INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

DOCUMENTS OF THE

Xth PLENARY ASSEMBLY

GENEVA, 1963

VOLUME IV

RADIO-RELAY SYSTEMS
SPACE SYSTEMS
RADIOASTRONOMY

GENEVE
1963
C.C.I.R.

Published by the
INTERNATIONAL TELECOMMUNICATION UNION
GENEVA, 1963

INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

DOCUMENTS OF THE

Xth PLENARY ASSEMBLY

GENEVA, 1963

VOLUME IV

RADIO-RELAY SYSTEMS

SPACE SYSTEMS

RADIOASTRONOMY

GENEVE 1963

C.C.I.R.

Published by the

INTERNATIONAL TELECOMMUNICATION UNION

GENEVA, 1963

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

RADIO-RELAY SYSTEMS

Recommendations of Section F (Radio-relay systems)

Reports of Section F (Radio-relay systems)

Questions and Study Programmes allocated to Study Group IX (Radio-relay systems); Opinions and Resolutions of interest to this Study Group

List of documents of the Xth Plenary Assembly concerning Study Group IX

SPACE SYSTEMS AND RADIOASTRONOMY

Recommendations of Section L (Space systems and radioastronomy)

Reports of Section L (Space systems and radio-astronomy)

Questions and Study Programmes allocated to Study Group IV (Space systems and Radioastronomy); Opinions and Resolutions of interest to this Study Group

List of documents of the Xth Plenary Assembly concerning Study Group IV

DISTRIBUTION OF THE TEXTS OF THE Xth PLENARY ASSEMBLY OF THE C.C.I.R. AMONG VOLUMES I—VI

1. Recommendations

Number	Volume	Number	Volume	Number	Volume
45	III	218, 219	III	289, 290	IV
48, 49	V	224	III	297–300	IV
75–77	III	237	I	302	IV
80	V	239	I	304–306	IV
100	III	240	III	310, 311	II
106	III	246	III	313	II
136	V	257, 258	III	314	IV
139, 140	V	259	IV	325–334	I
162	III	261, 262	V	335–349	III
166	III	264–266	V	350–367	IV
168	II	268	IV	368–373	II
182	III	270, 271	IV	374–379	III
205	V	275, 276	IV	380–406	IV
212	V	279	IV	407–421	V
214–216	V	281–283	IV	422–429	III
				430, 431	I

2. Reports

Number	Volume	Number	Volume	Number	Volume
19	III	107	III	195–203	III
32	V	109	III	204–226	IV
42	III	111	III	227–266	II
43	II	112	III	267–282	III
46	II	122	V	283–290	IV
77	V	130	IV	291–316	V
79	V	134	IV	317–320	III
93	III	137	IV	321	I
106	III	151	II	322	*
		175–194	I		

3. Resolutions

Number	Volume	Number	Volume	Number	Volume
1	III	14–16	III	19, 20	III
2–13	II	17, 18	IV	21, 22	I
				23–29	VI

* Published separately.

4. Opinions

Number	Volume	Number	Volume	Number	Volume
1, 2	I	4–10	II	12–14	IV
3	IV	11	III	15–19	V
				20, 21	III

5. Questions

Number	Volume	Number	Volume	Number	Volume
3	III	163	III	221	IV
23	V	166	V	222	V
43	III	175–177	I	225	I
66	V	180–183	III	226	III
74	III	185	II	227–231	I
81	III	188	III	232, 233	III
95	III	191	III	234–245	IV
102	V	192–195	IV	246–248	II
118	V	197	IV	249–259	III
120, 121	V	199, 200	V	260, 261	IV
132, 133	III	205	V	262–270	V
140	III	206	III	271–275	III
152–154	V	207	I	276–279	IV
156, 157	V	219, 220	I	280–282	III

6. Study Programmes *

Number	Volume	Number	Volume	Number	Volume
		127	I	176	II
36	V	139	II	177	V
57	II	148	II	180–185	I
102	III	153	II	186, 187	III
110	V	161, 162	V	188–206	II
119	V	170	V	207	III

---

* This list includes only those Study Programmes which do not derive from Questions. A Study Programme derived from a Question carries the same serial number as this Question, followed by a letter (e.g. S.P. 102A (XII)). It is inserted in the book immediately after the text of the Question from which it is derived.

ARRANGEMENT OF VOLUMES I TO VII OF THE DOCUMENTS OF THE Xth PLENARY ASSEMBLY OF THE C.C.I.R.

(Geneva, 1963)

VOLUME I	Emission. Reception. Vocabulary (Sections A, B and K and Study Groups I, II and XIV).
VOLUME II	Propagation (Section G and Study Groups V and VI).
VOLUME III	Fixed and mobile services. Standard frequencies and time signals. International monitoring (Sections C, D, H and J and Study Groups III, XIII, VII and VIII).
VOLUME IV	Radio-relay systems. Space systems. Radioastronomy (Sections F and L and Study Groups IX and IV).
VOLUME V	Sound broadcasting and television (Section E and Study Groups X, XI, XII and the C.M.T.T.).
VOLUME VI	Resolutions of a general nature. Reports to the Plenary Assembly. List of participants. List of documents in numerical order.
VOLUME VII	Minutes of the Plenary Meetings.

Note 1. — To facilitate references, the pagination in the English and French texts is the same.

Note 2. — At the beginning of Volume VI will be found information concerning the Xth Plenary Assembly of the C.C.I.R. and the participation at this meeting, the presentation of texts (Definitions, origins, numbering, complete lists, etc.) together with general information on the organization of the C.C.I.R.

TABLE OF CONTENTS OF VOLUME IV

F. 3—Hypothetical reference circuits and noise

Page

REPORTS OF SECTION F (RADIO-RELAY SYSTEMS)

F. 1—Interconnection

F. 2—Radio-frequency channel arrangements

F. 3—Hypothetical reference circuits and noise

F. 4—Maintenance

F. 5—Characteristics

Page

QUESTIONS AND STUDY PROGRAMMES ASSIGNED TO STUDY GROUP IX (RADIO-RELAY SYSTEMS): OPINIONS AND RESOLUTIONS OF INTEREST TO THIS STUDY GROUP

The following texts, which are not contained in this Volume, also concern radio-relay systems:

Page

RECOMMENDATIONS OF SECTION L (SPACE-SYSTEMS AND RADIO-ASTRONOMY)

L. 1—General

L. 2—Communication satellites

REPORTS OF SECTION L (SPACE-SYSTEMS AND RADIOASTRONOMY)

L. 3—Direct broadcasting from satellites

L. 4—Radionavigation by satellites

L. 5—Meteorological satellites

L. 6—Maintenance telemetering, tracking and telecommand

No Reports in this sub-section

L. 7—Space research

L. 8—Radioastronomy

Page

L. 9—Radar astronomy

QUESTIONS AND STUDY PROGRAMMES ASSIGNED TO STUDY GROUP IV (SPACE SYSTEMS AND RADIOASTRONOMY); OPINIONS AND RESOLUTIONS OF INTEREST TO THIS STUDY GROUP

The following texts, which are not contained in this Volume, also concern space-systems and radioastronomy:

Text	Title	Volum
Opinion 5	Influence of the troposphere on frequencies used for telecommunication with and between spacecraft	II
Study Programme 190 (V)	Tropospheric propagation factors affecting the sharing of the radio-frequency spectrum between radio-relay systems, including space and terrestrial telecommunications systems	II
Resolution 2	Tropospheric propagation data for broadcasting, space and point-to-point communications	II
Study Programme 191 (V)	Tropospheric absorption and refraction in relation to space telecommunication systems	II
Report 263	Factors affecting propagation in communications with spacecraft	II
Resolution 6	Use of satellite-borne ionosondes in orbits above the F2 peak (topside sounders) for the study of ionospheric propagation	II
Study Programme 204 (VI)	Characteristics of the ionosphere affecting space telecommunication systems	II
Study Programme 205 (VI)	Effects of radio noise in space on communications with spacecraft	II
Opinion 9	Effects of the ionosphere on radio waves used for telecommunication with and between spacecraft beyond the lower atmosphere	II
Study Programme 249A (VII)	Standard-frequency and time signal emissions from artificial earth satellites	III
Report 276	Monitoring at fixed monitoring stations of radio emissions from spacecraft	III
Question 188 (VIII)	Monitoring at fixed monitoring stations of radio emissions from spacecraft	III

RECOMMENDATIONS OF SECTION F: (RADIO-RELAY SYSTEMS)

F.1-Interconnection

RECOMMENDATION 268 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Interconnection at audio frequencies

(Question 192 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that frequency-division multiplex radio-relay systems may form part of an international circuit;

(b) that international connections between such systems, among themselves or with other radio-relay or line systems, may at times have to be made at audio frequencies;

(c) that general conformity with the relevant C.C.I.T.T. Recommendations in respect of overall performance measured between audio-frequency terminals is already covered by Recommendation 335 relating to systems operating above about 30 Mc/s;

(d) that it will be necessary to signal over telephone circuits provided by means of such systems;

UNANIMOUSLY RECOMMENDS

that, as far as is practicable, frequency-division multiplex radio-relay systems forming part of an international circuit should conform with the relevant C.C.I.T.T. Recommendations for modern types of telephone circuit in the following respects:

1. the method of making international connections at audio frequencies;
2. the characteristics of the frequency-division multiplex terminal equipment;
3. the method of signalling over international circuits.

RECOMMENDATION 270

RADIO-RELAY SYSTEMS FOR TELEVISION

Interconnection at video signal frequencies

(Question 194 (IX))

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that radio-relay systems for television may form part of an international circuit;

* This Recommendation replaces Recommendation 188.

(b) that international connections of such systems amongst themselves, or with other radio-relay or line systems, may at times have to be made at video signal frequencies;

UNANIMOUSLY RECOMMENDS

that radio-relay systems for television, forming part of an international circuit, should conform in their baseband characteristics to the requirements for video interconnection points given in Recommendation 421, § 2; in particular the following characteristics are preferred:

1, nominal impedance at the point of interconnection: 75 Ω unbalanced (see Note 1);

2. amplitude of the video signal at input and output: 1 V peak-to-peak (see Note 2);

3. the nominal upper limit of the video frequency band for different television systems should also conform with those quoted in Recommendation 421, as shown in the following table:

Number of lines	405	525	625	625	819	819
Nominal upper limit of the video frequency band, (Mc/s)	3	4	5	6	5	10

Note 1. — Details of the acceptable values of return loss are given in § 2.1 of Recommendation 421.

Note 2. — In the design of equipment, account should be taken of the losses in the interconnecting cables, when the video interconnection point is at some distance from the terminals of the modulating and demodulating equipment.

RECOMMENDATION 297 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING TIME-DIVISION MULTIPLEX

Interconnection at audio frequencies

(Question 92)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that time-division multiplex radio-relay systems may form part of an international circuit;

(b) that international connections between such systems among themselves or with other radio-relay or line systems may, at times, have to be made at audio frequencies;

(c) that general conformity with the relevant C.C.I.T.T. Recommendations in respect of overall performance measured between audio-frequency terminals is already covered by Recommendation 335 relating to systems operating above about 30 Mc/s;

(d) that it will be necessary to signal over telephone circuits provided by means of such systems;

* This Recommendation replaces Recommendation 186.

UNANIMOUSLY RECOMMENDS

that as far as is practicable, time-division multiplex radio-relay systems forming part of an international circuit should conform to the relevant C.C.I.T.T. Recommendations for modern types of telephone circuit in the following respects:

1. the method of making international connections at audio frequencies;
2. the method of signalling over international circuits.

RECOMMENDATION 299

RADIO-RELAY SYSTEMS FOR TELEPHONY USING TIME-DIVISION MULTIPLEX

Agreement on major characteristics

(Question 92)

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that several different types of multi-channel radio-telephone systems using time-division-multiplex have been developed;

(b) that such systems are rarely installed across national boundaries;

(c) that C.C.I.R. Recommendations 297 and 298 and Report 134 already cover certain aspects of these systems;

UNANIMOUSLY RECOMMENDS

1. that in any international connection the characteristics not covered by the above Recommendations and Report be the subject of agreement between the Administrations concerned;
2. the study of Question 92 should be considered terminated.

RECOMMENDATION 304 *

RADIO-RELAY SYSTEMS FOR TELEPHONY

Interconnection of different systems of multiplexing

(Question 90)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that frequency-division multiplex, in accordance with C.C.I.T.T. Recommendations, is used widely for multi-channel telephony on line and for radio-relay systems, while time-division multiplex is used only for radio-relay systems of limited channel capacity;

(b) that interconnections between systems employing frequency-division multiplex in accordance with C.C.I.T.T. Recommendations can readily be made for groups of 12, supergroups of 60 and mastergroups of 300 channels, while interconnections between existing time-division multiplex systems on the one hand and frequency-division multiplex systems on the other

---

* This Recommendation replaces Recommendation 183.

must be made channel by channel at audio frequencies, requiring the use of additional equipment at the connection point and having disadvantages from the standpoints of economy, operation and circuit quality;

(c) that future time-division multiplex systems may combine small blocks of speech channels by frequency-division multiplex before multiplexing these blocks by time-division methods;

(d) that for level stabilization, etc., some frequency-division multiplex systems transmit pilot signals which it is advantageous to transmit from one switching section to the next and that the extension of such pilot signals over a time-division multiplex system may give rise to appreciable complications;

(e) that the interconnection of basically different types of multiplex systems would generally add to the problems of maintenance, since circuit techniques, routine measurements and fault-finding procedures would tend to differ;

UNANIMOUSLY RECOMMENDS

1. that, where for operational reasons all international connections to a radio-relay system must be made at audio frequencies, either a time-division multiplex or a frequency-division multiplex radio-relay system may be employed and that, in such cases, interconnection should be made on a four-wire basis in accordance with the relevant C.C.I.T.T. rules;

2. that, where there are no operational reasons for an international connection between a new radio-relay system and an existing radio-relay or line system to be made at audio frequency, the new radio-relay system should preferably use the same form of multiplexing as the system to which it is to be connected, in order to permit the connection to be made at baseband, intermediate or radio frequency as may be appropriate;

3. that, where the interconnection of time-division multiplex and frequency-division multiplex systems cannot be avoided, it should be made on a four-wire basis in accordance with the relevant C.C.I.T.T. rules, either at audio frequencies or, if appropriate, at the baseband frequencies corresponding to the blocks of channels combined by frequency-division methods before time-division multiplexing;

4. that, in any international connection not covered by the above, frequency-division multiplex is, in general, to be preferred.

RECOMMENDATION 306 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Procedure for the international connection of systems with different characteristics

(Question 113)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that, to simplify interconnection across frontiers and to ensure the best transmission quality on international circuits, interconnection between systems with different characteristics should be avoided as far as possible;

* This Recommendation replaces Recommendation 204.

(b) that, however, when such interconnection cannot be avoided, special arrangements will have to be made at the junction;

(c) that the C.C.I.T.T. recommends * that, where different types of coaxial systems are directly connected across a frontier, each Administration concerned should accept, on the receiving side, the transmission conditions normal to the incoming system;

UNANIMOUSLY RECOMMENDS

that, if different types of radio-relay systems are directly connected across a frontier, each Administration concerned should accept, on the receiving side the transmission characteristics normal to the incoming system, unless a better or more practical arrangement can be arrived at between the Administrations concerned.

RECOMMENDATION 380 **

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Interconnection at baseband frequencies

(Question 192 (IX))

The C.C.I.R., (Warsaw, 1956 — Geneva, 1963)

CONSIDERING

(a) that frequency-division multiplex radio-relay systems may form part of an international circuit;

(b) that international connections between such systems, among themselves and with other radio-relay or line systems, may at times have to be made at baseband frequencies;

(c) that definitions for the points *R* and *R′* of interconnection at baseband frequencies are given in the Annex to this Recommendation and Fig. 1;

(d) that the levels of the points *T* and *T′*, which are the responsibility of C.C.I.T.T. (Doc. 175 of Geneva, 1963), should be known to system designers;

UNANIMOUSLY RECOMMENDS

1. that the important baseband characteristics for a frequency-division multiplex radio-relay system forming part of an international circuit are:

1.1 maximum number of telephone channels;

1.2 limits of band occupied by telephone channels;

1.3 frequency limits of the baseband, including pilots or frequencies which might be transmitted to line;

1.4 relative input and output power levels, at the points of interconnection *R* and *R′*;

1.5 nominal impedance of the baseband circuits at the point of interconnection;

2. that as far as practicable these characteristics should conform to the preferred values given in the Table *** below;

3. the return loss at the points of interconnection should be $\geqq$ 24 db.

---

* C.C.I.T.T., Recommendation G. 336, (Vol. III) "Interconnection of coaxial carrier systems using different techniques".

** This Recommendation, which replaces Recommendation 269, applies to line-of-sight and near line-of-sight radio-relay systems, and also to tropospheric-scatter radio-relay systems of the capacities concerned.

*** It is recognized that in certain cases and regions it may be desirable to use baseband characteristics other than those given above, by agreement between the Administrations concerned.

1	2	3	4	5	6	7	8
Maximum No. of telephone traffic channels (Note 5)	Limits of band occupied by telephone channels (kc/s)	Frequency limits of baseband (kc/s) (Note 4)	Nominal impedance at baseband (Ω)	Relative power level per channel (dbr) (Notes 1, 2)			
				Radio equipment output output *R* (Note 7)	Main repeater station		Radio equipment input *R′* (Note 7)
					T	*T′*	
24	12–108 (Notes 3, 6)	12–108 (Notes 3, 6)	150 bal.	—15	—23	—36	—45
60	12–252 60–300	12–252 60–300	150 bal. 75 unbal.	—15	—23	—36	—45
120	12–552 60–552	12–552 60–552	150 bal. 75 unbal.	—15	—23	—36	—45
300	60–1300 64–1296	60–1364	75 unbal.	—18	—23	—36	—42
600	60–2540 64–2660	60–2792	75 unbal.	—20(1)	—23 —33	—36 —33	—45(1)
960	60–4028 316–4188	60–4287	75 unbal.	—20(1)	—23 —33	—36 —33	—45(1)
1800	312–8204 316–8204	300–8248	75 unbal.	—28	—33	—33	—37
2700 (2)	312–12 388 316–12 388	308–12 435	75 unbal.	—28	—33	—33	—37

(1) Alternative levels $R = -23$ dbr and $R' = -42$ dbr can be used when the associated line transmission equipment is wholly of a type for which the C.C.I.T.T. recommends baseband interconnection levels $T = -33$ dbr and $T' = -33$ dbr (Main repeater station equipped with transistors).

(2) The recommendation of a 2700 channel radio-relay system is under study; the values of columns 2 and 3 are still to be agreed by the C.C.I.T.T.; the values of levels for *R* and *R′* (columns 5 and 8) can only be provisional and C.C.I.T.T. is invited to comment on these values.

Note 1. — The particular preferred values for the relative power level given in the table are agreed with the C.C.I.T.T. These values apply to future systems.

Note 2. — The level shown is referred to a point of zero relative level in the system, in accordance with the practice of the C.C.I.T.T.

Note 3. — For 12-channel systems either of the basic groups A (12–60 kc/s) or B (60–108 kc/s) recommended by the C.C.I.T.T. may be accommodated in the band 12–108 kc/s.

Note 4. — Including pilots or frequencies which might be transmitted to line.

Note 5. — Larger capacity systems are not excluded by the Table.

Note 6. — A permissible alternative arrangement uses the frequency range 6–108 kc/s. With this first alternative, it is possible to use only the noise measuring channel, situated above the baseband, according to Recommendation 293. A further permissible alternative arrangement uses the frequency range 12–120 kc/s. With this second alternative it is possible to use only a continuity pilot situated below the baseband according to Recommendation 401.

Note 7. — The variation with frequency, over the range of baseband frequencies, of the equivalent loss of a homogenous section of the hypothetical reference circuit from point R' to point R should not exceed a provisional limit of ± 2 db relative to the nominal value. This tolerance is similar to that accepted by the C.C.I.T.T. for cable systems (see C.C.I.T.T. Recommendation M. 45).

The subject of variation with frequency should be studied further. It is also desirable to study the variation of loss as a function of time.

ANNEX

DEFINITION OF THE POINTS OF INTERNATIONAL CONNECTION AT BASEBAND FREQUENCIES

The points of international interconnection at baseband frequencies, called R and R', form the input and output channels of radio equipment conforming to C.C.I.T.T. Recommendation G. 423 and the present Recommendation.

At the output point of the radio equipment (point R) the following conditions are found in the baseband of the radio-relay system:

1. All the telephony groups (groups, supergroups, mastergroups, etc.) and the pilots (line regulating, frequency comparison and monitoring pilots) included in the baseband are assembled in the positions in which they are transmitted, as defined in the C.C.I.T.T. and C.C.I.R. Recommendations mentioned above.

2. All the continuity and switching pilots and other signals transmitted in a radio-relay system outside the telephony band, inherent to the radio equipment, are suppressed in accordance with Recommendation 381.

3. Any radio stand-by switching shall be performed on the radio equipment side. With diversity reception, the combined output of the receivers used corresponds to point R.

4. Any de-emphasis networks are part of the radio equipment, so that the relative levels of the telephone channels are independent of frequency, within the limits of the tolerances stated in Note 7 of this Recommendation.

A similar point R' is defined for the baseband input of the radio equipment, where similar conditions are to be met.

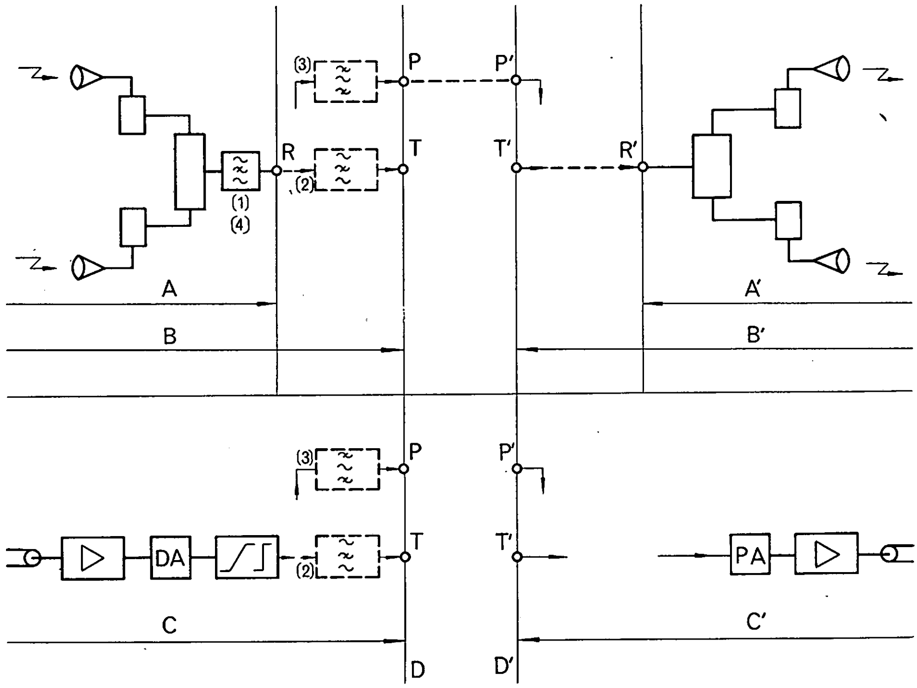


FIGURE 1

A, A′: Radio equipments,
B, B′: Radio system,
C, C′: Cable system,
D, D′: Boundary of the high-frequency line equipment.

