the CCIR, in consultation with the CCITT, to provide Recommendations related to the protection of telecommunications equipment from lightning discharges;

(b) that there are areas in the world where, although protective devices against lightning have been installed, equipments constantly deteriorate, often very seriously, following discharges produced during electrical or violent storms;

(c) that radio transmitting and receiving stations may have large antennas often covering large areas and are therefore particularly susceptible to lightning damages;

(d) that modern radiocommunication systems, especially unattended radio stations requiring high reliability, are becoming increasingly more vulnerable than conventional stations;

(e) that other electromagnetic disturbances, e.g. auroral effects, may also result in deterioration of performances of all equipments,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the mechanisms by which lightning generated fields introduce destructive energy into radiocommunication equipments;

2. what protective techniques and devices are necessary for the efficient and economic use of radiocommunication equipments;

3. what measures are necessary for the protection of equipments against other electromagnetic disturbances such as auroral effects?

Note 1. – The attention of Administrations is drawn to the CCITT publication "The protection of telecommunication lines and equipment against lightning discharges", which contains much valuable and relevant information on this subject.

Administrations are also encouraged to keep themselves informed of the ongoing work of CCITT Study Group V relevant to this matter.

Note 2. – The attention of Study Group 1 is directed to the need to also study the levels and other characteristics of the near electric and magnetic fields produced by electromagnetic disturbances other than lightning, such as auroral effects.

Note 3. – See Report 861.

QUESTION 32/3 *

FREQUENCY SHARING WITH OTHER SERVICES BELOW 30 MHz

(1982)

The CCIR,

CONSIDERING

(a) Recommendations Nos. 301 and 504 of the WARC-79;

(b) that preliminary theoretical studies have indicated that satisfactory sharing would be predictable with high confidence under certain circumstances;

(c) that practical experience has shown the difficulties of achieving frequency sharing in a way satisfactory to both parties due to there being a wide disparity in required field strengths, protection ratios and operating procedures,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the diverse factors to be taken into account when sharing between the fixed service and other services at frequencies below about 30 MHz is studied;

2. what are the constraints which need to be applied to ensure that sharing between the fixed service and other services at frequencies below about 30 MHz will be satisfactory to the sharing parties?

Note. – See Report 859 and Opinion 66.

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* The Director, CCIR, is requested to bring this Question to the attention of the IFRB and Study Groups 1, 8 and 10.

QUESTION 33/3

CRITERIA TO BE USED IN DIFFERENTIATING BETWEEN CLASSES OF OPERATION

(1982)

The CCIR,

CONSIDERING

(a) Recommendations Nos. 60 and 64 of the WARC-79;

(b) that the WARC-79 has recognized the need to identify the class of operation of the fixed service assignments as follows (see Resolution No. 9 of the WARC-79):

Symbol A – assignment for regular operational use which is not provided by another satisfactory means of telecommunication,

Symbol B – assignment for use as a stand-by to some other means of telecommunication,

Symbol C – assignment for occasional use on a reserve basis and not requiring internationally recognized protection from harmful interference;

(c) that for the conduct of technical examination of such frequency assignments, the WARC-79 has decided that (see Article 12 of the Radio Regulations):

- the IFRB shall apply protection criteria for class of operation A higher than for class of operation B,
- the IFRB shall disregard the probability of interference to frequency assignments of class of operation C, and
- the different protection criteria to be applied by the IFRB for classes of operation A and B shall be published in the Technical Standards of the IFRB,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the protection ratios and other technical parameters that are required for classes of operation A and B?

Note. – See Report 860.

OPINION 66 *

FREQUENCY SHARING BETWEEN SERVICES BELOW 30 MHz

(Question 32/3)

(1982)

The CCIR,

CONSIDERING

(a) Recommendations Nos. 301 and 504 of the WARC-79;

(b) that preliminary theoretical studies have indicated that satisfactory sharing would be predictable with high confidence under certain circumstances;

(c) that practical experience has shown the difficulties of achieving frequency sharing in a way satisfactory to both parties due to there being a wide disparity in required field strengths, protection ratios and operating procedures,

IS UNANIMOUSLY OF THE OPINION

1. that, for the time being, sharing between services below 30 MHz requires consideration on a case by case basis;

2. that quantification of the constraints which need to be applied to ensure a satisfactory outcome requires further studies embracing all the many and diverse factors involved.

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* The Director, CCIR, is requested to bring this Opinion to the attention of the IFRB and Study Groups 1, 8 and 10.

DECISION 45

REQUIRED SIGNAL-TO-NOISE RATIOS AND PROTECTION RATIOS IN THE FIXED SERVICE IN THE BANDS BETWEEN 3000 kHz AND 27 000 kHz

(Question 1/3, Study Programme 1A/3)

(1980)

CCIR Study Group 3,

CONSIDERING

(a) that the World Aministrative Radio Conference, Geneva, 1979 (WARC-79) adopted Recommendations Nos. 60 and 64;

(b) that Recommendation No. 60 urges the CCIR to expedite all phases of the programme of studies which will assist the IFRB in the further refinement of its Technical Standards;

(c) that Recommendation No. 64 invites the CCIR to continue to study for the various services:

- the protection ratios which define the threshold of harmful interference,
- the signal-to-noise ratios and the minimum field strengths required for satisfactory reception of the different classes of emission, and
- the fading allowances;

(d) the modification to the Table of Frequency Allocations and other decisions relating to the fixed service in frequency bands below 27 500 kHz adopted by WARC-79;

(e) that the IFRB has particularly requested the CCIR to consider signal-to-noise and signal-to-interference protection ratios for stable conditions and the fading allowances applicable to the various types of service,

DECIDES

1. that an Interim Working Party 3/1 be established with the following terms of reference:

to complete, and revise if necessary, as a matter of urgency and to the greatest extent practicable, the Tables in Recommendation 240-2 (Kyoto, 1978): "Signal-to-interference protection ratios", and Recommendation 339-3 (Geneva, 1974): "Bandwidths, signal-to-noise ratios and fading allowances in complete systems";

2. that IWP 3/1 shall be composed as shown in Annex I;

3. that any other Administrations or organizations participating in the work of Study Group 3 which would like to take part in the work of IWP 3/1 should make known to the Director, CCIR, the names and addresses of their experts as soon as possible;

4. that the Director, CCIR, shall communicate any changes to Annex I which may come to his attention, to the Chairman and Vice-Chairman of Study Group 3, as well as to the Chairman of IWP 3/1, without such changes being considered as modifications to the present Decision;

5. that IWP 3/1 shall report to the next meeting of Study Group 3 the results of its work and, if appropriate, make proposals for new CCIR texts and/or modifications to existing ones, relating to its terms of reference.

ANNEX I

List of participants in IWP 3/1:

Chairman:	Dr. H. Kaji 2-1-23, Nakameguro Meguro-ku Tokyo 153 Japan
Administrations:	United States of America India Japan United Kingdom U.S.S.R.
International Telecommunication Union:	IFRB

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