Point P′: provided for possible injection of regulating pilots.
Between T and T′: telephony translating equipment and/or direct through-connection equipment.

DA: de-emphasis network.
PA: pre-emphasis network.

(1): Blocking of continuity pilots, and if necessary, of regulating pilots.

(2): Blocking, if necessary, of regulating pilots, and pilots that must not go beyond the line link.

(3): Through-connection filter for regulating pilots, if necessary.
Through-connection filter for telephone groups, can, if necessary, be inserted.

(4): Blocking of unspecified pilots or supervisory signals.

RECOMMENDATION 381 *

INTERCONNECTION OF RADIO-RELAY AND LINE SYSTEMS

Line regulating and other pilots. Limits for the residues of signals outside the baseband **

(Study Programme 28 and Question 96)

The C.C.I.R., (London, 1953 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it may be necessary to interconnect radio-relay and line systems when establishing international circuits;

(b) that a continuity pilot may be required to establish the continuity of the transmission path between the input and output terminals of a radio-relay system independently of the frequency-division multiplex telephony being transmitted;

(c) that in addition, a line-regulating pilot may be required to measure the level stability in the baseband of a frequency-division-multiplex telephony radio-relay system;

(d) that the variations of the level of the line-regulating pilot should correspond closely to the variations of the overall gain of the radio-relay system between its input and output terminals at the frequencies of the frequency-division-multiplex telephony signals;

(e) that pilots are also required on line systems for gain-regulating, monitoring and frequency-comparison purposes;

(f) that the line pilots used for monitoring and frequency comparison may also be required to be transmitted over a radio-relay system;

(g) that a pilot frequency of 308 kc/s is already in use by line systems for gain regulating and other purposes, and that there is a gap in the frequency-division-multiplex signal spectrum within which the pilot is located;

(h) that, in some radio-relay systems, it is permissible to place the service channels of a radio-relay system below the baseband (in certain cases, a service channel may be very near to a telephone channel in the general network);

(i) that it is essential to avoid undesirable effects, such as the interaction of the gain-regulating systems and interference or crosstalk from the pilots, when radio-relay and line systems are interconnected;

(j) that all signals transmitted on a radio-relay system, even if they cannot cause interference to either the telephone channels or the pilots of a cable system interconnected with that radio-relay system, must have a limited power, to avoid overloading the cable system;

(k) that, if such interfering signals have to be eliminated by a filter incorporated in the radio equipment, that filter, the attenuation characteristic of which has a finite slope, must not cause appreciable attenuation distortion on the telephone channel thus protected;

---

* This Recommendation, which replaces Recommendation 291, applies to line-of-sight systems and near line-of-sight systems, and also where appropriate, to tropospheric-scatter systems.

** Attention is drawn to the fact that for direct through-connection between two radio-relay systems, frequencies outside the baseband may pass between the points *R* and *R'*, with negligible attenuation relative to the baseband. The precautions called for to protect cable systems may, therefore, also be necessary to protect radio-relay systems. The points *R* and *R'* are defined in Fig. 1 to Recommendation 380, as are also the points *T* and *T'*.

UNANIMOUSLY RECOMMENDS

1. that the point of interconnection between a radio-relay system and a line system forming part of an international circuit shall be considered as a junction between line regulating sections, except when the cable system constitutes a short extension of the radio system and is then a part of the same line regulating section; if the radio-relay link constitutes a regulated line section, the station at one end of the system will be called "the radio link control station" and the station at the other end will be called "the radio link sub-control station". The duties of these stations are given in the maintenance instructions in Volume IV of the C.C.I.T.T.;

2. that the continuity pilot of a multi-channel telephony radio-relay system should be located *outside* the band of frequencies occupied by the frequency-division-multiplex signal and the preferred frequencies and levels will be as shown in Recommendation 401*;

3. that the level of the continuity pilot of a radio-relay system for telephony be suppressed below —50 dbm0 at the point of connection with a line system (point *R*);

4. that for a line regulating pilot on a frequency-division-multiplex telephony radio-relay system with a capacity of 60 channels or more, 308 kc/s ± 3 c/s is the preferred frequency and the preferred pilot level is —10 dbm0. A second line regulating pilot situated in the upper part of the baseband can also be used, the preferred value of frequency and level of which should be those recommended by the C.C.I.T.T. for cable systems **;

5. that the level of the line regulating pilot of a telephony radio-relay system shall be suppressed below —50 dbm0 at the point of connection with a line system in all cases where this point is a junction between line regulating sections (point *T* or before this point);

6. that the level of any line regulating pilot of a line system to which a radio-relay system is connected be suppressed below —50 dbm0, preferably before the input terminals of the radio-relay system (point *T′*) in all cases where this is the junction between line regulating sections, except by agreement between the Administrations concerned;

7. that when cable systems constitute short extensions of the radio system and are then part of the same line regulating section, the same line regulating pilots can be transmitted in the two systems;

8. that in the absence of any special agreement between Administrations, the level of any pilot or supervisory signals transmitted outside the baseband of a radio-relay system at a frequency not specified by the C.C.I.R. should, within the radio equipment, be reduced below —50 dbm0 at point *R*;

9. that similarly, in the absence of special agreements between the Administrations concerned, the levels of all pilots or supervisory signals transmitted over the cable system and having frequencies outside the baseband of the radio-relay link should, within the equipment of the cable system, be reduced below —50 dbm0 at point *T* (and consequently at point *R′*);

10. that, if a radio-relay system service channel, adjacent to a telephone channel in the baseband, uses the levels, frequency allocation and signalling levels corresponding to those which would be recommended by the C.C.I.T.T. for an ordinary telephone channel in the same position in the frequency spectrum, the channel filters are adequate to avoid the risk of crosstalk inter-

---

* A continuity pilot within the baseband, possibly acting as the line regulating pilot, may be used, in systems of up to 120 channels for reasons of economy, after agreement between the Administrations concerned.

** For low-capacity systems (up to 120 channels) a line regulating pilot of 60 kc/s with a level of − 10 dbm0 may be used; in this case the suppression level should conform with the provisions of C.C.I.T.T. Recommendation G. 243, (Vol. III) A-a; thus the level of the line regulating pilot established by the C.C.I.T.T. for lines differs according to whether it concerns coaxial cables or symmetrical pairs: −10 dbm0 for coaxial cables and −15 dbm0 for symmetrical pair systems).

ference; if this condition is not met, an additional filter may be necessary and must be provided within the radio equipment;

11. that the frequencies mentioned in §§ 8 and 10 must be sufficiently distant from the baseband to ensure that the filters (or other appropriate devices) required to eliminate them do not cause attenuation distortion in the passband to exceed the recommended values;

12. that, to avoid overloading the cable system, the level of any other signal outside the baseband range must be less than —20 dbm0 at the point *R*;

13. that, further, the level of the total power of all the signals outside the baseband range, including thermal and intermodulation noise, must be less than —17 dbm0 at the point *R*;

14. that all other line pilots within the band of frequencies occupied by the frequency-division-multiplex telephony signal shall be freely transmitted by the radio-relay system to which the line system is connected.

Note. — The problems raised by continuity pilots for television transmission should be the subject of a separate study.

F. 2-Radio-frequency channel arrangements

RECOMMENDATION 279 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Radio-frequency channel arrangements for 300 channel systems operating in the 2 and 4 Gc/s bands **

(Question 192 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that it is sometimes desirable to be able to interconnect radio-relay systems on international circuits at radio frequencies in the 2 and 4 Gc/s bands;

(b) that it is desirable in such cases to use a radio-frequency arrangement for systems transmitting 300-channel telephone signals which is compatible with that for systems of 600 channels or more using the same frequency band;

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to six go and six return radio-frequency channels, each accommodating 300 telephone channels is the same as that given in § 1 of Recommendation 382;

2. that where additional radio-frequency channels, each accommodating 300 telephone channels, are required on the same route, up to six additional pairs of channels may be interleaved between the initial channels at channel frequencies which are 14·5 Mc/s below those of the corresponding initial channel frequencies;

3. that in a section over which the international interconnection is arranged, all the go channels shall be in one half of the band and all the return channels shall be in the other half of the band;

4. that the initial six channels in any one half of the band should have the same polarization;

5. that the second six channels in any one half of the band should have a polarization which differs from that of the initial six channels in the same half of the band, except by agreement between the Administrations concerned;

6. that, to minimize interference within a system, the centre frequency f_o should preferably be as given below:

in the 2 Gc/s band, f_o = 1903 or 2101 Mc/s,
in the 4 Gc/s band, f_o = 4003·5 Mc/s;

other centre frequencies may be used by agreement between the Administrations concerned ***.

---

* This Recommendation replaces Recommendation 193.

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

*** Interference due to certain harmonics of the shift frequency, which may fall near radio-frequency channel frequencies f_n in radio-frequency repeaters, or may fall near ($f_n \pm 70$) Mc/s in repeaters using an intermediate frequency of 70 Mc/s, may in certain cases be serious. Such interference may be reduced by choosing a suitable value for f_o, such as those given in § 6 of this Recommendation.

RECOMMENDATION 281 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred radio-frequency channel arrangements for television **

(Questions 192 (IX) and 194 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that it is sometimes desirable to interconnect radio-relay systems at radio frequencies on international circuits;

(b) that it is desirable to use, as far as possible, the same radio-frequency arrangements for radio-relay systems for television as for the larger capacity multi-channel telephone systems;

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency arrangements for the international interconnection of radio-relay systems transmitting television signals with any combination, either on the same radio channel or on different channels, of the following signals—television of 819 lines, television of 625 lines or less or multichannel telephony are the same as that given in Recommendations 382 and 383. The choice of the particular channels for the television signals should be agreed between the Administrations concerned;

2. that, for the international connection of systems transmitting television signals (of 625 lines or less) only, the preferred radio-frequency arrangements are the same as those given in Recommendations 382 and 383;

3. that, for the international connection of systems transmitting television signals (of 819 lines only), the preferred radio-frequency channels are 1 and 4 of the frequency arrangements defined in § 1, 2 and 3 of Recommendation 382. Alternatively, if further channels are required radio-frequency channels 3 and 6 of the interleaved radio-frequency channels, defined in § 5 of Recommendation 382 may be used by agreement between the Administrations concerned.

RECOMMENDATION 282 ***

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Use of special radio-frequency channel arrangements **

(Questions 192 (IX) and 194 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that interconnection of radio-relay systems at radio frequencies is the most common practice in international connection, and that it is desirable to define the preferred values of the characteristics for such interconnection and in particular the frequency plan to be used;

---

* This Recommendation replaces Recommendation 195.

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

*** This Recommendation replaces Recommendation 192.

(b) that, in certain existing circuits, use is made of special frequency arrangements since each Administration is free to use any system of its own choice within its national territory;

(c) that Study Group IX had already indicated preferred values in a draft Report (Docs. 62-Rev. and 69-Rev. of Geneva, 1954) and that certain Administrations use, in a 400 Mc/s band between 3800 and 4200 Mc/s, equipments operating in accordance with frequency arrangements as given in these documents;

UNANIMOUSLY RECOMMENDS

that international connection of radio-relay systems should preferably be carried out in conformity with Recommendations 279, 381, 382 and 383. Nevertheless, when such a course is justified to use an existing design of equipment, and provided that no harmful interference results, international connection involving the equipment and systems referred to in §§ *(b)* and *(c)*, or their possible extension, may be carried out in accordance with the particular characteristics of such installations, after agreement between the Administrations concerned.

RECOMMENDATION 283 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Radio-frequency channel arrangements for 60- and 120-channel telephony systems operating in the 2 Gc/s band

(Question 192 (IX), Study Programme 104)

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that it is sometimes desirable to be able to interconnect 60- and 120-channel radio-relay systems on international circuits at radio frequencies in the 2 Gc/s band;

(b) that in a frequency band 200 Mc/s wide it may be desirable to interconnect up to six go and six return radio-frequency channels;

(c) that economy may be achieved if at least three go and three return channels can be interconnected between systems each of which uses a common transmit-receive antenna;

(d) that many interfering effects can be substantially reduced by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;

(e) that, it may sometimes be desirable to interleave additional radio-frequency chanels between those of the main pattern;

(f) that it is desirable for the values of the mid-frequencies of the radio-frequency channels to be the same for 60- and for 120-channel telephony systems;

(g) that the spacing between the mid-frequencies of the radio-frequency channels should be such that the systems can work with the maximum frequency deviation given in Recommendation 404 for such systems;

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

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to six go and six return channels, each accommodating 60 or 120 telephone channels and operating within the frequency band 1700–2300 Mc/s, should be as shown in the attached figure and should be derived as follows:

   Let f_o be the frequency of the centre of a 200 Mc/s band of frequencies occupied (Mc/s);

   f_n be the centre frequency of one radio-frequency channel in the lower half of this band (Mc/s);

   f'_n be the centre frequency of one radio-frequency channel in the upper half of this band (Mc/s);

   then the frequencies in Mc/s of individual channels are expressed by the following relationships:

   lower half of band, $f_n = f_o - 108{\cdot}5 + 14\,n$,
   upper half of band, $f'_n = f_o + 10{\cdot}5 + 14\,n$,
   where $n = 1, 2, 3, 4, 5$ or 6;

2. that in a section over which the international connection is arranged, all the *go* channels should be in one half of the band, all the *return* channels should be in the other half of the band;

3. that, when common transmit-receive antennae are used and three radio-frequency channels are accommodated on a single antenna it is preferable that the channel frequencies be selected by either making $n = 1$, 3 and 5 in both halves of the band or making $n = 2$, 4 and 6 in both halves of the band;

4. that, when additional radio-frequency channels, interleaved between those of the main patterns are required, the values of the centre frequencies of these radio-frequency channels should be 7 Mc/s above those of the corresponding main channel frequencies;

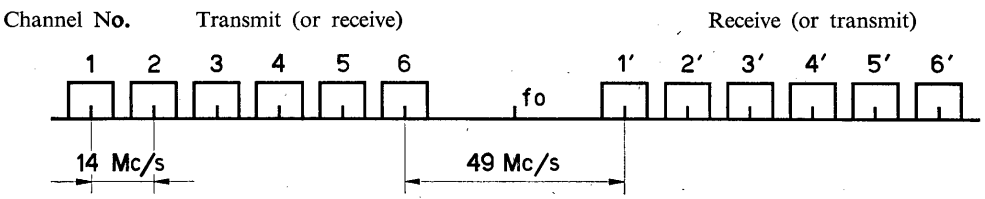
5. that the centre frequencies for 60- and 120-channel telephony systems should preferably be those shown below:

   $f_o = 1808$ Mc/s for the band 1700—1900 Mc/s,
   $f_o = 2000$ Mc/s for the band 1900—2100 Mc/s,
   $f_o = 2203$ Mc/s for the band 2100—2300 Mc/s.

   Other centre frequencies may be used by agreement between the Administrations concerned.

Note 1. — When the frequency band 1900–2300 Mc/s or 1700–2100 Mc/s is used for a large capacity radio-relay system and a 60- or 120-channel system is used on the same route, the possibility of introducing mutual interference is greatly reduced if separate antennae are used for the two systems.

Note 2. — When operational difficulties may be experienced along a route, due to problems of over-reach and the like, additional frequencies are available for use as stagger frequencies, spaced 3·5 Mc/s from the allocations given above.



Radio-frequency channel arrangement for international connection of radio-relay systems for 60 or 120 channels operating in the 2 Gc/s band.

RECOMMENDATION 382 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Radio-frequency channel arrangements for systems for 600 to 1800 telephone channels, or the equivalent, operating in the 2 and 4 Gc/s bands

(Question 192 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that, it is sometimes desirable to be able to interconnect radio-relay systems on international circuits at radio frequencies in the 2 and 4 Gc/s bands;

(b) that, in a frequency band 400 Mc/s wide, it may be desirable to interconnect up to six go and six return radio-frequency channels;

(c) that economy may be achieved if at least three go and three return channels can be interconnected between systems each of which uses common transmit-receive antennae;

(d) that many interfering effects can be substantially reduced by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;

(e) that, it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to six go and six return channels, each accommodating 600 to 1800 telephone channels, or the equivalent, and operating at frequencies in the 2 and 4 Gc/s bands, should be as shown in Fig. 3 and should be derived as follows:

   Let f_0 be the frequency of the centre of the band of frequencies occupied (Mc/s),

   f_n be the centre frequency of one radio-frequency channel in the lower half of the band (Mc/s);

   f'_n be the centre frequency of one radio-frequency channel in the upper half of the band (Mc/s);

   then the frequencies in Mc/s of individual channels are expressed by the following relationships:

   lower half of band, $f_n = f_0 - 208 + 29\,n$,

   upper half of band, $f'_n = f_0 + 5 + 29\,n$,

   where $n = 1, 2, 3, 4, 5$ or 6;

2. that in a section over which the international connection is arranged all the *go* channels should be in one half of the band, and all the *return* channels should be in the other half of the band;

3. that for adjacent radio-frequency channels in the same half of the band, different polarizations should preferably be used alternately; i.e. the odd numbered channels in both directions of

* This Recommendation, which replaces Recommendation 278, applies only to line-of-sight and near line-of-sight radio-relay systems.

transmission on a given section should use H (V) polarization, and the even numbered channels should use V (H) polarization, as shown in Fig. 1 below:

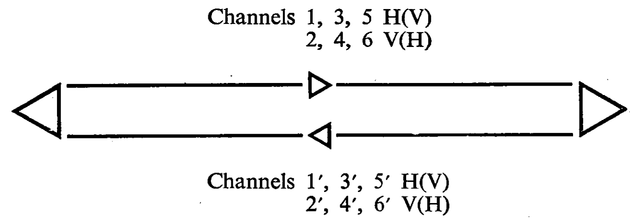


FIGURE 1

Note. — When antennae for double polarization are used, the arrangement of channels as shown in Fig. 2 may be used by agreement between Administrations;

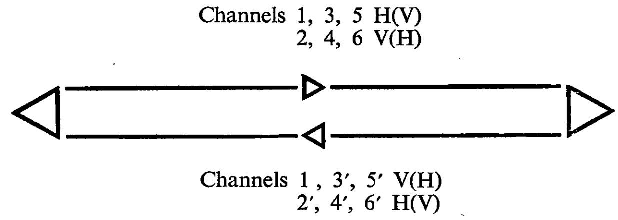


FIGURE 2

4. that when common transmit-receive antennae are used and not more than three radio-frequency channels are acommodated on a single antenna it is preferred that the channel frequencies be selected by either making $n = 1, 3$ and 5 in both halves of the band or making $n = 2, 4$ and 6 in both halves of the band;

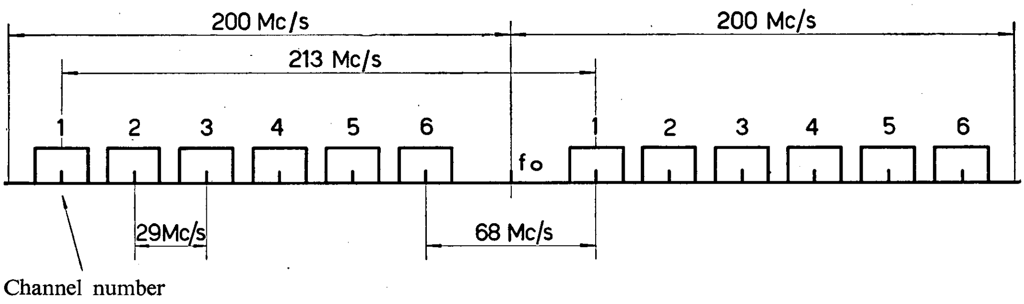


FIGURE 3

Radio-frequency channel arrangement for radio-relay systems with capacities from 600 to 1800 telephone channels or the equivalent operating in the 2 and 4 Gc/s bands, for use in international connections

(All frequencies are in Mc/s)

5. that when additional radio-frequency channels, interleaved between those of the main pattern, are required, the values of the centre frequencies of these radio-frequency channels should be 14·5 Mc/s below those of the corresponding main channel frequencies *;

* In systems for 1800 telephone channels, or the equivalent, it may not be practicable to use interleaved frequencies, because of the wide bandwidth occupied by the modulated carrier

6. that to minimize interference within a system, the centre frequency f_o should preferably be as given below:

   in the 2 Gc/s band, $f_o = 1903$ or 2101 Mc/s,
   in the 4 Gc/s band, $f_o = 4003{\cdot}5$ Mc/s.

   Other centre frequencies may be used by agreement between the Administrations concerned *;

7. that due regard be taken of the fact that in some countries, mostly in a large part of Region 2 and in certain other areas, another radio-frequency channel arrangement for 4 Gc/s systems is used. A description of this radio-frequency channel arrangement is given in the Annex. Attention is drawn to the problem of interconnection (See Recommendation 282).

ANNEX

DESCRIPTION OF THE RADIO-FREQUENCY CHANNEL ARRANGEMENT REFERRED TO IN § 7

1. The radio-frequency channel arrangement for a band 500 Mc/s wide and for up to six go and six return channels (group 1) and an interleaved pattern of six go and six return channels (group 2), each accommodating about 960 telephone channels or the equivalent, operating in the 4 Gc/s band, is as shown in Fig. 4 and is derived as follows:

   Let f_r be the frequency of the lower edge of the band of frequencies occupied (Mc/s);
   f_n be the centre frequency of one radio-frequency channel in the go (return) channel of the band (Mc/s);
   f'_n be the centre frequency of one radio-frequency channel in the return (go) channel of the band (Mc/s);

   then the frequencies in Mc/s of individual channels are expressed by the following relationships:

   Group 1

   go (return) channel, $f_n = f_r - 50 + 80\,n$,
   return (go) channel, $f_n' = f_r - 10 + 80\,n$,

   where $n = 1, 2, 3, 4, 5$ and 6.

   Group 2

   go (return) channel, $f_n = f_r - 70 + 80\,(n - 6)$,
   return (go) channel, $f_n' = f_r - 30 + 80\,(n - 6)$,

   where $n = 7, 8, 9, 10, 11$ and 12;

2. In a section over which international connections are arranged, the *go* and *return* channels are in the same group and are adjacent channels in that group;

3. In any section both the *go* and *return* channels of any one group are of one polarization;

4. In any section the channels of each group are of different polarizations;

5. In general the value of f_r is 3700 Mc/s.

---

* Interference due to certain harmonics of the shift frequency, which may fall near radio-frequency channel frequencies f_n in radio-frequency repeaters, or may fall near ($f_n \pm 70$) Mc/s in repeaters using an intermediate frequency of 70 Mc/s, may in certain cases be serious. Such interference may be reduced by choosing a suitable value for f_o, such as those given in § 6 above.

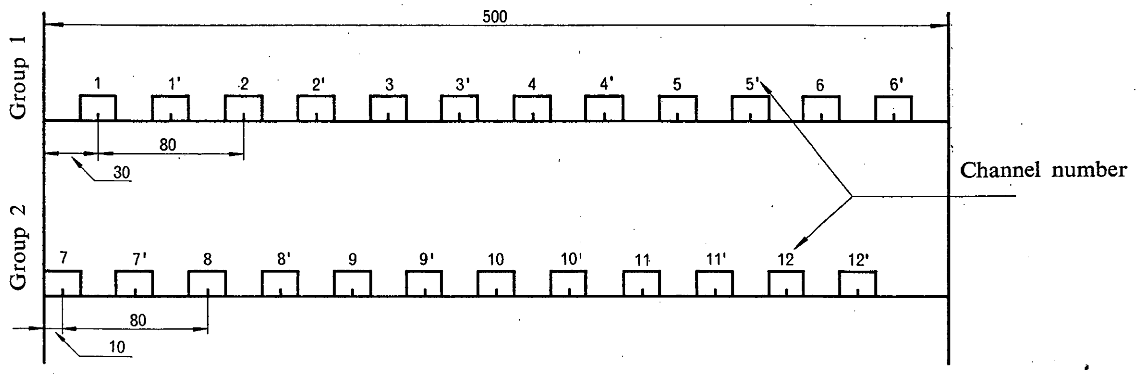


FIGURE 4

Radio-frequency channel arrangement, described in the Annex

(All frequencies are in Mc/s)

RECOMMENDATION 383 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Radio-frequency channel arrangements for systems for 600 to 1800 telephone channels, or the equivalent, operating in the 6 Gc/s band

(Question 192 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that, it is sometimes desirable to be able to interconnect radio-relay systems on international circuits in the 6 Gc/s band at radio frequencies;

(b) that, in a frequency band 500 Mc/s wide, it may be desirable to interconnect up to eight go and eight return channels;

(c) that economy may be achieved if at least four go and four return channels can be interconnected between systems, each of which uses common transmit-receive antennae;

(d) that many interfering effects can be substantially reduced by a carefully planned arrangement of the radio-frequencies in radio-relay systems employing several radio-frequency channels;

(e) that, it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;

---

* This Recommendation, which replaces Recommendation 280, applies only to line-of-sight and near line-of-sight radio-relay systems.

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to eight go and eight return channels, each accommodating 600 to 1800 telephone channels or the equivalent, and operating at frequencies in the 6 Gc/s band, should be as shown in Fig. 1 and should be derived as follows:

Let f_o be the frequency (Mc/s) of the centre of the band of frequencies occupied;
f_n be the centre frequency (Mc/s) of one radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (Mc/s) of one radio-frequency channel in the upper half of the band;

then the frequencies (Mc/s) of individual channels are expressed by the following relationships:

lower half of the band, $f_n = f_o - 259{\cdot}45 + 29{\cdot}65\, n$,

upper half of the band, $f'_n = f_o - 7{\cdot}41 + 29{\cdot}65\, n$,

where $n = 1, 2, 3, 4, 5, 6, 7$ or 8;

2. that in a section over which the international connection is arranged, all the *go* channels should be in one half of the band, and all the *return* channels should be in the other half of the band;

3. that the go and return channels on a given section should preferably use polarizations as shown below:

	Go				*Return*			
H(V)	1	3	5	7	2′	4′	6′	8′
V(H)	2	4	6	8	1′	3′	5′	7′

The following alternative arrangement of polarization may be used by agreement between the Administrations concerned:

	Go				*Return*			
H(V)	1	3	5	7	1′	3′	5′	7′
V(H)	2	4	6	8	2′	4′	6′	8′

4. that when common transmit-receive antennae for double polarization are used and not more than four channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by either making $n = 1, 3, 5$ and 7 in both halves of the band or making $n = 2, 4, 6$ and 8 in both halves of the band (see Note 2);

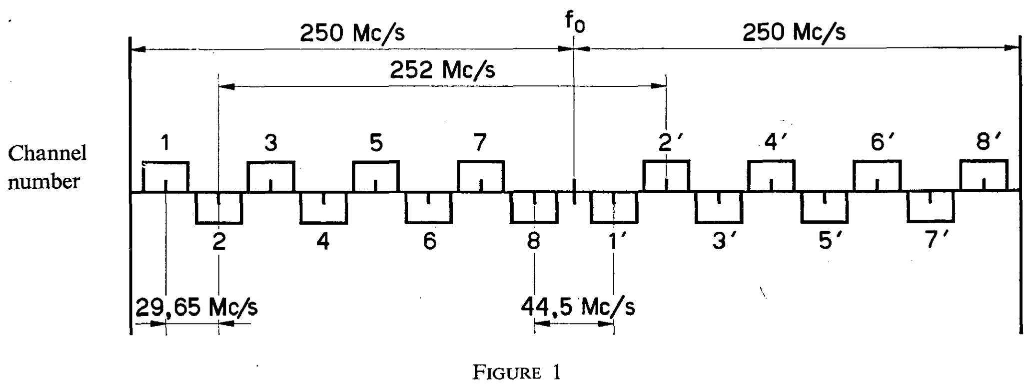


FIGURE 1

Radio-frequency channel arrangement for radio-relay systems operating in the 6 Gc/s band, for use in international connections (the frequencies shown are approximate)

(All frequencies are in Mc/s)

5. that when additional radio-frequency channels, interleaved between those of the main pattern, are required, the values of the centre frequencies of these radio-frequency channels should be 14·825 Mc/s below those of the corresponding main channel frequencies; in systems for 1800 channels or the equivalent it may not be practical, because of the bandwidth of the modulated carrier, to use interleaved frequencies;

6. that the preferred centre frequency is 6175·0 Mc/s; other centre frequencies may be used by agreement between the Administrations concerned.

Note 1. — The radio-frequency arrangement shown in Fig. 1 is suitable for use with the preferred intermediate frequency of 70 Mc/s (see Recommendation 403). It is also suitable for use with an intermediate frequency of 74·13 Mc/s, which enables a common oscillator (14·82 Mc/s) to be used for generating all the local oscillations for the system, if desired.

Note 2. — When common transmit/receive antennae are used and not more than four channels are accommodated on a single antenna, channel frequencies may be selected, by agreement between Administrations, by making $n = 1, 3, 5$ and 7 in the lower half of the band, and $n = 2, 4, 6$ and 8 in the upper half of the band. If a second similar antenna is used for four further channels, the channel frequencies may be selected by making $n = 2, 4, 6$ and 8 in the lower half of the band and $n = 1, 3, 5$ and 7 in the upper half of the band, but if only three further channels the required the channel frequencies may be selected by making $n = 2, 4$ and 6 in the lower half of the band and $n = 3, 5$ and 7 in the upper half of the band to avoid the difficulty of separating frequencies 8 and 1′.

RECOMMENDATION 384 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Radio-frequency channel arrangements for systems with a capacity of either 2700 telephone channels or 960 telephone channels, or the equivalent, operating in the 6 Gc/s band

(Study Programme 192 A(IX))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that radio-relay systems with a capacity of 2700 telephone channels should prove to be feasible in the 6 Gc/s band, if due care is exercized in the planning of radio paths to reduce multipath effects;

(b) that, it is sometimes desirable to be able to interconnect, at radio frequencies, radio-relay systems on international circuits in the 6 Gc/s band;

(c) that it may be desirable to interconnect up to eight go and eight return channels in a frequency band 680 Mc/s wide;

(d) that economy may be achieved if at least four go and four return channels can be interconnected between radio-relay systems, each of which uses common transmit-receive antennae;

(e) that a common radio-frequency channel arrangement for both 960 and 2700 telephone channel radio-relay systems offers considerable advantages;

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

(f) that many interfering effects can be reduced substantially by a carefully planned arrangement of the radio-frequencies in radio-relay systems employing several radio-frequency channels;

(g) that the radio-frequency channels should be so arranged that an intermediate frequency of 70 Mc/s may be used for 960 channel systems;

(h) that the radio-frequency channels should be so arranged that an intermediate frequency of either 100 Mc/s or 140 Mc/s may be employed for 2700 channel systems, as outlined in Report 287;

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for up to eight go and eight return channels, each accommodating 2700 telephone channels or the equivalent, and operating at frequencies in the 6 Gc/s band should be derived as follows:

   Let f_o be the frequency (Mc/s) of the centre of the band of frequencies occupied;

   f_n be the centre frequency (Mc/s) of one radio-frequency channel in the lower half of the band;

   f'_n be the centre frequency (Mc/s) of one radio-frequency channel in the upper half of the band;

   then the frequencies (Mc/s) of individual channels are expressed by the following relationship:

   lower half of the band: $f_n = f_o - 350 + 40\,n$,
   upper half of the band: $f_n' = f_o - 10 + 40\,n$,

   where $n = 1, 2, 3, 4, 5, 6, 7$ or 8;

2. that, in the section over which the international connection is arranged, all the *go* channels should be in one half of the band, and all the *return* channels should be in the other half of the band;

3. that different polarizations should be used alternately for adjacent radio-frequency channels in the same half of the band;

4. that when common transmit-receive antennae are used, and not more than four channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by making either:

   $n = 1, 3, 5$ and 7 in both halves of the band or

   $n = 2, 4, 6$ and 8 in both halves of the band;

5. that the preferred arrangement of radio-frequency polarization which depends on whether antennae for single or double polarization are used and on whether an intermediate frequency of 100 or 140 Mc/s is employed, is shown in Fig. 1;

6. that the preferred radio-frequency channel arrangement for up to 16 go and 16 return channels, each accommodating 960 telephone channels or the equivalent, should be obtained by interleaving additional channels between those of the main pattern and should be expressed by the following relationship:

   lower half of the band: $f_N = f_o - 350 + 20\,N$,
   upper half of the band: $f'_N = f_o - 10 + 20\,N$,

   where $N = 1, 2, 3, \ldots, 15, 16$;

7. that, in the section over which international connection is arranged, all the *go* channels should be in one half of the band and all the *return* channels in the other half of the band;

8. that different polarizations should be used alternately for adjacent radio frequency channels in the same half of the band;

9. that when common transmit-receive antennae are used, and not more than four radio-frequency channels are accommodated on a single antenna, it is preferred that the channel frequencies be selected by making either:

$N = 1, 5, 9, 13$ or
$N = 2, 6, 10, 14$ or
$N = 3, 7, 11, 15$ or
$N = 4, 8, 12, 16,$

in both halves of the bands and the preferred arrangement of radio-frequency polarization is shown in Fig. 2;

10. that the preferred centre frequency, f_o, is 6770 Mc/s; other centre frequencies may be used by agreement between the Administrations concerned.

Note 1. — This radio-frequency channel arrangement permits all local oscillator frequencies to be derived from a common oscillator, if desired.

Note 2. — The radio-frequency channel arrangements for systems of 960 channel capacity and of 2700 channel capacity may be used on intersecting routes as long as adequate antenna discrimination is provided. The use of a mixed arrangement of 960 and 2700 channel systems on the same route should be the subject of further study.

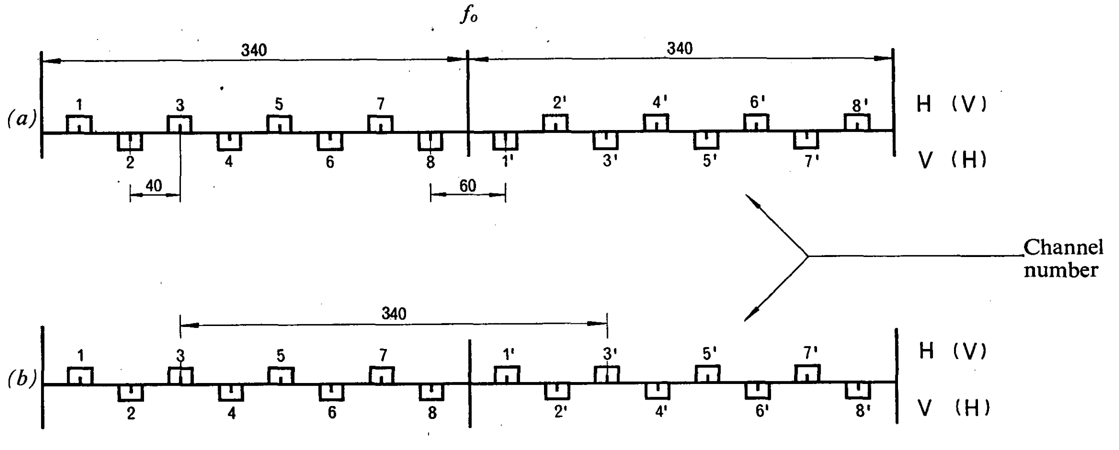


FIGURE 1

(a) Channel arrangement for either:

— antennae with single polarization and an IF of 100 Mc/s, or
— antennae with double polarization and an IF of 140 Mc/s.

(b) Channel arrangement for either.

— antennae with single polarization and an IF of 140 Mc/s, or
— antennae with double polarization and an IF of 100 Mc/s.

(All frequencies are in Mc/s)

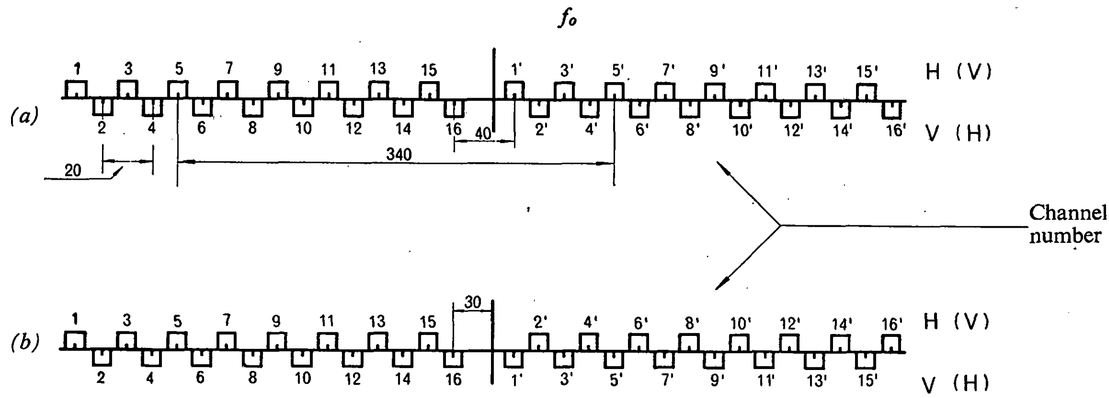


FIGURE 2

(All frequencies are in Mc/s)

(a) Channel arrangement for antennae with single polarization

(b) Channel arrangement for antennae with double polarization

RECOMMENDATION 385 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Radio-frequency channel arrangements for 60-, 120- and 300-channel telephony systems operating in the 7 Gc/s band

(Question 192 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it is desirable to be able to interconnect 60-, 120- and 300-channel radio-relay systems no international circuits at radio frequencies in the 7 Gc/s band;

(b) that frequency bands 300 Mc/s wide may be available for such systems;

(c) that economy may be achieved, if several go and return channels are connected to one common transmit-receive antenna;

(d) that many interfering effects can be minimized by a carefully planned arrangement of the radio frequencies in radio-relay systems employing several radio-frequency channels;

(e) that, for reasons of frequency economy, it is desirable to interleave additional radio-frequency channels between those of the main pattern;

(f) that it is desirable that the values of the mid-frequencies of the radio-frequency channels be the same for 60-, 120- and 300-channel systems;

(g) that the spacing between the mid-frequencies of the radio-frequency channels should be such that the systems can work with the maximum frequency deviation given in Recommendation 404 for such systems:

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangemenι ιor several radio-relay systems, each accommodating 60, 120 or 300 telephone channels and operating in the 7 Gc/s band should be derived as follows (see Fig. 1):

Let f_o be the frequency of the centre of the band of frequencies occupied (Mc/s);

f_n be the centre frequency of one radio-frequency channel in the lower half of this band (Mc/s);

f'_n be the centre frequency of one radio-frequency channel in the upper half of this band (Mc/s);

then the frequencies (Mc/s) of the individual channels are expressed by the following relationships:

lower half of band: $f_n = f_o - 154 + 7\,n$ **,

upper half of band: $f'_n = f_o + 7 + 7\,n$ **,

where $n = 1, 2, 3, \ldots, 20$;

* This Recommendation, which replaces Recommendation 284, applies only to line-of-sight and near line-of-sight radio-relay systems.

** The formulae for f_n and f'_n and the values for f_o given here differ from those given in Recommendation 284 (Los Angeles 1959). This change, which is purely formal, has been made so that the "centre frequency" f_o falls, in reality, in the centre of the and of frequencies occupied. No change in the individual channel frequencies will result from this modification.

2. that in a section over which the international connection is arranged, all the *go* channels should be in one half of the band and all the *return* channels should be in other half of the band;

3. that when common transmit-receive antennae are used and three radio-frequency channels are accommodated on a single antenna, it is preferable that the channel frequencies be selected by making:

   $n = 1$, 8 and 15, or
   $n = 2$, 9 and 16, or
   $n = 3$, 10 and 17, or
   $n = 4$, 11 and 18, or
   $n = 5$, 12 and 19, or
   $n = 6$, 13 and 20,

   in both halves of the band;

4. that for international connections, the centre frequency should preferably be:

   $f_o = 7575$ Mc/s for the band 7425–7725 Mc/s *;

   other centre frequencies may be used in certain geographical areas by agreement between the Administrations concerned; (e.g.):

   $f_o = 7275$, 7400 or 7700 Mc/s *;

5. that the channel arrangement and antenna polarization should be agreed between the Administrations concerned;

6. that, when systems with 300 telephone channels are operated in a radio-frequency band, channel combinations which result in differences between channel frequencies of less than 14 Mc/s, should in general be avoided. If sufficient antenna discrimination is available, this precaution may be disregarded.

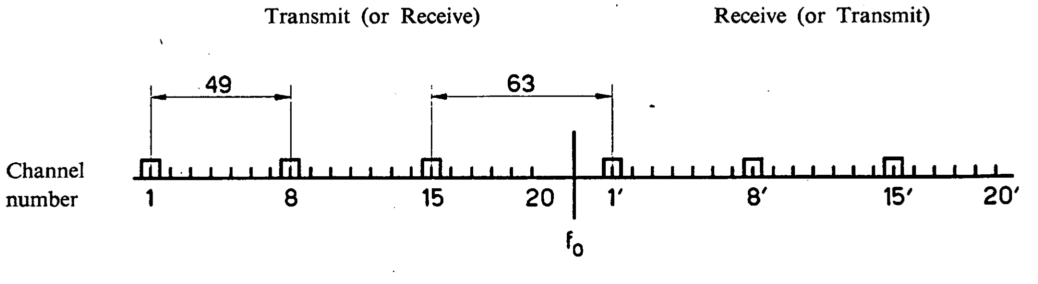


FIGURE 1

Radio-frequency channel arrangement for international connection of radio-relay systems for 60, 120 or 300 channels operating in the 7 Gc/s band
(All frequencies are in Mc/s)

---

* The formulae for f_n and f'_n and the values for f_o given above differ from those given in Recommendation 284 (Los Angeles, 1959). This change, which is purely formal, has been made so that the "centre frequency" f_o falls, in reality, in the centre of the band of frequencies occupied. No change in the individual channel frequencies will result from this modification.

RECOMMENDATION 386

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Radio-frequency channel arrangements for systems with a capacity of 960 telephone channels, or the equivalent, operating in the 8 Gc/s band

(Question 192 (IX))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that it may be desirable to be able to interconnect radio-relay systems on international circuits in the 8 Gc/s band at radio frequencies;

(b) that, for some Administrations, a frequency band, 300 Mc/s wide, may be available in the 8 Gc/s range for such systems;

(c) that it may be desirable to interconnect in such a band up to six systems with a capacity of 960 channels or the equivalent;

(d) that such a frequency arrangement should also be suitable for 300 channel systems;

(e) that for reasons of frequency economy, it is desirable to interleave additional radio-frequency channels between those of the main pattern;

(f) that economy may be achieved, if at least three go and three return channels can be interconnected between systems using common transmit-receive antennae;

(g) that many interfering effects can be minimized by a carefully planned frequency arrangement for systems employing several radio-frequency channels;

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement in the 8 Gc/s band, should be derived as follows:

Let f_0 be the frequency of the centre of the band of frequencies occupied (Mc/s);

f_n be the centre-frequency of one radio-frequency channel in the lower half of this band (Mc/s);

f'_n be the centre-frequency of one radio-frequency channel in the upper half of this band (Mc/s);

then the frequencies of the individual channels are expressed by the following relationships:

lower half of band: $f_n = f_0 - 151{\cdot}614 + 11{\cdot}662\, n$,
upper half of band: $f'_n = f_0 + 11{\cdot}662\, n$,

where for systems with a capacity of 960 telephone channels or the equivalent

$n = 1, 3, 5, 7, 9$ and 11;

for systems with a capacity of 300 telephone channels:

$n = 1, 2, 3, 4, 5, \ldots, 12$;

2. that in a section over which the international connection is arranged, all the *go* channels should be in one half of the band, and all the *return* channels should be in the other half of the band;

3. that for adjacent radio-frequency channels in the same half of the band horizontal and vertical polarization shall be used alternately;

4. that when common transmit-receive antennae are used and three radio-frequency channels are accommodated on a single antenna, it is preferable that for systems with a capacity of 960 telephone channels (or the equivalent), channel frequencies be selected by making:

$n = 1$, 5 and 9
or
$n = 3$, 7, and 11
} in both halves of the band;

when using systems with a capacity of 300 telephone channels it is preferable to select:

$n = 1$, 5 and 9 or
$n = 2$, 6 and 10 or
$n = 3$, 7 and 11 or
$n = 4$, 8 and 12
} in both halves of the band;

5. that when additional radio-frequency channels are required for 960 channel systems or the equivalent, interleaved between those of the main pattern, the value of the centre frequency shall be obtained by making:

$n = 2$, 4, 6, 8, 10 and 12;

6. that for international connections the centre frequency should preferably be:

$f_0 = 8350$ Mc/s

this value corresponds to the band 8200–8500 Mc/s. Other values may be taken by agreement between the Administrations concerned.

Note. — This radio-frequency channel arrangement permits all local oscillator frequencies to be derived from the common oscillator frequency 11·662 Mc/s.

The frequency pattern allows for economical use of the frequency band, but as a result of the intermediate frequency of 70 Mc/s being a multiple of the channel spacing, adequate system selectivity will have to be provided to avoid undue interference.

RECOMMENDATION 387

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Radio-frequency channel arrangements for systems with a capacity of 960 channels, or the equivalent, operating in the 11 Gc/s band

(Question 192 (IX))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that at 11 Gc/s, radio-relay systems with a capacity of up to 960 telephone channels or television seem to be feasible in many regions of the world where rainfall conditions permit, and if the repeater spacing is planned with regard to the specific climatic conditions of a country;

(b) that it is desirable to interconnect such systems at radio-frequencies on international circuits;

(*c*) that a uniform radio-frequency channel arrangement for both smaller and larger capacities offers considerable advantages;

(*d*) that in a frequency band 1000 Mc/s wide it may be desirable to interconnect up to twelve go and twelve return channels;

(*e*) that economy may be achieved if at least three go- and three return-channels can be accommodated on a common antenna;

(*f*) that it may sometimes be desirable to interleave additional radio-frequency channels between those of the main pattern;

(*g*) that the channels should be so arranged as to enable an intermediate frequency of 70 Mc/s to be used;

UNANIMOUSLY RECOMMENDS

1. that the preferred radio-frequency channel arrangement for radio-relay systems with a maximum capacity of 960 telephone channels, or the equivalent, and operating in the 11 Gc/s band should be derived as follows:

Let f_o be the frequency (Mc/s) of the centre of the band of frequencies occupied;

f_n be the centre frequency (Mc/s) of one radio-frequency channel in the lower half of the band;

f'_n be the centre frequency (Mc/s) of one radio-frequency channel in the upper half of the band;

then the frequencies (Mc/s) of individual channels are expressed by the following relationship:

lower half of the band, $f_n = f_o - 525 + 40\,n$,
upper half of the band, $f'_n = f_o + 5 + 40\,n$,

where $n = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11$ or 12.

The frequency arrangement is illustrated in Fig. 1;

2. that when additional radio-frequency channels, interleaved between those of the main pattern are required, the values of the centre frequencies of these radio-frequency channels should be 20 Mc/s below those of the corresponding main channel frequencies *;

3. that when radio-frequency channels are also required for auxiliary radio-relay systems, the preferred frequencies for 11 go- and 11 return-channels, including two pairs of auxiliary channels in both the main and interleaved patterns should be derived by making:

$n = 2, 3, 4 \ldots 12$ in the lower half of the band,
$n = 1, 2, 3 \ldots 11$ in the upper half of the band.

The radio frequencies (Mc/s) for the auxiliary systems should be chosen as shown below:

	Main pattern	*Interleaved pattern*
lower half of the band	$f_o - 485$	$f_o - 495$
	$f_o - 15$	$f_o - 25$
upper half of the band	$f_o + 15$	$f_o + 2{\cdot}5$
	$f_o + 485$	$f_o + 465$

The radio-frequency arrangement is illustrated in Fig. 2, which also shows a possible polarization arrangement;

4. that in a section over which the international connection is arranged, all the *go* channels should be in one half of the band and all the *return* channels should be in the other half of the band;

* Channel 1 of the interleaved pattern in the lower half of the band is beyond the lower extremity of a 1000 Mc/s band and may therefore not be available for use.

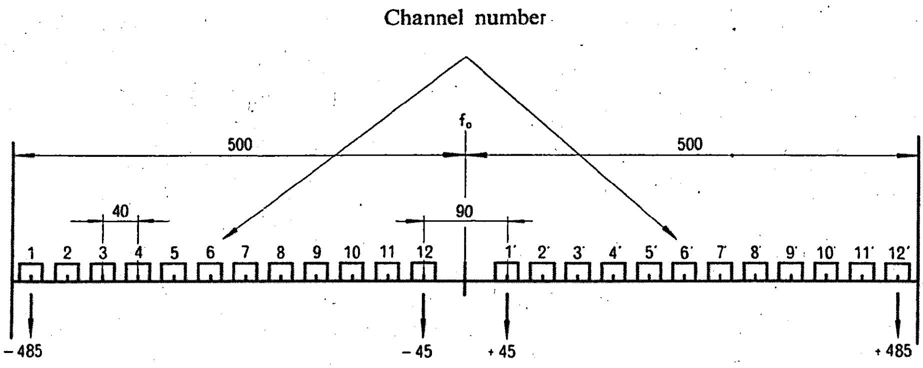


FIGURE 1

Radio-frequency channel arrangement for radio-relay systems operating in the 11 Gc/s band (Main pattern)

(All frequencies in Mc/s)

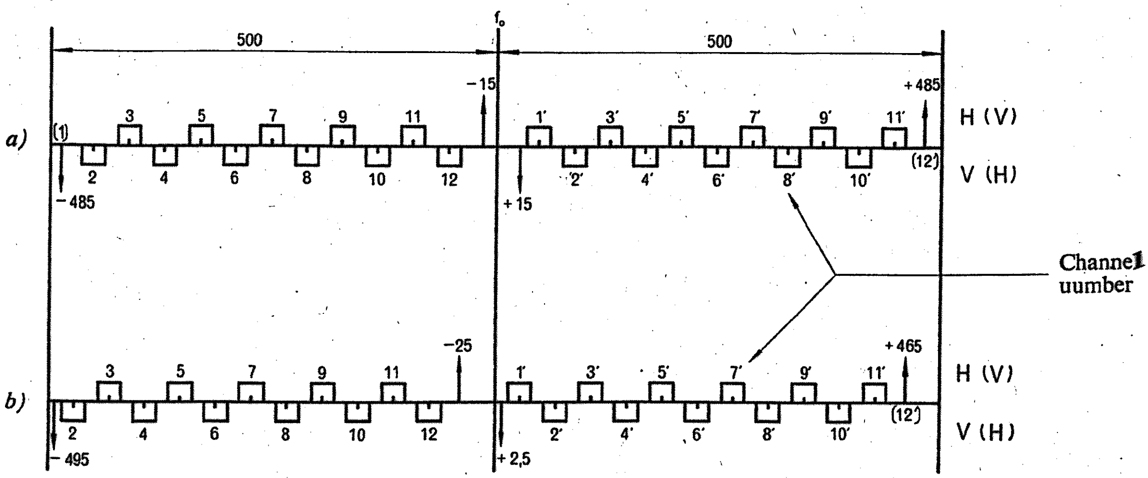


FIGURE 2

Radio-frequency channel arrangement for main and auxiliary radio-relay systems operating in the 11 Gc/s banp

(All frequencies in Mc/s)

(a) Main pattern

(b) Interleaved pattern

5. that if, for example, only three go-and three return-channels are accommodated on a common transmit-receive antenna, it is preferable that the channel frequencies (in Mc/s) be selected by making:

$n = 1, 5, 9$ or
$n = 2, 6, 10$ or
$n = 3, 7, 11$ or
$n = 4, 8, 12$

in both halves of the band;

6. that for adjacent radio frequency channels in the same half of the band different polarizations should preferably be used alternately;

7. that the preferred centre frequency is 11 200 Mc/s; other centre frequencies may be used by agreement between the Administrations concerned.

RECOMMENDATION 388 *

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Radio-frequency channel arrangements

(Question 260 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that tropospheric-scatter radio-relay systems are already in service and that systems of this type will come into more extensive use in the future;

(b) that the high radiated power of tropospheric-scatter radio-relay systems and the long range of tropospheric-scatter propagation may give rise to serious interference at distances extending beyond international boundaries, for example 1000 km;

(c) that interference both between and within tropospheric-scatter radio-relay systems could be minimized by the co-ordination of radio-frequency channel arrangements over a large geographical area;

(d) that many interfering effects between equipments at the same station could be minimized by a carefully planned arrangement of radio frequencies;

(e) that some technical information for the planning of such systems exists, but that the design of tropospheric-scatter radio-relay systems is subject to change;

(f) that different methods of modulation are at present being used or proposed, among them frequency modulation and single-sideband amplitude modulation;

(g) that, at the present time, standardization of preferred radio-frequency channel arrangements might therefore unduly restrict the future development of tropospheric-scatter radio-relay systems;

(h) that, nevertheless, a common basis for planning such systems is desirable;

UNANIMOUSLY RECOMMENDS

1. that the radio-frequency channel arrangements for the international connection of tropospheric-scatter radio-relay systems should be agreed between the Administrations concerned;

---

* This Recommendation replaces Recommendation 303.

2. that the basis of planning of the radio-frequency channel arrangements for radio-relay systems using frequency modulation given in Report 286 may be used, where appropriate, as a guide.

RECOMMENDATION 389 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred characteristics of auxiliary radio-relay systems operating in the 2, 4, 6 or 11 Gc/s bands

(Question 195 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that an auxiliary radio-relay system may be required for the provision of service channels for the maintenance, supervision and control of radio-relay links using either the radio-frequency channel arrangements of Recommendations 382, 383 or 387;

(b) that sometimes, the auxiliary radio-relay system may be required to operate with frequencies in or near the band of the main radio-relay system, and may, for reasons of economy, share the same antennae;

(c) that occasionally, a different frequency band from that of the main radio-relay system may be preferred for the auxiliary radio-relay system (Study Programme 195A (IX));

(d) that the characteristics of an auxiliary radio-relay system sharing the same frequency band as the main radio-relay system and, in particular, the radio-frequency channel arrangement, should be such as not to cause mutual interference;

(e) that the auxiliary radio channels may employ either frequency or amplitude modulation;

(f) that two pairs of frequency allocations may be needed for the auxiliary radio-relay system to provide either two normal service channels in each direction, or a normal service channel and a stand-by service channel in each direction, and to allow for the use of frequency diversity where this is essential and other forms of diversity are not practicable;

(g) that the numbers of the service channels to be provided and their functions have been defined in Recommendation 400;

UNANIMOUSLY RECOMMENDS

1. that for an auxiliary radio-relay system sharing the same frequency band as the main radio-relay system, operating in the 2 or 4 Gc/s bands (Recommendation 382), the preferred frequencies (Mc/s) of the radio-frequency channels of the auxiliary system should be related to the centre frequency f_o of the normal pattern of the main system as shown below:

Normal:

lower half of band: $f_o - 204{\cdot}5$ and $f_o - 12$
upper half of band: $f_o + 8{\cdot}5$ and $f_o + 199$

* This Recommendation replaces Recommendation 296.

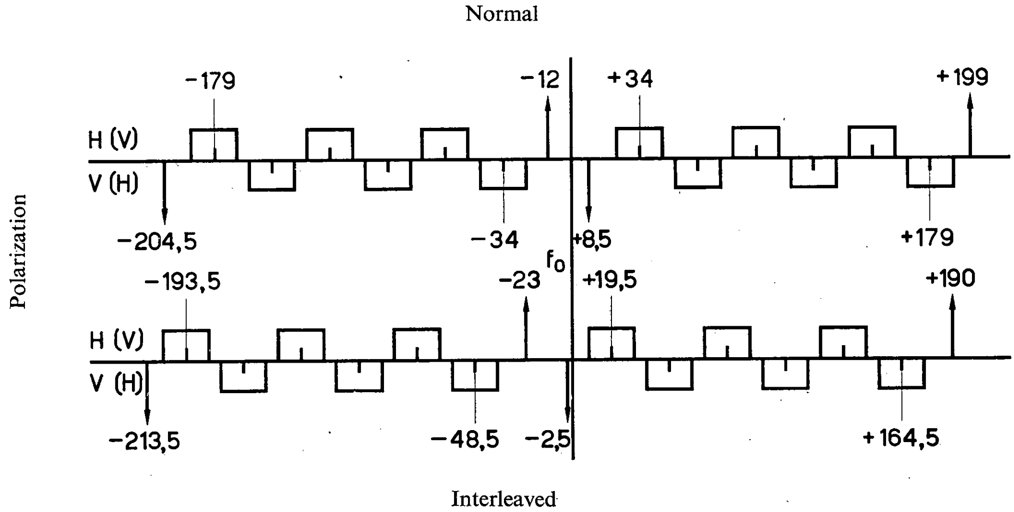


FIGURE 1

Radio-frequency channel arrangement for main and auxiliary radio-relay systems operating in the 2 and 4 Gc/s bands

(All frequencies are in Mc/s)

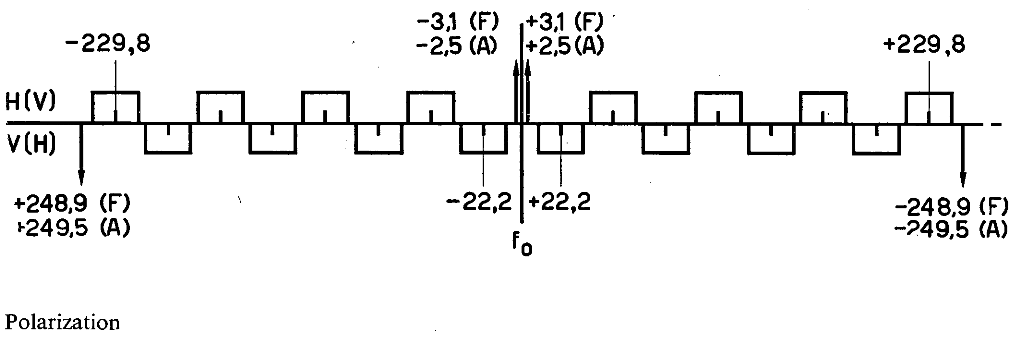


FIGURE 2

Radio-frequency channel arrangement for main and auxiliary radio-relay systems operating in the 6 Gc/s band

(All frequencies are in Mc/s)

↑ or ↓ indicate the radio-frequency channels of the auxiliary radio-relay system

A indicates amplitude-modulation

F indicates frequency-modulation

Interleaved:

lower half of band: f_o — 213·5 and f_o — 23
upper half of band: f_o — 2·5 and f_o + 190.

The arrangement of the radio-frequency channels and the preferred polarizations are shown in Fig. 1. Other radio-frequency channel arrangements for the auxiliary radio-relay systems may be used by agreement between the Administrations concerned;

2. that, for an auxiliary radio-relay system sharing the frequency band of the main radio-relay system, operating in the 6 Gc/s band (Recommendation 383), the preferred frequencies (in Mc/s) of this auxiliary system radio-frequency channels should be related to the centre-frequency f_o of the normal pattern of the main system, as shown below:

2.1 *For frequency-modulated systems *:*

lower half of band: f_o — 248·9 and f_o — 3·1,
upper half of band: f_o + 3·1 and f_o + 248·9;

2.2 *For amplitude-modulated or frequency-modulated systems *:*

lower half of band: f_o — 249·5 and f_o — 2·5,
upper half of band: f_o + 2·5 and f_o + 249·5.

The arrangement of the radio-frequency channels and the preferred polarizations are shown in Fig. 2;

3. that for an auxiliary radio-relay system sharing the frequency band of the main radio-relay system operating in the 11 Gc/s band (Recommendation 387), the preferred provisions to that end, set out in § 3 of that Recommendation, should be observed;

4. that the other characteristics of the auxiliary radio-relay system should be the subject of further study and, for the present, be subject to agreement between the Administrations directly concerned.

---

* Apart from the type of modulation, certain other characteristics (e.g. load on main channels, frequency stability, frequency allocation plan of the adjacent bands) should be taken into account, in accordance with Study Programme 195A(IX).

F. 3 - Hypothetical reference circuits and noise

RECOMMENDATION 289

RADIO-RELAY SYSTEMS FOR MONOCHROME TELEVISION

Permissible noise in the hypothetical reference circuit

(Questions 193 (IX) and 194 (IX))

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that the hypothetical reference circuit defined in Recommendation 421 is intended as a guide to designers and constructors of actual systems;

(b) that the total noise power in a radio-relay system is dependent on the one hand upon a number of factors concerned with equipment design, and on the other hand upon the path attenuation and the variation of path attenuation with time, which are in turn dependent upon factors such as the spacing of stations and the nature of the intervening terrain;

(c) that the total noise power in the hypothetical reference circuit should not be such as would appreciably affect the transmission of television signals;

(d) that the minimum signal-to-noise ratios which should be achieved are stated in § 3.3.1 of Recommendation 421 (see Note 1 below); however, certain difficulties arise in the use of a noise objective relating to 1% of a month and it is therefore desirable to express the noise objective in terms of other percentages of a month;

(e) that on radio-relay systems it may be necessary to accept slightly lower signal-to-noise ratios for very small percentages of time;

(f) that on radio-relay systems it is possible to provide a better signal-to-noise ratio for the majority of the time than is required by Recommendation 421;

(g) that the relative distribution with time of noise on radio-relay systems for television or frequency-division multiplex telephony will be similar and it is appropriate therefore to employ similar methods for specifying the noise performance;

(h) that a simple method is required of defining the noise contributions of the different sections of the hypothetical reference circuit;

(i) that to take account of the daily and seasonal variations in radio propagation conditions the period of time considered should be long, e.g. a month;

(j) that in Recommendation 421 the use of instruments with an effective time constant or integrating time of 1 s, is recommended and Administrations are asked to make measurements with instruments having this time constant;

UNANIMOUSLY RECOMMENDS

1. that in the 2500 km hypothetical reference circuit for the transmission of television, the ratio of the peak-to-peak signal, excluding synchronizing pulses, to the r.m.s. value of continuous random noise read on an instrument having an effective time constant (or integrating time) in terms of power of one second, and using the recommended weighting network (see Note 1), should not fall below values given below in terms of X, where X is the appropriate figure taken from the table in Note 1 (see also Note 3):

1.1 $(X + 4)$ db for more than 20% of any month;

1.2 (X — 8) db for more than 0·1% of any month;
these values are provisional;

2. that in a part of a hypothetical reference circuit consisting of one or two of the three equal homogeneous sections defined by Recommendation 421, the mean noise power which should not be exceeded for more than 20% of a month shall be considered to be proportional to the number of homogeneous sections involved (see Note 4);

3. that in a part of a hypothetical reference circuit consisting of one or two of the three equal homogeneous sections defined by Recommendation 421, the small percentages of a month during which the signal-to-noise ratio may fall below the values indicated in § 1.2 above shall be regarded as proportional to the number of homogeneous sections involved (see Note 5).

Note 1. — The numerical values of X should be those given in Recommendation 421 from which the following extracts are taken:

"The signal-to-noise ratio for continuous random noise is defined as the ratio, expressed in decibels, of the peak-to-peak amplitude of the picture signal (see Fig. 2) to the r.m.s. amplitude of the noise within the range between 10 kc/s and the nominal upper limit of the video frequency band, f_c. The purpose of the lower frequency limit is to enable power supply hum and microphonic noise to be excluded from practical measurements.

For the hypothetical reference circuit, the signal-to-noise ratio should not be less than the values given in Table I when measured with the appropriate low-pass filter described in Annex II, the appropriate weighting network described in Annex III, and an instrument having an "effective time constant" or "integrating time" in terms of power, of 1 s (0·4 s in the U.S.A. and Canada);"

TABLE I

System	No. of lines	405	525	625	625	819	819
System	Nominal upper limit of video fre-band, fc (Mc/s)	3	4	5	6	5	10
Signal-to-wieghted-noise ratio X (db) . . .		50	52 (Japan) 56 (U.S.A. and Canada)	52	57		50

Note 2. — The Recommendation relates only to "line-of-sight" radio-relay systems with adequate clearance over intervening terrain.

Note 3. — Based on the information supplied by the joint C.C.I.T.T./C.C.I.R. Working Party on circuit noise obtained from measurements, with a time constant of one minute of the total noise (thermal noise and cross-talk) of telephone circuits, it is likely that signal-to-thermal noise ratio for 20% of one month and the signal-to-thermal-noise ratio for 0·1% of one month at the most will differ by about 12 db; the signal-to-thermal noise ratio obtained during at least 99% of one month, mentioned by the television specialists, is likely to be lower by about 4 db than the signal-to-noise ratio for 20% of a month; this explains the values (X + 4) db and (X — 8) db shown in § 1, these values being such that the signal-to-noise ratio obtained during at least 99% of one month must be equal to X db as the television specialists desire.

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

Note 4. — The law of proportionality given in § 2, is based on the assumption that noise due to fading can be neglected for all but 20% of a month, and that the noise exceeded for 20% of a month corresponds to the mean noise in the absence of fading.

Note 5. — The law of proportionality given in § 3 is based on the assumption that individual fades which:

— are of such magnitude that they occur for only very small percentages of time;

— originate in different sections of a complete circuit;

do not occur simultaneously. This assumption may not always be completely justifiable, but the error is small, and the approximation is regarded as acceptable.

Note 6. — This Recommendation relates to the hypothetical reference circuit. The figures given are design objectives, but it is not intended that they should be quoted in specifications of equipment or used for acceptance tests.

RECOMMENDATION 300 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING TIME-DIVISION MULTIPLEX

Hypothetical reference circuit for radio-relay systems with a capacity of 60 telephone channels or less

(Question 193 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that it is desired to define hypothetical reference circuits for radio-relay systems to offer guidance to the designers of equipment and systems for use in international telecommunication networks;

(b) that time-division multiplex radio-relay systems may form a part of an international circuit;

(c) that hypothetical reference circuits for radio-relay systems should, as far as possible, be in agreement with the hypothetical reference circuits specified by the C.C.I.T.T. for cable systems;

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for time-division multiplex radio-relay systems with a capacity of 60 or less telephone channels per radio channel should be 2500 km long;

2. that this reference circuit should be constituted by six sections of equal length with voice-channel modulation and demodulation at each terminal of a section.

* This Recommendation, which together with Recommendation 301 replaces Recommendation 201, applies only to line-of-sight and near line-of-sight radio-relay systems.

RECOMMENDATION 302

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Limitation of interference

(Question 196 (IX))

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that tropospheric-scatter radio-relay systems can cause interference over large distances which in many cases may extend across national boundaries;

(b) that line-of-sight systems are far less likely to cause international interference;

(c) that tropospheric-scatter systems need some form of diversity to circumvent fading;

(d) that multiple-diversity can be provided without using additional frequencies, e.g. by employing spaced antennae, with or without cross-polarization;

UNANIMOUSLY RECOMMENDS

in planning tropospheric-scatter radio-relay systems:

1. that account be taken of the high degree of international co-ordination and planning which will be involved if tropospheric-scatter radio-relay systems of this type are to occupy the same frequency bands in nearby countries without mutual interference, and that the problem would become much more complex if in addition they were to occupy the same frequency bands as conventional line-of-sight systems or other services;
2. that the utmost frequency-economy should be observed;
3. that frequency-diversity should be avoided as far as possible, particularly in those parts of the world where the frequency spectrum is likely to become congested;
4. that special efforts should be made to operate such radio-relay systems at the lowest practicable level of radiated power;
5. that special efforts should be made to reduce radiation in and reception from undesired directions;
6. that special efforts should be made to reduce spurious emissions to the lowest practicable level.

RECOMMENDATION 303

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Radio-frequency channel arrangements

(Question 260 (IX))

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that tropospheric-scatter radio-relay systems are already in service and that systems of this type will come into more extensive use in the future;

(b) that the high radiated power of tropospheric-scatter systems and the long range of tropospheric-scatter propagation may give rise to serious interference at distances extending beyond international boundaries, for example 1000 km;

(c) that interference both between and within tropospheric-scatter systems could be minimized by the co-ordination of radio-frequency channel arrangements over a large geographical area;

(d) that many interfering effects between equipments at the same station could be minimized by a carefully planned arrangement of radio frequencies;

(e) that some technical information for the planning of such systems exists, but that the design of tropospheric-scatter radio-relay systems is subject to change;

(f) that different methods of modulation are at present being used or proposed, among them frequency modulation and single-sideband amplitude modulation;

(g) that, at present, no definite frequency bands are allocated to tropospheric-scatter radio-relay systems;

(h) that, at the present time, standardization of preferred radio-frequency channel arrangements might therefore unduly restrict the future development of tropospheric-scatter radio-relay systems;

(i) that, nevertheless, a common basis for planning such systems is desirable;

UNANIMOUSLY RECOMMENDS

1. that the radio-frequency channel arrangements for the international connection of tropospheric-scatter radio-relay systems should be agreed between the Administrations concerned;

2. that the basis of planning of the radio-frequency channel arrangements for radio-relay systems using frequency modulation given in Report 286 may be used, where appropriate, as a guide.

RECOMMENDATION 390

DEFINITIONS OF HYPOTHETICAL REFERENCE CIRCUITS

(Question 193 (IX))

The C.C.I.R. (Geneva, 1963)

UNANIMOUSLY RECOMMENDS

that the following definitions be used for defining the nature and properties of hypothetical reference circuits.

1. Hypothetical reference circuit.

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

It is a necessary element in the study of certain characteristics of long-distance circuits (e.g., noise).

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

2. Hypothetical reference circuit for telephony.

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

Various "hypothetical reference circuits for telephony" have been defined to permit coordination between the various specifications for the constituent parts of multiplex carrier telephony systems, so that the complete telephone circuits established over these systems should satisfy the C.C.I.T.T. standards. (See § 5.2, 5.3, 5.4, 5.7).

These various hypothetical reference circuits are all conceived for the same total length (except of course, hypothetical reference circuits for satellite systems) and type of operation. They are intended, as a guide only, in the planning of carrier systems.

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

3. Homogeneous section (for telephony).

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

All hypothetical reference circuits are built up from homogeneous sections of equal length (six or nine sections ** as the case may be).

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

4. Other definitions.

Using the same principles, other hypothetical reference circuits and homogeneous sections have been determined for other types of signals; television, programme circuits, etc. (See § 5.5, 5.6, 5.7).

5. References.

5.1 *General definition* — C.C.I.T.T. Recommendation G. 212, Vol. III.

5.2 *Hypothetical reference circuit for telephony* — C.C.I.T.T. Recommendation G. 212, Vol. III

- — on symmetrical cable pairs — C.C.I.T.T. Recommendation G. 321, Vol. III, § A. *a*,
- — on coaxial cables (4 Mc/s systems) — C.C.I.T.T. Recommendation G. 332, Vol. III, § *d*,
- — on coaxial cables (12 Mc/s systems) — C.C.I.T.T. Recommendation G. 333, Vol. III, § *d*,
- — on open wire lines — C.C.I.T.T. Recommendation G. 311, Vol. III, § *g*.

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

- — using frequency-division multiplex (with a capacity of 12 to 60 telephone channels) — C.C.I.R. Recommendation 391,
- — using frequency-division multiplex (for more than 60 telephone channels) — C.C.I.R. Recommendation 392,
- — using time-division multiplex with a capacity of 60 telephony channels or less — C.C.I.R. Recommendation 300.

5.4 *Hypothetical reference circuit for telephony on tropospheric-scatter radio-relay systems*

- — using frequency-division multiplex — C.C.I.R. Recommendation 396.

* Except for the hypothetical reference circuit for radio-relay systems using time-division multiplex, which contain six pairs of channel modulators.

** The number is not specified for tropospheric-scatter systems.

5.5 *Hypothetical reference circuit for television* — C.C.I.R. Recommendation 421, § 1.2.

5.6 *Hypothetical reference circuit for programme circuits* — C.C.I.T.T. Recommendation J. 21, Vol. III.

5.7 *Hypothetical reference circuit for satellite systems* — C.C.I.R. Recommendation 352.

RECOMMENDATION 391 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Hypothetical reference circuit for radio-relay systems with a capacity of 12 to 60 telephone channels

(Question 193 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it is desired to establish hypothetical reference circuits for radio-relay systems to afford guidance to the designers of equipment and systems for use in international telecommunication networks;

(b) that hypothetical reference circuits for radio-relay systems should, as far as possible, be in agreement with the hypothetical reference circuits specified by the C.C.I.T.T. for cable systems;

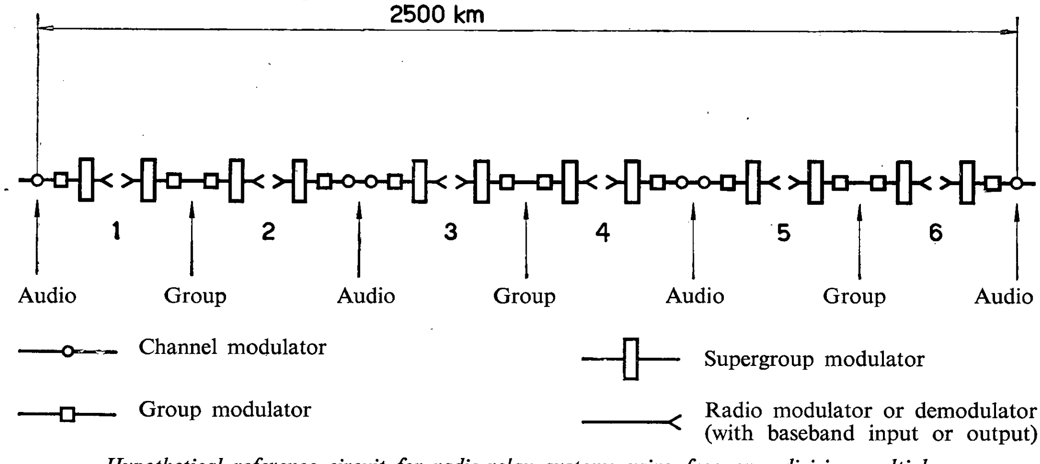
UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for frequency-division multiplex radio-relay systems with a capacity of 12 to 60 telephone channels per radio channel should be 2500 km long;

2. that this circuit should include, for each direction of transmission:
- 3 sets of channel modulators,
- 6 sets of group modulators,
- 6 sets of supergroup modulators,

it being understood that a "set of modulators" comprises a modulator and a demodulator;

3. that this circuit should include, respectively, six sets of radio modulators and demodulators, for each direction of transmission and that these should divide the circuit into six homogeneous sections of equal length.



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

---

* This Recommendation, which replaces Recommendation 285, applies only to line-of-sight and near line-of-sight radio-relay systems.

RECOMMENDATION 392 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Hypothetical reference circuit for radio-relay systems with a capacity of more than 60 telephone channels

(Question 193 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it is desired to establish hypothetical reference circuits for radio-relay systems, to afford guidance to the designers of equipment and systems for use in international telecommunication networks;

(b) that hypothetical reference circuits for radio-relay systems should, as far as possible, be in agreement with the hypothetical reference circuits specified by the C.C.I.T.T. for cable systems;

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for frequency-division multiplex radio-relay systems with a capacity of more than 60 telephone channels per radio channels should be 2500 km long;

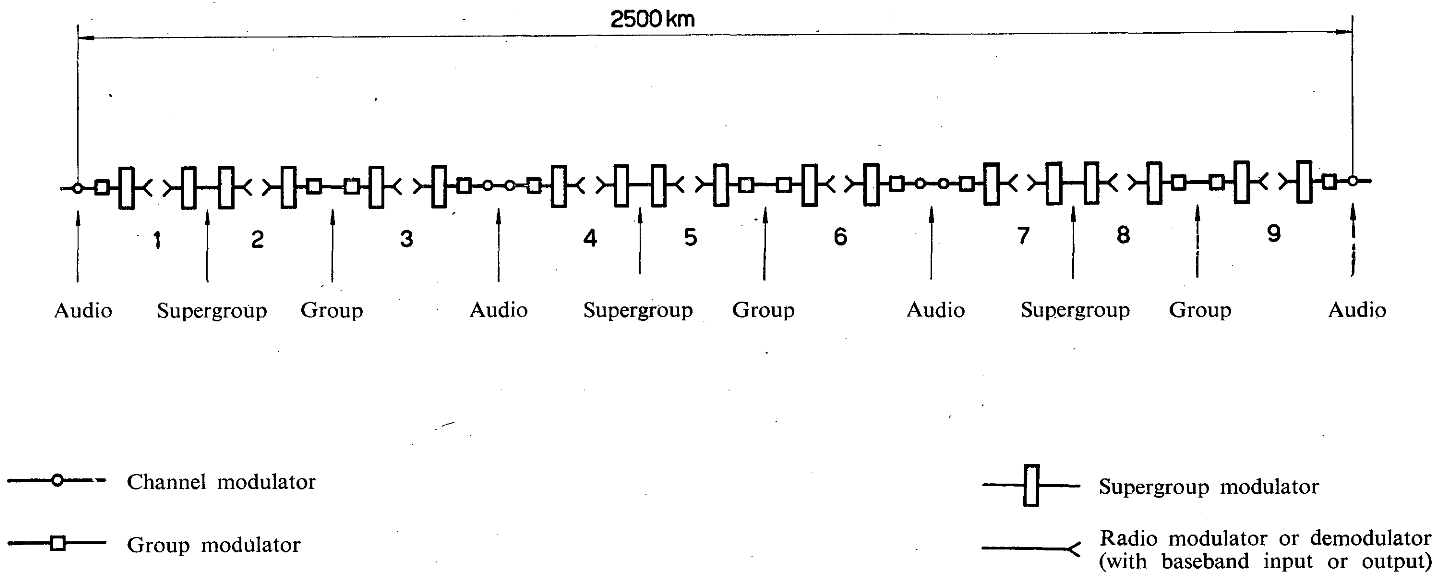
2. that this circuit should include, for each direction of transmission:

— 3 sets of channel modulators,
— 6 sets of group modulators,
— 9 sets of supergroup modulators,

it being understood that a "set of modulators" comprises a modulator and a demodulator;

3. that this circuit should include nine sets of radio modulators and demodulators respectively, for each direction of transmission, and that these should divide the circuit into nine homogeneous sections of equal length.

* This Recommendation, which replaces Recommendation 286, applies only to line-of-sight and near line-of-sight radio-relay systems.



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

RECOMMENDATION 393 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Allowable noise power in the hypothetical reference circuit

(Question 193 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

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

(b) that the total noise power in a radio-relay system is dependent on the one hand upon a number of factors concerned with equipment design, and on the other hand upon the path attenuation and the variation of path attenuation with time, which are in turn dependent upon factors such as the spacing of stations and the nature of the intervening terrain;

(c) that the total noise power in the hypothetical reference circuit should not be such as would appreciably affect conversation in a substantial number of telephone calls or the transmission of telephone signalling;

(d) that, in the opinion of the C.C.I.R., based on evidence so far available from the C.C.I.T.T., the typical distributions of one-minute-mean noise power in any month given in the Annex would not seriously affect telephone conversations;

(e) that, if the conditions given in Notes 3 and 4 of this Recommendation were met, it is unlikely that there would be large numbers of noise surges either of long or of short duration and interference to telephone signalling due to such noises could be neglected;

UNANIMOUSLY RECOMMENDS

1. that the noise power at a point of zero relative level in any telephone channel on a 2500 km hypothetical reference circuit for frequency-division multiplex radio-relay systems should not exceed the provisional values given below, which have been chosen to take account of fading:

1.1 7500 pW psophometrically weighted ** mean power in any hour ***;

1.2 7500 pW psophometrically weighted ** one-minute mean power **** for more than 20% of any month;

1.3 47 500 pW psophometrically weighted ** one-minute mean power for more than 0·1% of any month;

1.4 1 000 000 pW unweighted (with an integrating time of 5 ms) for more than 0·01% of any month;

2. that in a part of hypothetical reference circuit consisting of one or more of the equal homogeneous sections defined in Recommendations 391 and 392, the mean noise power in any hour, and the one-minute mean noise power in 20% of a month shall be considered to be proportional to the number of homogeneous sections involved;

* This Recommendation replaces Recommendation 287.

** The level of uniform-spectrum noise power in a 3·1 kc/s band must be reduced by 2·5 db to obtain the psophometrically-weighted noise power.

*** The hours when the noise is greatest are usually those in which the fading is most severe. These hours will sometime be different from the busy hours.

**** The one-minute mean power was chosen by C.C.I.T.T. Study Group XII which is responsible for all studies concerned with the quality of telephone transmission (C.C.I.T.T. Red Book, 1957, Vol. I, pp. 110 and 662).

3. that in parts of a hypothetical reference circuit consisting of one or more of the equal homogeneous sections defined in Recommendations 391 and 392, the small percentage of a month in which the one-minute mean power many exceed 47 500 pW and in which the 5 ms noise power may exceed 1 000 000 pW shall be regarded as proportional to the number of homogeneous sections involved;

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

Note 1. — Noise in the frequency-division-multiplex equipments is excluded from the above. On a 2500 km hypothetical reference circuit the C.C.I.T.T. allows 2500 pW mean value for this noise in any hour.

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

Note 3. — The Recommendation relates only to "line-of-sight" radio-relay systems with adequate clearance over intervening terrain.

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

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

Note 6. — Designers should indicate their own assumptions regarding the lengths of repeater sections, the nominal attenuation between transmitter outputs and receiver inputs, intermodulation noise in feeders and the radio path, possible interference between the radio channels of the system under consideration, precautions taken against fading, in particular the use or otherwise of diversity reception and protection channels, and the distribution curve of fading over short periods of time. It is preferred that the predicted distribution curve of one-minute mean noise power in any month should satisfy the values recommended in §§ 1.2 and 1.3. Designers are expected to fit their distribution curves to fall below both values. That portion of the curve relating to 50% or so of the time will then give the "non-fading" noise value upon which the design is based.

Note 7. — It is assumed that at junctions between the homogeneous sections of a hypothetical reference circuit the telephone channels, groups, supergroups and mastergroups are interconnected at random; and that the noise coming from the homogeneous sections of the hypothetical reference circuit is power-additive.

Note 8. — It will be assumed that, during the busy hour, the multiplex signal can be represented by a uniform-spectrum signal, the mean power absolute level of which, at a point of zero relative level is equal to $(-15 + 10 \log_{10}N)$ dbm for 240 channels or more, and $(-1 + 4 \log_{10}N)$ dbm* for numbers of channels between 12 and 240, N being the total number of channels for which the radio-relay system is to be designed.

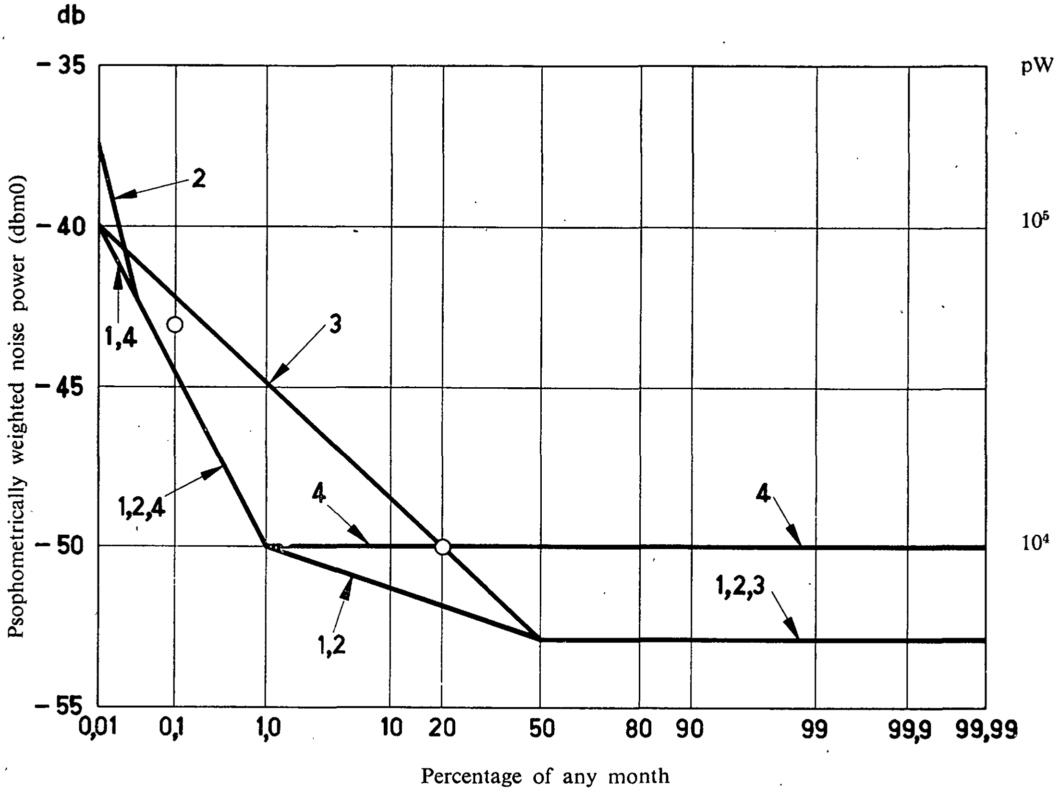
Note 9. — The requirement indicated by § 1.4 is related to the need to transmit signalling for telephony satisfactorily. It is also related to the need for VF telegraphy at 50 bauds over telephone channels. Whereas the requirement indicated by § 1.4 is likely to be satisfactory when 50 baud, frequency-modulation VF telegraph equipment is used, the extent to which the operation of 50 baud, amplitude-modulation VF telegraphy systems will be satisfactory is still under study by the C.C.I.T.T.

---

* This value is provisional for systems the capacity of which is less than 60 channels.

ANNEX I

EXAMPLES OF DISTRIBUTION CURVES FOR THE PSOPHOMETRICALLY WEIGHTED ONE-MINUTE MEAN NOISE POWER AT THE END OF THE HYPOTHETICAL REFERENCE CIRCUIT



The noise figures include 2500 pW for terminal equipments.

O Design objectives, including terminal noise.

The numbers 1 to 4 are used to distinguish the curves.

RECOMMENDATION 394 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING TIME-DIVISION MULTIPLEX

Allowable noise power in the hypothetical reference circuit

(Question 193 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that a hypothetical reference circuit for radio-relay systems for telephony using time-division multiplex has been defined in Recommendation 300;

* This Recommendation replaces Recommendation 301.

(b) that the total noise power in the hypothetical reference circuit should not be such as would appreciably affect conversation in a substantial number of telephone calls or the transmission of telephone signalling;

(c) that the allowable noise power in hypothetical reference circuits for telephony radio-relay systems using time-division multiplex should conform to the values given for frequency-division multiplex (see Recommendation 393);

UNANIMOUSLY RECOMMENDS

1. that the noise power at a point of zero relative level in any telephone channel on the 2500 km hypothetical reference circuit for time-division multiplex radio-relay systems should not exceed the provisional values given below, which have been chosen to take account of fading, under conditions equivalent to those in normal service:

1.1 10 000 pW, psophometrically weighted * mean power in any hour;

1.2 10 000 pW, psophometrically weighted * one-minute mean power for more than 20% of any month;

1.3 50 000 pW, psophometrically weighted * one-minute mean power for more than 0·1% of any month;

1.4 1 000 000 pW, unweighted (with an integrating time of 5 ms) for more than 0·01% of any month;

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

Note 1. — The Recommendation relates to the hypothetical reference circuit. The figures given are design objectives, and it is not intended that they should be quoted in specifications or used for acceptance tests.

Note 2. — The requirement indicated by § 1.4 is related to the need to transmit signalling for telephony satisfactorily. It is also related to the need for VF telegraphy at 50 bauds over telephone channels. Whereas the requirement indicated by § 1.4 is likely to be satisfactory when 50 baud, frequency-modulation VF telegraph equipment is used, the extent to which the operation of 50 baud, amplitude-modulation VF telegraphy systems will be satisfactory is still under study by the C.C.I.T.T.

RECOMMENDATION 395 **

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Noise in real circuits ***

(Question 193 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that provisional maximum values of noise in hypothetical reference circuits are given in Recommendation 393 as a guide to designers of equipment;

* The level of uniform-spectrum noise power in a 3·1 kc/s band must be reduced by 2·5 db to obtain the psophometrically weighted noise power.

** This Recommendation, which replaces Recommendation 288, applies only to line-of-sight radio-relay systems.

*** Where the term "circuit" appears in this Recommendation, it shall be understood to refer to a circuit as defined in No. 02.06 of the I.T.U. List of Essential Telecommunication Terms, 2nd. Impression, Geneva, 1961.

(b) that each designer of a radio-relay equipment must take his own assumptions including those regarding the length of repeater sections, the extent of fading and any precautions taken, for example, the use if necessary of diversity reception and of protection channels;

(c) that, if the composition of a real circuit is similar to the hypothetical reference circuit, and if the design assumptions made are those corresponding to the real circuit, it is expected that the levels of noise on the real circuit will be of the same order as those predicted for the hypothetical reference circuit;

(d) that real circuits will sometimes differ in composition from the hypothetical reference circuit;

(e) that sometimes real circuits will differ in composition from the hypothetical reference circuit; not exceed 47 500 pW one-minute mean power for more than $(L/2500) \times 0{\cdot}1\%$ of any month;

UNANIMOUSLY RECOMMENDS

1. that the psophometrically weighted * noise power at a point of zero relative level in the telephone channels of a real radio-relay system using frequency-division multiplex, of length L km, where L is between 280 and 2500 km, and whose composition does not differ appreciably from the hypothetical reference circuit, should not:

1.1 exceed $3L$ pW mean power in any hour;

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

2. that as a planning objective, and recognizing that the performance achieved for very short periods of time by real circuits, when installed, may differ from the planning objective and is difficult to measure precisely, the psophometrically-weighted noise power at a point of zero relative level in the telephone channels of such a real system as is considered in § 1 should not exceed 47500 pW one-minute mean power for more than $(L/2500) \times 0{\cdot}1\%$ of any month;

3. that as a planning objective for real circuits **, whose length is greater than 50 km but less than 280 km, the psophometrically weighted noise power * (at a point of zero relative level) in a telephone channel of a frequency-division multiplex radio-relay system, the length of which is L km, should not exceed:

3.1 $50\sqrt{L}$ pW mean power in any hour;

3.2 $50\sqrt{L}$ pW one-minute mean power for more than 20% of any month;

3.3 47 500 pW one-minute mean power for more than $(280/2500) \times 0{\cdot}1\%$ of any month;

4. that, as a planning objective for real circuits longer than 280 km (the composition of which differs considerably from that of the hypothetical reference circuit), the requirements of § 2 should apply;

5. that, because it is not possible at the present time to adopt permissible noise powers corresponding to § 1.1 and 1.2 for systems of greater length than 280 km, the composition of which differs considerably from that of the hypothetical reference circuit, this problem should be studied further;

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

---

* The level of uniform-spectrum noise power in a 3·1 kc/s band must be reduced by 2·5 db to obtain the psophometrically-weighted noise power.

** Where baseband sections, or parts thereof, are permanently through-connected, the requirements of §§ 1, 2 and 3 shall apply, not only to circuits in individual baseband sections, but also to longer circuits obtained by through-connection between baseband sections (excluding, however, noise in the frequency-division multiplex equipment) (See Note 1).

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

Note 2. — The Recommendation relates only to "line-of-sight" radio-relay systems with adequate clearance over intervening terrain.

Note 3. — It is assumed that noise surges and clicks from power-supply systems and from switching apparatus are reduced to negligible proportions and will not be taken into account when calculating the noise power.

Note 4. — It is assumed in planning systems that at the demodulation points of the real circuit the telephone channels, groups, supergroups and mastergroups, are interconnected at random; and that the noise coming from the different sections is power-additive.

Note 5. — It will be assumed that, during the busy hour, the multiplex signal can be represented by a uniform-spectrum signal, the mean power absolute level of which at a point of zero relative level, is equal to $(-15 + 10 \log_{10} N)$ dbm for 240 channels or more, and $(-1 + 4 \log_{10} N)$ dbm * for numbers of channels between 12 and 240, N being the total number of channels for which the radio-relay system is designed.

RECOMMENDATION 396

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Hypothetical reference circuit for radio-relay systems for telephony using frequency-division multiplex

(Question 260 (IX))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that tropospheric-scatter radio-relay systems may form part of an international connection;

(b) that the characteristics of tropospheric-scatter systems do not allow the application of existing hypothetical reference circuits for line-of-sight radio-relay systems;

UNANIMOUSLY RECOMMENDS

1. that a hypothetical reference circuit for tropospheric-scatter radio-relay systems should be 2500 km long;

2. that the hypothetical reference circuit for tropospheric-scatter radio-relay systems should not be divided into homogeneous sections of fixed length, because these systems, in contredistinction to line-of-sight systems, are usually composed of long radio sections, the length of which depends on local conditions and may vary considerably (e.g., between 100 and 400 km);

3. that, if a radio section under study is L km long, the hypothetical reference circuit should be composed of $(2500/L)$ sections of this type in tandem, the value $(2500/L)$ being taken to the nearest whole number;

---

* This value is provisional for systems the capacity of which is less than 60 channels.

4. that the hypothetical reference circuit should include:

— 3 sets of channel modulators,

— 6 sets of group modulators,

— 9 sets of supergroup modulators,

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

RECOMMENDATION 397

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Allowable noise power in the hypothetical reference circuit for telephony transmission using frequency-division multiplex

(Question 260 (IX))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that a hypothetical reference circuit for radio-relay systems using tropospheric-scatter propagation is established in Recommendation 396 as a guide to the designers of systems in use in international telecommunication networks;

(b) that, wherever practicable and possible, tropospheric-scatter radio-relay systems should meet the same performance regarding noise as recommended for line-of-sight systems in Recommendation 393;

(c) that, nevertheless, the achievement of this desirable objective would sometimes result in a very high, even prohibitive cost or a power that is impractically high, or such that is likely to result in harmful interference;

(d) that this might well retard desirable extensions of the telephone network;

UNANIMOUSLY RECOMMENDS

1. that, from the point of view of performance, tropospheric-scatter radio-relay systems be divided into two classes;

2. that when a tropospheric-scatter system is intended to operate between two points for which other transmission systems could be used without excessive difficulty, e.g., line-of-sight radio-relay, underground cable, etc., the hypothetical reference circuit should be established in accordance with Recommendation 396. The noise power at the end of this hypothetical reference circuit will be calculated by statistical combination of the noise power in each of its radio sections. The statistical distribution curve of the one-minute mean psophometric power, during the most unfavourable month, should then pass below the points defined in Recommendation 393, §§ 1.2 and 1.3. Besides which, the mean psophometric power during any hour should not exceed the figure laid down in § 1.1 of Recommendation 393;

3. that if a tropospheric-scatter system is to be used between points, for which other transmission systems cannot be used without excessive difficulty, and if the conditions laid down in Recommendation 393 cannot be met without excessive difficulty, the following conditions will apply, once the statistical noise power distribution at the end of the hypothetical reference circuit has been calculated by the method set out in § 2 above;

3.1 the mean psophometric power during one minute must not exceed 25 000 pW for more than 20% of any month;

3.2 the mean psophometric power during one minute must not exceed 63 000 pW for more than 0·5% of any month;

4. that for the two classes of system defined above, the unweighted noise power (with an integration time of 5 ms) must meet Recommendation 393, § 1.4, but with the percentage of the most unfavourable month changed to 0·05% for the systems referred to in § 3 in the present Recommendation;

5. that the conditions given in §§ 3 and 4 above are provisional and should be reconsidered later.

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

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

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

Note 4. — In accordance with § 3 of this Recommendation, systems which comply only with the terms of §§ 3 and 4, will be excluded from the main international and intercontinental routes; consequently in a world-wide connection, a maximum of one or two circuits of medium length will be encountered which comply only with the terms of § 4 with a percentage of 0·05%; as far as telephone signalling is concerned, this state of affairs is acceptable.

Note 5. — The question of telegraph transmission over radio-relay systems using tropospheric-scatter propagation has been considered by Study Groups IX and XV of the C.C.I.T.T. Whilst experience to date seems to show that satisfactory transmission is generally only obtainable if an appropriate diversity system is employed on the radio-relay system, additional clauses cannot yet be suggested.

F. 4 - Maintenance

RECOMMENDATION 290 *

MAINTENANCE PROCEDURE FOR RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Measurements to be made

(Question 96)

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

that the operation of frequency-division multiplex (FDM) radiotelephony relay systems would be facilitated by maintenance procedures similar to those in existence for line networks;

UNANIMOUSLY RECOMMENDS

1. that transmission quality be checked by the following maintenance measurements:
- — stability of the net gain or loss in the baseband;
- — total noise including cross-talk noise;

2. that net gain or loss stability in the baseband should be measured by means of a line regulating pilot (Recommendation 381). Such measurements can be made during normal operation without interrupting the link and can be supplemented by a measurement of the linear attenuation distortion at the frequencies in the baseband;

3. that total noise be measured in specially reserved measuring channels, listed in Recommendation 398, outside the spectrum of the FDM signal, so that noise can be measured during normal operation of the link, the load consisting of the multiplex signal. Noise can also be measured by interrupting the multiplex signal and replacing it by the uniform spectrum signal defined in Recommendation 399, the measurement being made either in the measurement channels referred to above or in the channels inside the telephone channel spectrum as defined in Recommendation 399. Noise may also be measured when the link is unloaded so that the contribution of each noise source can be determined.

RECOMMENDATION 305 **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Stand-by arrangements

(Question 96)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that in radio-relay systems it is indispensable to have stand-by arrangements to decrease the time when the circuit is out of action as a result of a fault in equipment or to facilitate periodical maintenance operations;

(b) that it is generally advisible to use for this purpose a stand-by channel replacing the channel normally in service along the entire length of a switching section;

---

* This Recommendation terminates the study of Question 96 for telephony.

** This Recommendation replaces Recommendation 196.

(c) that, for technical or operational reasons, it may be desirable to use, in certain cases, stand-by installations of a different type such as stand-by equipment with switching at each station on the same carrier frequency;

(d) that a distinction should be made according to whether the system is intended for the transmission of telephone channels, of telephone and television channels possessing very similar radio characteristics, or of telephone and television channels with differing characteristics;

UNANIMOUSLY RECOMMENDS

1. that when several radio channels possessing the same characteristics are used for multiplex telephony, it is preferable to use a stand-by channel common to the channels in service (or several such stand-by channels, if necessary);

2. that when some of the radio channels are utilised for multiplex telephony and others for television and all the radio channels possess very similar characteristics, it is preferable to use a stand-by channel common to the channels in service (or several such stand-by channels, if necessary;

3. that in certain specific cases such as when some of the radio channels are utilized for multiplex telephony and others for television and when the characteristics of such channels are substantially dissimilar, the Administrations concerned may, by mutual agreement and if they so desire, use stand-by arrangements differing from those specified in §§ 1 and 2 of the present Recommendation, such as stand-by equipment operating on the same carrier frequency as the equipment in service and which can be substituted for that equipment station by station.

RECOMMENDATION 398 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Maintenance measurements in actual traffic

(Question 96)

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that measurements by means of a generator producing white noise (according to Recommendation 399) are only possible when the radio-frequency channel is not carrying traffic and that the measuring channels used for this kind of measurement can lie within the frequency range occupied by telephone channels **;

(b) that systems carrying multi-channel telephony cannot be withdrawn from service at will for measurement;

(c) that stand-by channels are not always available for maintenance purposes;

(d) that maintenance measurements of the total noise (thermal and intermodulation noise) are of use to determine the quality of a system and must be made during the traffic;

(e) that it is convenient to place the channels used for this kind of measurement outside the total bandwidth of the multiplex signal;

---

* This Recommendation replaces Recommendation 293.

** In this Recommendation, the words "frequency range occupied by telephone channels" are intended to mean the part of the baseband actually transmitted (in cases where a system is used below its maximum capacity).

(f) that, in the case where these measuring channels are located outside the total multiplex signal band, they should be positioned as near the limits of the total signal band as possible, to measure the intermodulation products due to the non-linearity of the system;

(g) that, on the other hand, to facilitate and to cheapen filter construction, the measuring chanels should not be positioned too near these limits;

(h) that measurements in channels above the multiplex signal band are generally more sensitive to changes of thermal and intermodulation noise in the radio-frequency and intermediate-frequency parts of the equipment, whereas measurements in channels below this band are more sensitive to changes in the modulators and demodulators;

(i) that it is usually necessary to use band stop filters at the input of a system to minimize noise on the incoming circuit in the bands occupied by the measuring channels and that it will be necessary to specify the minimum performance of these filters, both in the stop range of these filters and at the edges of the total multiplex signal band;

(j) that the specification of frequencies situated about 10% above the upper limit of the total multiplex signal band for continuity pilots (Recommendation 401) suggests the use of the same frequencies as centre frequencies of the measuring channels;

(k) that it may be of use to combine the evaluation of the power of the continuity pilot with the measurement of the noise around it;

(l) that it may be of use to employ the measuring channels outside the multiplex signal band also for measurements with white noise, according to Recommendation 399;

UNANIMOUSLY RECOMMENDS

1. that noise in radio links should be measured during actual traffic at the output of the system in relatively narrow bands situated outside (below and/or above) the total multiplex signal band;

2. that the central frequencies of these measuring bands should be those shown in the table below;

3. that the attenuation of the stop band filters at the input of the system should exceed 50 db over a minimum frequency band of $\pm$ (0·005 f + 2) kc/s *, f being the centre frequency in kc/s of the measuring channel. The additional attenuation caused by the insertion of the stop filters at the lower edge and at the upper edge of the total multiplex signal band shall not exceed 0·3 db referred to the additional attenuation caused in the centre of the multiplex signal band;

4. that the effective bandwidth of the filters in the receiving equipment should be small enough for use with the input stop filter mentioned above;

5. that in all cases where different frequency bands are used, or where there are differences between the measurement techniques, special agreements should be made;

6. that the design of the band stop and measuring filters should enable them to be used both for maintenance measurements according to this Recommendation and for measurements with white noise according to Recommendation 399.

Note. — In certain telephone channels and in combinations of them harmonic distortion may be produced, which may make it necessary to leave these channels disconnected, e.g. if the second or third harmonics coincide with the centre frequencies of the noise measuring channels.

* Except when the centre frequency is 10 kc/s; the minimum frequency band is then 10 $\pm$ 1 kc/s.

System capacity (channels)	Limits of band occupied by telephone channels (kc/s)	Frequency limits of baseband (1) (kc/s)	Centre frequencies (f) of noise measuring channels (kc/s)	
			Below	Above
24	12–108	12–108	10	116 or 119
60	12–252 60–300	12–252 60–300	10 50	304 331
120	12–552 60–552	12–552 60–552	10 50	607 607
300	60–1300 64–1296	60–1364	50	1499
600	60–2540 64–2660	60–2792	50	3200
960	60–4028 316–4188	60–4287	50 270	4715 4715
1800	312–8204 316–8204	300–8248	270	9023
2700 (2)	312–12 388 316–12 388	308–12 435	270	13 627

(1) Including pilots or frequencies which might be transmitted to line.

(2) Radio-relay systems with a capacity of 2700 channels are at present under study; the central frequencies of the corresponding measurement channels are only given for information purposes, and the figures indicated in no way commit the future.

RECOMMENDATION 399 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Measurement of performance with the help of a signal consisting of a continuous uniform spectrum

(Study Programme 28 and Question 96)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it is desirable to measure the performance of radio-relay systems for frequency-division multiplex telephony under conditions closely approaching those of actual operation;

(b) that a signal with a continuous uniform spectrum (white noise), has statistical properties similar to those of a multiplex signal, when the number of channels is not too small;

(c) that the use of a signal with a continuous uniform spectrum to measure the performance of such radio-relay systems is already widespread;

* This Recommendation replaces Recommendation 294.

(d) that it is necessary to standardize, as soon as possible, the frequencies and bandwidths of the measuring channels to be used for such tests;

(e) that it is necessary to standardize, as soon as possible, the minimum attenuation and the bandwidth of the stop filters which may have to be used in the white noise generator;

(f) that the C.C.I.T.T. has indicated, for the planning of telephone circuits, a mean value of speech power in a telephone channel to be taken into consideration during the busy hour (C.C.I.T.T. Recommendation G. 222, Vol. III);

UNANIMOUSLY RECOMMENDS

1. that the performance of frequency-division multiplex radio-relay systems should be measured by means of a signal of a continuous uniform spectrum in the frequency band used for the telephone channels;

2. that the power level of the signal with a uniform continuous spectrum should, for radio channels with at least 240 telephone channels, be equal to $(-15 + 10 \log_{10} N)$ db, relative to 1 mW, at a point of zero relative level, N being the total number of channels in the circuit;

3. that the power level of this signal with a uniform continuous spectrum for radio channels with a capacity of at least 12 and not more than 240 telephone channels should be equal to $(-1 + 4 \log_{10} N)$ db * relative to 1 mW at a point of zero relative level, N being the total number of channels in the circuit;

4. that measurements of total noise (thermal noise and intermodulation noise) should be performed:
   - either in the noise measuring channels used during actual traffic (Recommendation 398);
   - or in noise measuring channels used in conjunction with a white noise spectrum. The use of these measuring channels seems preferable for special tests, e.g. acceptance tests, calibration or tests on very wide band systems. They can be positioned either within the multi-channel signal band or outside;

5. that the frequencies of the measuring channels should be those shown in Table I:

TABLE I

System capacity (channels)	Bandwidth (1) of white noise spectrum (kc/s)	Centre-frequencies of measurement channels (kc/s)				
		Lower channel (2)		Centre channel	Upper channel (2)	
60	60–300	50	70		270	331
120	60–552	50	70	270	534	607
300	60–1300	50	70	534	1248	1499
600	60–2660	50	70	1248	2438	3200
960	60–4028	50	70	2438	3886	4715
	316–4188	270	534	2438	3886	4715
1800	316–8204	270	534	3886	8002	9023
2700 (3)	316–12 388	270	534	3886 (4) 4715 8002	12 150	13 627

(1) Within this band the r.m.s. noise voltage levels measured with a narrow bandwidth of about 2 kc/s shall not vary by more than 1 db. Outside this band the power must drop sharply and be more than 25 db down at all frequencies greater than 10% above and 20% below the band.

(2) Either of the two frequencies indicated in this column may be used.

(3) 2700-channel radio-relay systems are at present under study; the centre frequencies of the corresponding measurement channels are only given for information purposes, and the figures indicated do not commit the future.

(4) Each Administration should choose, from among these three frequencies, the one it desires.

* This value is provisional for systems of less than 60 channels.

6. that the attenuation of noise in each stop band at the output of the sending equipment should exceed 80 db over a band at least 3 kc/s wide, and should be close to, but not less than 3 db at frequencies of $\pm (0{\cdot}02 f + 4)$ kc/s with respect to the centre frequency, f being expressed in kc/s. The shape of the filter characteristics should be such that, when all three band stop filters are simultaneously brought into circuit, the errors * in measurement as compared with a measurement carried out with a perfectly uniform source and an indefinitely narrow stop band should not exceed 1 db;

7. that the effective bandwidth of the filters in the receiving equipment should be small enough for use with a transmitter stop band having 3 db attenuation at frequencies $\pm (0{\cdot}02 f + 4)$ kc/s with respect to the centre frequency f of the stop band;

8. that additional or alternative measuring channels may be provided by agreement between the Administrations concerned.

Note. — A more satisfactory definition of the filter characteristics (§§ 6 and 7) should be the subject of a complementary study; an exchange of views with the C.C.I.T.T. would be advantageous in this respect, also with regard to measurement channels to be envisaged for systems with a capacity of 2700-channels.

RECOMMENDATION 400 *

SERVICE CHANNELS FOR RADIO-RELAY SYSTEMS

Types of service channel to be provided

(Question 195 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that service channels are required for the maintenance, supervision and control of radio-relay links providing a number of radio-frequency channels for each direction of transmission;

(b) that, if for any reason the radio-relay system itself fails to function, communications between various stations along the route, and from those stations to other points is likely to assume special importance;

(c) that agreement is desirable on the number and function of the service channels to facilitate the planning of radio-relay systems;

UNANIMOUSLY RECOMMENDS

that, on international radio-relay systems:

1. all staffed stations should be connected directly to the public telephone network;

---

* The "error" is due to the loss by the insertion of filters, to the changes in the spectral distribution of thermal and intermodulation noise produced by this insertion and to other causes.

** This Recommendation, which replaces Recommendation 295, applies to radio-relay systems which will transmit at least 60 telephone channels or a television signal and comprise two staffed terminal stations, in which the signals are demodulated to baseband, and any number of unstaffed intermediate stations. This Recommendation applies, where appropriate, to tropospheric-scatter radio-relay systems.

2. when a radio-relay link is extended by means of short cable sections, and when these cable sections and the radio-relay link taken together constitute a regulated line section, the terminal stations of the radio-relay link itself should have speaker circuits to the stations at the ends of the regulated line section;

3. a telephone service channel (an omnibus speaker circuit) should be set up, to connect together all the stations on the system, whether staffed or not;

4. that a second telephone service channel (a main or express speaker circuit) should be provided for direct telephonic communication between the staffed stations receiving supervisory signals;

5. wherever possible and after agreement between the Administrations concerned, one or two service channels should be provided in each direction for the transmission of supervisory and control signals between the stations of the system *;

6. one of the channels mentioned in § 5 might be used for the transmission of high speed signals associated with the switching of broad-band radio channels, the other could be used for the transmission of a number of relatively low speed supervisory signals **;

7. all telephone service channels should possess, whenever possible, the characteristics recommended by the C.C.I.T.T. for international telephone circuits and, in particular, should be able to transmit the frequency band 300–3400 kc/s;

8. the service channels should be provided either over metallic circuits or over an auxiliary radio-relay system, in the same band as the main system, or in a different band following the same route as the main system;

9. for small-capacity, line-of-sight radio-relay systems (maximum 300 channels) and for tropospheric-scatter radio-relay systems, for reasons of economy, the necessary speaker circuits should be located in the band of frequencies located below the band occupied by the multiplex signal, their precise arrangement being the subject of agreement between the Administrations concerned;

10. the characteristics of the supervisory signals and the control signals to be transmitted between the stations of the system, should be the subject of agreement between the Administrations concerned.

Note. — Certain Administrations use the following arrangement of the baseband for auxiliary radio-relay systems, operating in a different frequency band from the main system:

- a telephone service channel (an omnibus speaker circuit), transmitted in the voice-frequency band;
- a second telephone service channel (a main or express speaker-circuit) transmitted between 12 and 16 kc/s, the sense of modulation being erect;
- a band of frequencies situated between the two telephone service channels, used for the transmission of relatively slow supervisory signals and control signals, and, perhaps also a pilot;
- a band of frequencies situated above the main telephone service channel used for the transmission of telemetry signals and possible rapid control signals, the occupied band being as wide as necessary.

Other arrangements of the baseband are also used.

---

* These signals may also be transmitted directly over the main radio-relay system, if it is established for telephony.

** It is also possible, by agreement between the Administrations concerned, to transmit the relatively slow signals in the upper part of the omnibus service channel mentioned in § 3.

RECOMMENDATION 401 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Frequencies and deviations of continuity pilots

(Question 96)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that special pilots are required on radio-relay systems to indicate the continuity of the circuit;

TABLE I

System capacity (channels)	Limits of band occupied by telephone channels (kc/s)	Frequency limits of baseband (kc/s) (1)	Continuity pilot frequency (kc/s)	Deviation (r.m.s.) produced by the pilot (kc/s) (2)
24	12–108	12–108	116 or 199	20
60	12–252 60–300	12–252 60–300	304 or 331	25, 50, 100 (3)
120	12–552 60–552	12–552 60–552	607 (4)	25, 50, 100 (3)
300	60–1300 64–1296	60–1364	1499, 7000 or 8500	100 or 140 (5)
600	60–2540 64–2660	60–2792	3200 or 8500	140
960	60–4028 316–4188	60–4287	4715 or 8500	140
1800	312–8204 316–8204	300–8248	9023	100
2700 (6)	312–12 388 316–12 388	308–12 435	13 627	
405-line Television			8500	140
625-line Television			8500	140
Television and FDM up to 600 channels sent simultaneously			9023	100

(1) Including pilot or frequencies which might be transmitted to line.

(2) Other values may be used by agreement between the Administrations concerned.

(3) Alternative values dependent on whether the deviation of the signal is 50, 100 or 200 kc/s (Recommendation 404).

(4) Alternatively 304 kc/s may be used by agreement between the Administrations concerned.

(5) The first figure applies to frequency 1499 kc/s, the second to frequency 7000 or 8500 kc/s.

(6) Study is being made of 2700 channel radio-relay systems; the corresponding continuity pilot frequency is given for information only and the figures indicated in no way commit the future.

* This Recommendation, which replaces Recommendation 292, applies to line-of-sight and near line-of-sight radio-relay systems and also, where appropriate, to tropospheric-scatter radio-relay systems.

(b) that these pilots should be situated outside the range of frequencies occupied by the telephony or the television signals (Recommendation 381);

(c) that a frequency about 10% higher than the upper limit of the frequency-division multiplex signal is convenient for such a pilot. To reduce intelligible crosstalk the continuity pilot should, when possible, have a frequency of $(4n - 1)$ kc/s; where n is an integer;

(d) that some Administrations wish to use the same continuity pilot for multi-channel telephony and for television signals;

UNANIMOUSLY RECOMMENDS

1. that for frequency-division multiplex telephony and television radio-relay systems, when the continuity pilot is above the baseband, its frequency and deviation should be that shown in Table I;

2. that a continuity pilot situated below the baseband can be used after agreement between the Administrations concerned;

3. that the frequency stability of the continuity pilot should be better than 5 parts in 10^5.

F.5 - Characteristics

RECOMMENDATION 271

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

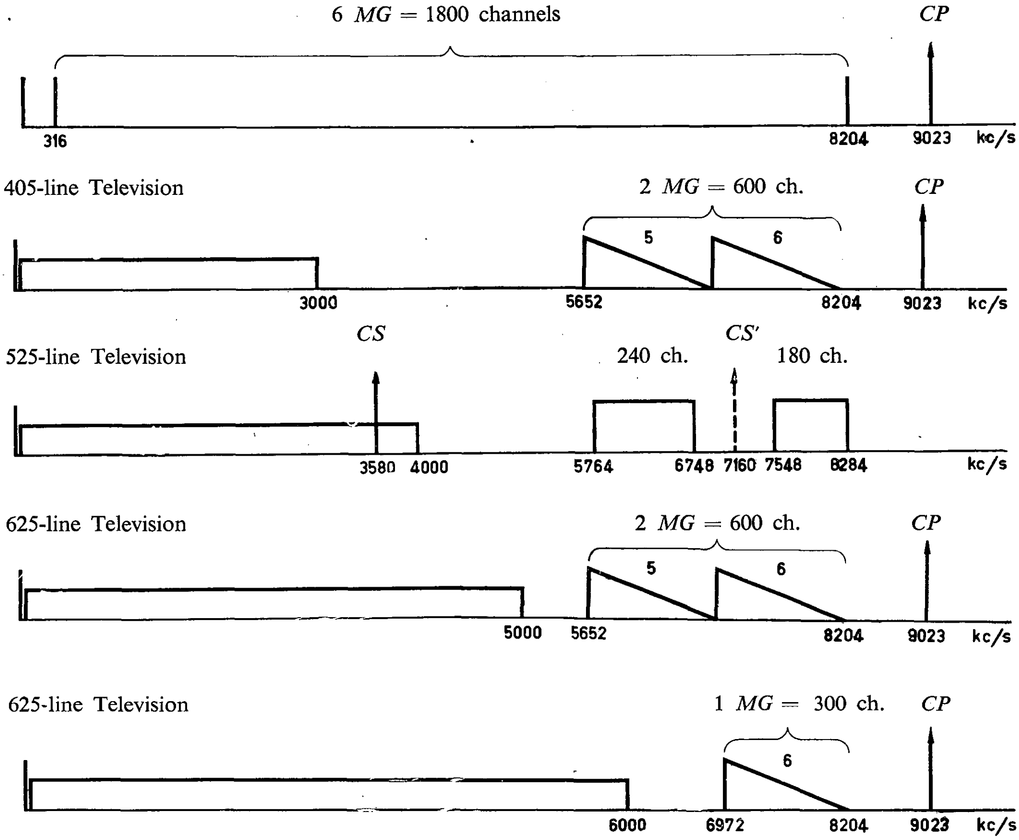
Simultaneous transmission by the same radio-frequency carrier. Baseband arrangements

(Question 194 (IX))

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that radio-relay systems for the simultaneous transmission of television and telephony on the same radio-frequency carrier may be established;



The master-group numbers shown in the diagrams are those proposed by the C.C.I.T.T.

MG = master-group of 300 telephone channels
CP = continuity pilot (see Recommendation 401)
CS = colour sub-carrier
CS' = second harmonic of *CS*

FIGURE 1

Examples of alternative baseband arrangements for radio-relay systems transmitting television and telephony simultaneously on the same radio-frequency carrier *(b)* that international connection of such systems at baseband frequencies may be required;

(c) that there are substantial advantages in respect of signal-to-noise ratio and distortion if the television signal is transmitted as a video signal in the lower part of the baseband rather than as a vestigal sideband signal;

UNANIMOUSLY RECOMMENDS

1. that in radio-relay systems for the simultaneous transmission of telephony and television on the same radio-frequency carrier, the television signal should be transmitted as a video signal in the lower part of the baseband;

2. that in such radio-relay systems, the telephony signals should be transmitted in the upper part of the baseband;

3. that the preferred arrangement of telephone channels in the baseband should be a subject for further study and agreement with the C.C.I.T.T.; various possible arrangements under consideration are given in Fig. 1;

4. that in the case of television systems in which a colour sub-carrier is transmitted, consideration be given to the omission of certain blocks of telephone channels to avoid interference from the second harmonic of the colour sub-carrier.

RECOMMENDATION 275

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Pre-emphasis characteristic for frequency modulation systems

(Question 192 (IX))

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that the pre-emphasis characteristic should preferably be such that the effective (r.m.s.) deviation due to the frequency-division multiplex telephony signal is the same with and without pre-emphasis (Recommendation 404);

(b) that in a frequency-modulation system for frequency-division multiplex telephony the thermal noise is highest in the top channel and decreases with decreasing baseband frequency;

(c) that in a phase-modulation system, or in a frequency-modulation system with pre-emphasis at 6 db per octave, the thermal noise is constant over the whole baseband;

(d) that the thermal noise in the highest channel of a phase-modulation system is approximately 4.8 db better than the corresponding channel of a frequency-modulation system, assuming that the two types of system are adjusted to have the same total frequency deviation;

(e) that the reduction in frequency deviation with decreasing baseband frequency in a phase-modulation system makes such a system more sensitive to low frequency interference and to the effects of non-linearity in the system;

(f) that the loss of advantage in the top channel is quite small and the effects due to non-linearity are not excessive if the range of pre-emphasis is restricted to about 8 db;

(g) that agreement on the pre-emphasis characteristic is desirable to facilitate international connection at radio frequencies or intermediate frequencies;

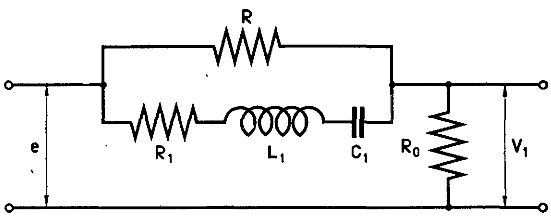
UNANIMOUSLY RECOMMENDS

1. that where pre-emphasis is used in radio-relay systems for frequency-division multiplex telephony, the same normalized attenuation-frequency characteristic should be used for systems with capacities up to and including 960 channels, and provisionally also for systems with a capacity of 1800 channels;

2. that the preferred pre-emphasis characteristic is that obtained by using a network, the insertion loss of which is given by:

$$20 \log_{10} \frac{e}{v_1} = 10 \log_{10} \left[1 + \frac{6{\cdot}90}{1 + \dfrac{5{\cdot}25}{\left(\dfrac{f_r}{f} - \dfrac{f}{f_r}\right)^2}} \right] \text{db}$$

where f_r (the resonant frequency of the network) $= 1{\cdot}25 f_{max}$, where f_{max} is the highest telephone channel baseband frequency of the system.



$R = 1{\cdot}81\ R_o$

$R_1 < 0{\cdot}01\ R_o$ at f_r

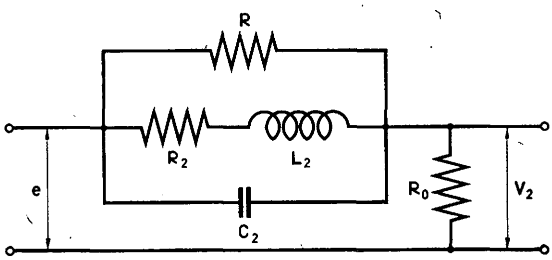
$\sqrt{\dfrac{L_1}{C_1}} = 0{\cdot}79\ R_o$

$f_r = 1{\cdot}25 f_{max} = \dfrac{1}{2\pi} \sqrt{\dfrac{1}{L_1 C_1}}$

where f_{max} is the highest baseband frequency

FIGURE 1

Basic pre-emphasis network



$R = 1{\cdot}81\ R_o$

$R_2 < 0{\cdot}02\ R_o$ at f_r

$\sqrt{\dfrac{L_2}{C_2}} = 1{\cdot}47\ R_o$

$f_r = 1{\cdot}25 f_{max} = \dfrac{1}{2\pi} \sqrt{\dfrac{1}{L_2 C_2}}$

where f_{max} is the highest baseband frequency

FIGURE 2

Basic de-emphasis network

Note. — Tolerances for both networks

Resistors	±1%
Capacitors	±0·5%
f_r	±0·5% (*L* resonating with *C*)

Table I shows f_{max} and f_r for the frequency-division multiplex systems of Recommendation 380;

3. that the pre-emphasis network should be derived from the basic network shown in Fig. 1 and that the de-emphasis network should be derived from the basic network in Fig. 2;

4. that the tolerances should not exceed those shown in association with Fig. 1 and 2.

Note 1. — The frequency at which the deviation should correspond to that without pre-emphasis (Recommendation 404) is 0·608 f_{max}; it may be convenient to adopt this frequency for testing the loss between baseband terminal points of systems when these are not in service. The variation of deviation with frequency is shown in Fig. 3.

Note 2. — It is recognized that it may sometimes be desirable to use a different pre-emphasis characteristic by agreement between the Administrations concerned.

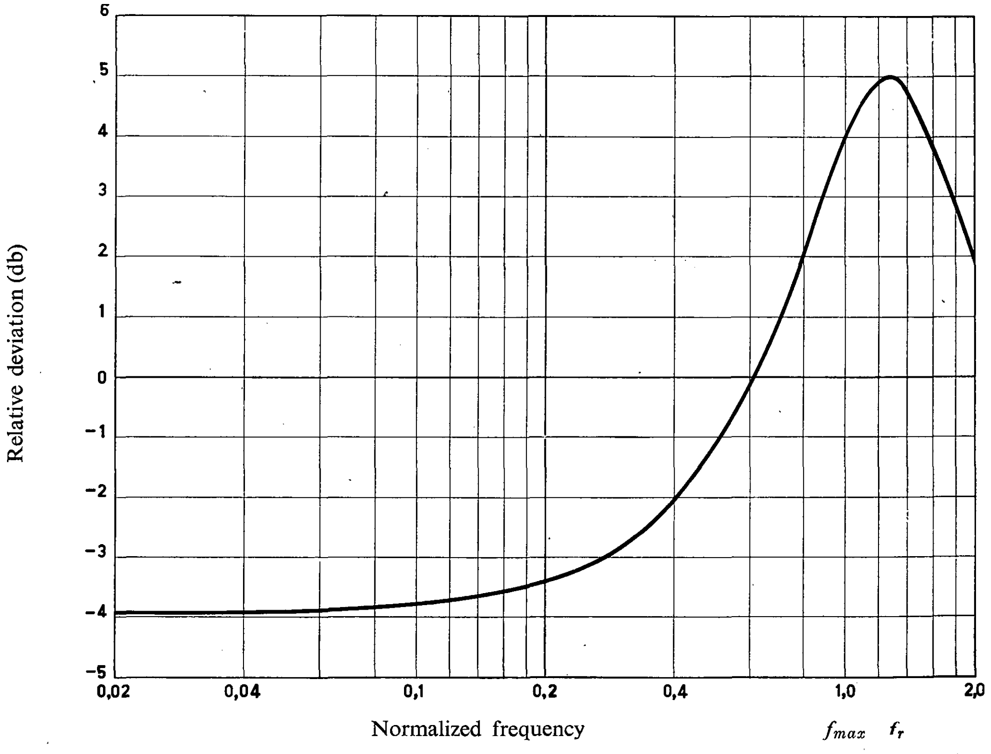


FIGURE 3

Pre-emphasis characteristic for telephony

TABLE I

Characteristic frequencies for pre- and de-emphasis networks for the frequency-division multiplex systems of Recommendation 380

Maximum number of telephone traffic channels (1)	f_{max} (kc/s)	f_r (kc/s)
24	108	135
60	300	375
120	552	690
300	1300	1625
600	2660	3325
960	4188	5235
1800 (2)	8204	10 255

(1) This figure is the nominal maximum traffic capacity of the system and applies also when only a smaller number of telephone channels are in service.

(2) For 1800 channel systems, this Recommendation is provisional in respect of both the networks used and the characteristic frequencies.

In the table:

f_{max} is the nominal maximum frequency of the band occupied by telephone channels;

f_r is the nominal resonant frequency of the pre- or de-emphasis network.

RECOMMENDATION 276 *

RADIO-RELAY SYSTEMS FOR TELEVISION

Frequency deviation and the sense of modulation

(Question 194 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that radio-relay systems for television using frequency modulation may form part of an international circuit;

(b) that international connections of such systems may at times have to be made at intermediate or radio frequencies;

(c) that the use of too large a frequency deviation results in an unnecessarily wide band of transmitted radio frequencies and should be avoided because of the need to economize in the use of the frequency spectrum;

(d) that for various reasons the use of pre-emphasis might be desirable (Recommendation 405);

UNANIMOUSLY RECOMMENDS

1. that the value of the frequency deviation without pre-emphasis in radio-relay systems for the transmission of television, referred to the nominal peak-to-peak amplitude of the video signal (see Recommendation 421, § 2.3), should be 8 Mc/s peak-to-peak for systems of 625

* This Recommendation, which replaces Recommendation 184, applies only to line-of-sight and near line-of-sight radio-relay systems.

lines or less, and between 8 Mc/s and 12 Mc/s peak-to-peak for systems of 819 lines. In particular cases of international connections with 819-line television systems the value of deviation should be agreed between the Administrations concerned;

2. that when pre-emphasis is applied according to Recommendation 405 the maximum frequency deviation should not exceed 8 Mc/s peak-to-peak for systems of 625 lines or less, or 8 Mc/s to 12 Mc/s peak-to-peak for systems of 819 lines;

3. that the sense of modulation at the point of international connection should be the subject of agreement between the Administrations concerned.

RECOMMENDATION 298 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING TIME-DIVISION MULTIPLEX

Preferred characteristics

(Question 92)

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that time-division multiplex radiotelephone systems may form parts of an international circuit;

(b) that general conformity with the relevant C.C.I.T.T. Recommendations in respect of overall performance measured between audio-frequency terminals, the method of making audio-frequency connections, and the method of signalling over international connections are already covered by Recommendations 297 and 335;

(c) that the techniques of time-division multiplex have not yet attained stability and, while most systems in current use employ pulse-position modulation and provide not more than 24 speech channels, even the development of such systems has not yet reached the stage where general agreement is possible on all the baseband parameters necessary for interconnection at other than audio frequency (see Report 134);

(d) that certain systems now in service or under development, provide for the transmission of several music channels or other types of service as an alternative to speech channels, or allow for more than 24 speech channels and that such systems could become of importance;

(e) that standardization of baseband parameters at the present stage might, therefore, unduly restrict the future development of time-division multiplex systems;

UNANIMOUSLY RECOMMENDS

that where direct interconnection is required, at other than audio-frequencies, between two time-division multiplex systems across an international boundary, the connection between the two systems should be made in accordance with Recommendation 306.

---

* This Recommendation replaces Recommendation 185.

RECOMMENDATION 402 *

RADIO-RELAY SYSTEMS FOR TELEVISION

Simultaneous transmission of a monochrome television signal and a single sound channel. Preferred characteristics of the sound channel

(Question 194 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it may be desirable for economical or operational reasons to transmit the sound signal accompanying a television signal over the same radio-relay system;

(b) that a channel suitable for the transmission of the sound signal may be provided by means of a frequency modulated sub-carrier inserted in the baseband of the radio-relay system above the video band and below the continuity pilot (see Recommendation 401);

(c) that a sound channel provided by these means may form part of an international connection;

UNANIMOUSLY RECOMMENDS

1. that the transmission performance of the sound channel should conform to the requirements of the C.C.I.T.T. for international programme circuits **;

2. that the following transmission characteristics are preferred:

	General Recommendation	French 819-line system	U.S.S.R. 625-line system
2.1 *Frequency of sub-carrier*	7·5 Mc/s	10 Mc/s	8 Mc/s
2.2 *Modulation characteristics of sub-carrier*			
2.2.1 Nominal input impedance of audio channel (Ω)	600 (bal.)	15 000 (bal.)	600 (bal.)
2.2.2 Maximum audio signal at a zero relative level point *** (db rel. 0.775 volts r.m.s.)	+9	+9 (in 600 Ω)	0 (input) +17 (output)
2.2.3 Audio bandwidth (c/s)	30–10 000 ****	40–12 000	50–10 000
2.2.4 Deviation of sub-carrier (for a sinusoidal test tone of maximum level given in § 2.2.2)	140 kc/s r.m.s.	70 kc/s r.m.s. (at 800 c/s)	150 kc/s peak

* This Recommendation replaces Recommendation 272.

** See C.C.I.T.T., Vol. III, Recommendation J. 21. The maintenance is contained in Vol. IV, Recommendations series N. The conditions of measurement should be the subject of further study.

*** The input and output levels for an international programme line and for an international programme link have been defined in Fig. 77 of C.C.I.T.T. Recommendation J. 13, Vol. III. It is the responsibility of the Administrations concerned to choose the appropriate value for their special use.

**** The upper limit may be increased should there be evidence of need.

2.2.5 Pre-emphasis of audio-channel (μs)	*	50 (see Rec. 412)	nil
2.3 *Deviation of IF and RF carrier*			
The amplitude of the unmodulated sub-carrier should be such as to produce a deviation of the IF and RF carrier of:	300 kc/s r.m.s.	600 kc/s r.m.s.	750 kc/s peak

---

RECOMMENDATION 403 **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Intermediate frequency characteristics

(Question 192 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that multiplex radio-relay systems for television and frequency-division multiplex telephony may form part of an international circuit;

(b) that it may at times be desirable to make international connections between such systems at the intermediate frequency;

(c) that to facilitate international connections at intermediate frequency, systems of the same channel capacity (independent of their radio-frequencies) should preferably have the same intermediate frequency;

(d) that, to facilitate the best choice for a radio-frequency channelling plan, it is desirable to adopt a preferred intermediate frequency;

UNANIMOUSLY RECOMMENDS

that, as far as is practicable, frequency-division multiplex radio-relay systems forming parf of an international circuit should have intermediate-frequency circuits which, at a point ot international connection, conform to the preferred values listed below:

1. Centre value of the intermediate frequency

The nominal centre values of the intermediate frequencies are:

— 35 Mc/s for radio frequencies up to 1000 Mc/s (for radio frequencies up to 1000 Mc/s the frequency of 70 Mc/s may also be used, for example, in larger capacity radio-relay systems);

— 70 Mc/s for systems of up to 1800 channels capacity employing radio frequencies higher than 1000 Mc/s. For systems of larger capacity, a different value of intermediate frequency may be desirable.

---

* Pre-emphasis may be used by agreement between the Administrations concerned. Attention is drawn to Recommendation 412, § 2. The network defined in that Recommendation may also be suitable for the sound channel, but it should be studied to see if the nominal deviation of 800 c/s can remain at the value used for transmission without pre-emphasis, or if it is necessary to fix the nominal deviation at a higher frequency to avoid increase in the peak signal to the sub-carrier modulator.

** This Recommendation, which replaces Recommendation 273, applies to line-of-sight and near line-of-sight radio-relay systems and, where appropriate, to tropospheric-scatter radio-relay systems.

The tolerance relative to the nominal centre value of the intermediate frequency should be agreed between the Administrations concerned.

2. Input and output voltage of the intermediate frequency signal

Output: 0·5 V r.m.s.;
Input: 0·3 V r.m.s.

The tolerance relative to the nominal input and output levels as a function of the frequency should be agreed between the Administrations concerned.

3. Impedance of the intermediate frequency circuit

Nominal impedance: 75 Ω unbalanced.

In frequency-division multiplex systems, the amount of intermodulation noise due to mismatch of the intermediate-frequency circuits at a point of international connection should not be excessive in relation to the overall noise requirements of the hypothetical reference circuit for such systems.

Similarly, in television systems, the amount of echo distortion due to impedance mismatch of the intermediate frequency circuits at a point of international connection should not be excessive in relation to the overall performance requirements of the hypothetical reference circuit for such systems.

The amount of intermodulation noise and the television echo distortion due to impedance mismatch in particular cases should be the subject of agreement between the Administrations concerned.

Note 1. — When diversity reception is used, the preferred values quoted above for impedance and output level apply to the combined output of the receivers used.

Note 2. — It is recognized that in certain cases and in certain regions, it may be desired to use, by agreement between the Administrations concerned, intermediate-frequency characteristics other than those given above.

RECOMMENDATION 404 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Frequency deviation

(Question 192 (IX))

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that frequency-division multiplex systems for telephony using frequency modulation may form part of an international circuit;

(b) that it may at times be desirable to make international connections between such systems at intermediate or radio frequencies;

(c) that to economize in the use of the frequency spectrum it is desirable to use the smallest satisfactory frequency deviation;

(d) that the use of pre-emphasis allows a more uniform distribution of signal-to-noise ratio in the various channels of a multi-channel telephony system;

* This Recommendation, which replaces Recommendation 274, applies to line-of-sight and near line-of-sight radio-rela systems and, where appropriate, to tropospheric-scatter radio-relay systems.

UNANIMOUSLY RECOMMENDS

that as far as is practicable frequency-division multiplex radio-relay systems for telephony forming part of an international circuit should conform to the following characteristics:

1. Frequency deviation without pre-emphasis.

Maximum number of channels	R.m.s. deviation per channel (1) (kc/s)
12	35
24	35
60	50, 100, 200
120	50, 100, 200
300	200
600	200
960	200
1800	140 (2)

(1) For 1 mW, 800 c/s tone at a point of zero reference level.
(2) Provisional value (assuming use of pre-emphasis).

Larger capacity systems are not excluded

Note. — It is recognized that it may sometimes be desirable to use other deviation by agreement between the Administrations concerned. This applies in particular to tropospheric-scatter systems.

2. Frequency deviation with pre-emphasis

Where pre-emphasis is to be used, the pre-emphasis characteristic should preferably be such that the effective (r.m.s.) deviation due to the multi-channel signal is the same with and without pre-emphasis.

RECOMMENDATION 405 *

RADIO-RELAY SYSTEMS FOR TELEVISION

Pre-emphasis characteristics for frequency modulation systems

(Question 194 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that it is generally preferable for the major intermediate-frequency and radio-frequency characteristics of international radio-relay systems for television to conform to those of large capacity systems for multi-channel telephony;

* This Recommendation replaces Recommendation 277.

(*b*) that the flexibility of radio-relay systems would be further increased if the modulators and demodulators could be used interchangeably for either television or frequency-division multiplex telephony;

(*c*) that the high-level low-frequency components in the video waveforn which are a barrier to the achievement of this flexibility, can be greatly reduced by attenuation of these components, i.e. by means of a pre-emphasis network before modulation, a corresponding de-emphasis network being inserted after demodulation;

(*d*) that pre-emphasis enables a simple control of the mean carrier frequency to be used both for television and frequency-division multiplex telephony;

(*e*) that pre-emphasis can reduce differential gain and differential phase distortion in a radio-relay system and may be particularly advantageous if the transmission of colour television signals, or a sound channel by means of a sub-carrier, is envisaged;

(*f*) that in determining the pre-emphasis characteristic, its effect on the overall weighted signal-to-noise ratio * and on adjacent channel interference must be taken into account;

(*g*) that excessive attenuation of the low-frequency components of the video signal can cause difficulties due to hum and microphony;

(*h*) that the optimum pre-emphasis characteristics for television and frequency division-multiplex telephony will not be the same;

(*i*) that, to achieve readily reproducible characteristics, the pre-emphasis network, and the corresponding de-emphasis network, should be simple;

UNANIMOUSLY RECOMMENDS

1. that the use of pre-emphasis is preferred for the transmission of monochrome television signals by radio-relay systems;

2. that a minimum phase shift network should be used for pre-emphasis;

3. that the pre-emphasis characteristic for the transmission of 405-line monochrome television signals should be derived from the basic network shown in Table I *a* and Fig. 1, the shape of the characteristic being as indicated by curve *a* in Fig. 2;

4. that the pre-emphasis characteristic for the transmission of 525-line monochrome television signals should be derived from the basic network shown in Table I *b* and Fig. 1, the shape of the characteristic being as indicated by curve *b* in Fig. 2;

5. that the pre-emphasis characteristic for the transmission of 625-line television signals should be derived from the basic network shown in Table I *c* and Fig. 1, the shape of the characteristic being as indicated by curve *c* in Fig. 2;

6. that the pre-emphasis characteristic for the transmission of 819-line monochrome television signals should be derived from the basic network shown in Table I *d* and Fig. 1, the shape of the characteristic being as indicated by curve *d* in Fig. 2;

7. that the tolerance on the pre-emphasis characteristics, and also on the de-emphasis characteristics referred to in Note 3, should be such that, within the frequency range 0·01 Mc/s to the nominal upper limit of the video frequency band, the departure of the characteristic of a practical network from the appropriate theoretical characteristic should be confined within a spread of $0{\cdot}1 + 0{\cdot}05\, f/f_c$ (db), f being the video frequency, f_c being the nominal upper limit of video frequency band. This corresponds to tolerances of the network components (resistors, capacitors, inductors) of about $\pm 1\%$. Further, the magnitude of the departure should exhibit no rapid variations within this frequency range.

---

* See Recommendation 421.

Note 1. — The total range of the network attenuation between zero and infinite frequency is 14 db.

Note 2. — The relative deviation 0 db corresponds to a peak-to-peak frequency deviation of 8 Mc/s for a sinusoidal wave of 1 V peak-to-peak applied at a point of interconnection at the input to the system (Recommendation 276).

Note 3. — When television signals are to be transmitted between countries with radio-relay systems designed for different numbers of lines, the Administration of the country receiving the signals should provide de-emphasis networks corresponding to the pre-emphasis network of the originating country; however, if preferred, other arrangements may be adopted by agreement between the Administrations concerned.

Note 4. — The attenuation of the pre-emphasis characteristic at 0·01 Mc/s relative to the reference deviation level given in Note 2 are: —7; —10; —11; and —12 db for the 819, 525, 625 and 405-line characteristics respectively.

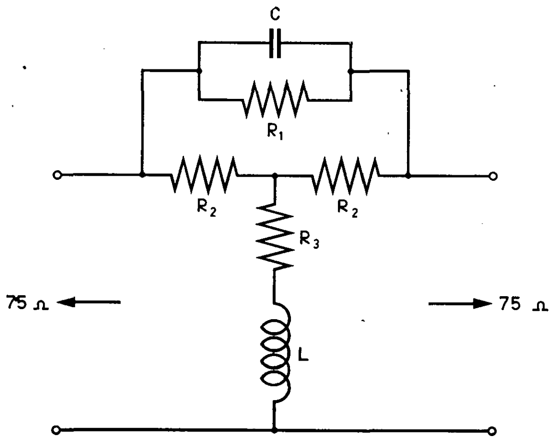


FIGURE 1

Television pre-emphasis network

TABLE I

Component values for television pre-emphasis network

Number of lines	405	525	625	819
Curve (Fig. 1)	*a*	*b*	*c*	*d*
L (μH)	22·22	17·35	9·54	4·77
C (pF)	3950	3085	1695	847·5
R_1 (Ω)	300	275·8	300	300
R_2 (Ω)	75	75	75	75
R_3 (Ω)	18·75	20·4	18·75	18·75

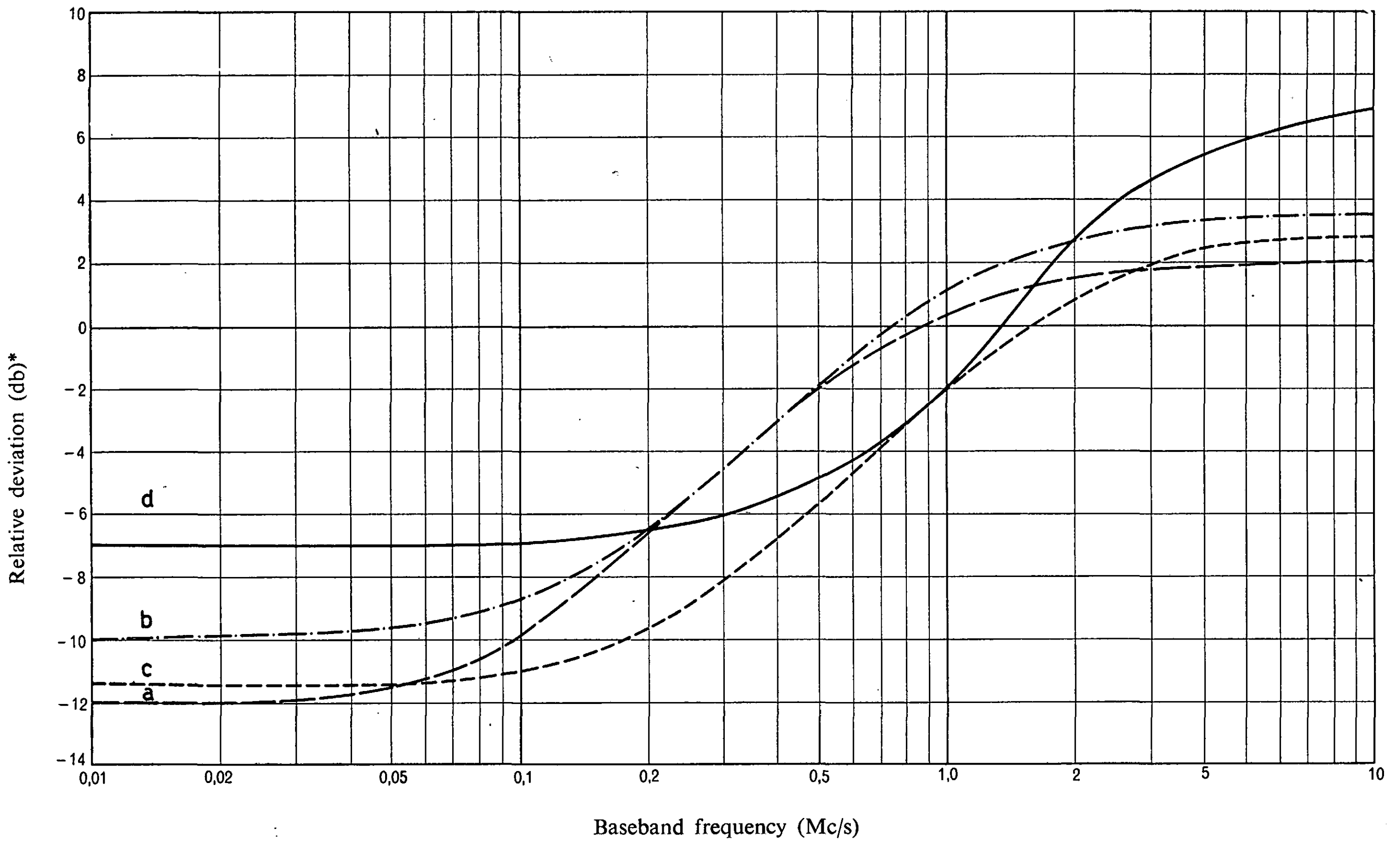


FIGURE 2

Television pre-emphasis characteristics for 405, 525, 625 and 819-line systems

0 db corresponds to a deviation of 8 Mc/s for a 1V peak-to-peak signal (see Recommendation 276).

RECOMMENDATION 406

LINE-OF-SIGHT RADIO-RELAY SYSTEMS SHARING THE SAME FREQUENCY BANDS AS THE SATELLITE RECEIVERS OF ACTIVE EARTH-SATELLITE COMMUNICATION SYSTEMS

Maximum effective radiated powers of line-of-sight radio-relay system transmitters

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that in the interests of spectrum economy, it would be advantageous for satellite communication systems to share certain frequency bands used for line-of-sight radio-relay systems operated in the range 1 to 10 Gc/s;

(b) that in the event of such sharing, to avoid significant interference to reception in satellite receivers without requiring excessive satellite-system earth-station transmitter powers or antenna sizes, it would be necessary to define a maximum allowable value for the effective radiated power of line-of-sight radio-relay system transmitters;

(c) that the maximum allowable value of effective radiated power should be such as not to place undue restriction on the design of line-of-sight radio-relay systems;

(d) that a Recommendation as to a maximum allowable value of effective radiated power of line-of-sight radio-relay system transmitters may be of value for the technical guidance of the Extraordinary Radio Conference which it is proposed to convene in 1963, in accordance with Recommendation No. 36 of the Administrative Radio Conference, Geneva, 1959;

(e) that it is desirable that radio-relay systems should employ highly directional antennae;

UNANIMOUSLY RECOMMENDS

1. that in the event of communication satellite receivers sharing frequency bands with line-of-sight radio-relay systems in the range 1 to 10 Gc/s;

1.1 the maximum effective radiated power of any such radio-relay system transmitter and its associated antenna should not exceed 55 dbW;

1.2 the power delivered to the antenna input by any such transmitter should not exceed 13 dbW;

2. that the above values be provisional pending further study *.

* These provisional values should be reconsidered by the XIth Plenary Assembly of the C.C.I.R.

REPORTS OF SECTION F: RADIO-RELAY SYSTEMS

F. 1-Interconnection

REPORT 134 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING TIME-DIVISION MULTIPLEX

Technical characteristics to be specified to enable interconnection between any two systems

(Question 92)

(Warsaw, 1956 — Los Angeles, 1959)

1. General

A number of different forms of time-division multiplex (TDM) system are in use or under consideration. Of those in service, the majority use pulse-position modulation (PPM), combined with amplitude modulation of the radio carrier (PPM-AM). However, PPM systems with frequency modulation of the radio carrier (PPM-FM) are also used, as are systems with pulse-amplitude modulation (PAM) combined with frequency modulation of the radio carrier (PAM-FM).

Different numbers of speech channels are provided by various systems; other systems again provide for telegraph channels, good quality music channels or other forms of traffic, either specifically or as alternatives to speech channels. Still further systems transmit groups of speech channels by time division, which are themselves assembled by frequency-division multiplex.

Systems using pulse-code modulation are not covered by this Report.

From the point of view of international connection, TDM systems can, in this Report, be divided conveniently into those using pulse-position modulation and those using pulse-amplitude modulation. Systems of one type can be interconnected with the other, or with FDM radio-relay links or landlines, at audio frequency, and recommendations regarding this are given in Recommendations 297 and 335.

Interconnection at baseband (by which is meant here the sequence of modulated pulses before application to the radio-frequency carrier) at intermediate frequency or at radio frequency, requires the two systems concerned to be of the same type (both PPM or both PAM) and that the specifications of certain parameters should be co-ordinated.

Section 2 of this Report lists those parameters requiring specification for baseband interconnection, while § 3 gives the *additional* parameters for intermediate-frequency interconnection. Intermediate-frequency interconnection is not normally used for PPM-AM systems, but could be appropriate for systems using frequency modulation of the radio carrier.

* This Report, which replaces Report 70, was adopted unanimously.

Where international connection at radio-frequency is more appropriate, it is considered that at present, the co-ordination of the necessary technical parameters should be the subject of direct agreement between the Administrations concerned.

To render unnecessary any specific agreement regarding the characteristics of the supervisory system, it is suggested that in an international connection between a TDM radio-relay system and a second telecommunication system (either similar or different), both supervisory systems should terminate at or near the international boundary, or that the method of interconnection should be the subject of agreement between the Administrations concerned.

A service channel is considered necessary as part of a TDM radio-relay system and this service channel should be accessible at all repeater stations.

2. Technical characteristics to be specified for baseband interconnection of any two TDM systems using pulse-position modulation or of any two TDM systems using pulse-amplitude modulation

A. *Characteristics applicable to both PPM and PAM systems*

2.1 Audio channel characteristics.

2.2 — maximum number of telephone traffic channels;

— maximum number and type of traffic channels for other types of service, e.g., music, telegraphy, facsimile, groups of telephone channels assembled in FDM.

2.3 Number of equal time intervals in a sequence.

2.4 Channel sampling rate:

— for telephone traffic,

— for other types of service.

2.5 Pulse polarity at the point of interconnection.

2.6 Impedance characteristics and resulting reflection effects at the point of interconnection.

2.7 Characteristics of synchronizing signal (or marker signals, if any) at the point of interconnection.

2.8 Characteristics and position of service channel, if included in the baseband.

2.9 Characteristics of any special signals sent over the system.

2.10 Type and characteristics of compandor, if used.

2.11 Special requirements, if any, for the insertion and dropping of channels and blocks of channels.

B. *Characteristics applicable to PPM systems only*

2.12 Width and shape of channel pulses at point of interconnection.

2.13 Significant characteristics of pulse.

2.14 Peak-to-peak excursion of the channel pulse, without compandors, for standard modulation *.

2.15 Input and output pulse amplitudes at the point of interconnection.

* By "standard modulation" is meant modulation by an 800 c/s signal of 1 mW at a point of zero relative level, or the equivalent signal for music or for other types of service.

C. *Characteristics applicable to PAM systems only*

2.16 Width and shape of channel pulses at point of interconnection:

— with zero modulation,

— with standard modulation *.

2.17 Input and output amplitudes of the channel pulse at the point of interconnection, with zero modulation.

2.18 Maximum and minimum amplitude of the channel pulse (without compandors) at the point of interconnection, for standard modulation *.

Co-ordination of all the above parameters is necessary at stations where channels are demodulated. At those repeater stations where channels are not demodulated, it is only necessary for the following characteristics to be co-ordinated:

for PPM, the characteristics given in § 2.5, 2.6, 2.12 and 2.15;

for PAM, the characteristics given in § 2.5, 2.6, 2.16, 2.17 and 2.18.

3. Technical characteristics additional to those listed in § 2 above, to be specified for interconnection at intermediate frequency of any two TDM systems using pulse-position modulation or of any two TDM systems using pulse-amplitude modulation

3.1 Centre value of the intermediate frequency.

3.2 The frequency deviation of the carrier and, if necessary, the sense of deviation (if frequency modulation is used), for standard modulation as defined in § 2 of this Report.

3.3 Input and output levels of the intermediate-frequency signal at the point of interconnection.

3.4 Impedance characteristics and resulting reflection effects at the point of interconnection.

4. Present position regarding the recommendation of specific values for the parameters listed in § 2

At present it has not been found possible to reach such agreement on these parameters as to make interconnection possible between any two different PPM or any two different PAM systems other than at audio frequency, and where such cases arise they should be dealt with in the manner indicated in Recommendation 306.

There has, however, been a general agreement on certains points, particularly concerning PPM systems. These agreed points are, therefore, listed below under the paragraph numbers used in § 2.

2.1 *Audio channel characteristics*

For telephone circuits reference is made to Recommendation 297.

2.2 *Maximum number of telephone traffic channels*

To achieve maximum economy in interconnection with other systems, particularly FDM radio-relay systems and line systems, it is highly desirable to provide telephone traffic channels in groups of 12.

* By "standard modulation" is meant modulation by an 800 c/s signal of 1 mW at a point of zero relative level, or the equivalent signal for music or for other types of service.

2.4 *Channel sampling rate for telephone traffic*

The preferred value of channel sampling rate is 8 kc/s with a tolerance of ± 8 c/s or better.

Unless otherwise agreed between the Administrations concerned, the pulse trains may be separately generated for the two directions of transmission.

2.5 *Pulse polarity at point of interconnection*

For PPM systems positive polarity is preferred.

2.6 *Impedance characteristics and resulting reflection effects at the point of interconnection*

The preferred nominal value of the impedance at the point of interconnection is 75 Ω.

2.12 }
2.16 } *Width and shape of channel pulses at point of interconnection*

Attention is drawn to the need to use pulse shapes requiring the minimum bandwidth consistent with the facilities given by the system.

2.16 *Grouping of channels using marker signal synchronization*

If marker signals are used, it is possible to assign to each group of 12 channels an individual marker signal as this will enable the other groups to continue to function properly when one or several groups suffer a break-down, and will also facilitate the branching-off of groups.

2.15 *Input and output pulse amplitudes at the point of interconnection in PPM systems*

The preferred value of the pulse amplitude at a point of international connection is 1·4 V at the output from receiving equipment and 0·7 V at the input to the transmitting equipment. The difference in level allows for loss in the means of interconnection.

REPORT 283 *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

Technical characteristics to be specified to enable interconnection between any two systems

(Question 192 (IX))

(Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Introduction

This Report is concerned with the preferred characteristics of radio-relay systems using frequency-division multiplex (FDM) which it is proposed to specify and reasons why such specifications are considered necessary.

The systems under consideration are those in which the input and output signals, i.e. the "baseband" signals, consist of an assembly of suppressed-carrier single-sideband tele-

* This Report, which replaces Report 131, was adopted unanimously.

phone signals in channels spaced 4 kc/s apart, using arrangements of channels recommended by the C.C.I.T.T.

It is assumed that the FDM signals themselves modulate the frequency or the phase of a radio-frequency carrier; other possible methods exist, e.g. the modulation of a sub-carrier by the FDM signal which, in turn, modulates the radio-frequency carrier, but such methods will not be considered further in this Report.

The specification of certain preferred characteristics of FDM radio-relay systems forming part of an international circuit is necessary to permit the ready interconnection of different radio-relay systems; the specification of some of these characteristics is also necessary to permit the ready interconnection of FDM radio-relay systems with FDM line systems.

2. Stages at which the interconnection of radio-relay systems among themselves or with line systems may be required

The interconnection of different radio-relay systems at national boundaries may be required at:

— baseband frequencies,

— intermediate frequencies,

— radio frequencies.

The interconnection of radio-relay systems at baseband frequencies may occasionally be essential to permit the extraction or insertion of individual channels, groups, supergroups, or mastergroups of channels, and it may also be necessary for level regulating, monitoring, supervisory or control purposes. The interconnection of radio-relay and line systems will normally be carried out at baseband frequencies, since the possibility of interconnection at intermediate or radio frequencies does not exist.

The interconnection of radio-relay systems at intermediate frequency enables the additional noise and distortion due to demodulation and remodulation to be avoided; it also reduces the amount of equipment required as compared with interconnection at baseband frequencies. It should be noted that interconnection at the intermediate frequency requires the specification of the baseband signal as well as the modulation characteristics, i. e. the deviation of the intermediate-frequency carrier. Interconnection of two radio-relay systems at intermediate frequency is, of course, more readily carried out if the two intermediate frequencies are the same; nevertheless, the possibility exists of translating from one intermediate frequency to another if need be, but it should be borne in mind that difficulties may arise if the two intermediate-frequency bands overlap.

However, the need for a preferred spacing between the radio-frequency channels (discussed below) makes it necessary to adopt a value for the intermediate frequency, such that interference in the working channels from the frequency-change oscillators of receivers and repeaters is avoided. This requirement, together with the need to facilitate interconnection at intermediate frequency, makes it desirable to adopt a preferred value for the intermediate frequency.

The interconnection of two radio-relay systems at radio frequencies may be needed when crossing a boundary between two countries where the topography is such that a common frontier station is impracticable or undesirable, for example, when the boundary is located in a wide river estuary or in a sea channel between the two countries. In such cases there must be agreement on the radio frequencies themselves, as well as on the modulation characteristics of the radio frequency carriers and on the baseband signal. This in turn necessitates agreement on the spacings between, and the arrangements of, the radio frequency channels. The adoption of preferred values for the spacing and arrangement of the radio-frequency channels has the advantages of economizing in the use of the frequency spectrum and of minimizing interference between radio-relay systems whose routes intersect or are in close proximity.

3. Characteristics to be specified for international connections

It is assumed that overall performance of the telephone channels should, as far as possible, be in accordance with the relevant C.C.I.T.T. recommendations for modern types of telephone circuit (Recommendations 268 and 335).

As standardization is not yet possible, it is suggested that preferred values should be indicated for the guidance of those concerned with the specification and design of radio-relay systems.

The characteristics for which preferred values should be given are listed below according to whether they relate to interconnection at the baseband, intermediate or radio frequencies.

3.1 *Interconnection at baseband frequencies:*

3.1.1 maximum number of telephone traffic channels;

3.1.2 highest and lowest frequencies of telephone traffic channels, i.e. the frequency limits of the basebands according to Recommendation 380: it is assumed that the arrangement of the telephone channels is in accordance with C.C.I.T.T. recommendations;

3.1.3 nominal impedance of baseband circuits at the point of interconnection;

3.1.4 relative input and output power levels at the points of interconnection *.

In addition to the above, consideration will need to be given to the monitoring, control or supervisory signals transmitted with the traffic channels.

3.2 *Interconnection at intermediate frequencies:*

For interconnection at intermediate frequencies, it will be necessary to give preferred values for the baseband characteristics given in § 3.1.1 and 3.1.2, in addition to the following characteristics:

3.2.1 centre value and stability of the intermediate frequency **; because of the wide range of radio frequencies and numbers of channels that may be employed, it may be necessary to give more than one preferred value for the intermediate frequency; the number of intermediate frequencies should, however, be no more than is essential to meet the various requirements;

3.2.2 the frequency deviation of the carrier caused by a tone of 1 mW applied to a channel at a point of zero relative level in the system; in systems with a large number of telephone channels, e.g. 600, it may be found desirable to use pre-emphasis, producing a larger deviation for the higher frequency channels to improve the signal-to-noise ratio; if this is so, it will be necessary to specify the amount of pre-emphasis to be employed at the various channel frequencies;

3.2.3 input and output levels of the intermediate-frequency signal at the point of interconnection;

3.2.4 impedance of the intermediate-frequency circuit at the point of interconnection.

3.3 *Interconnection at radio-frequencies:*

For interconnection at radio frequencies, it will be necessary to give preferred values for the baseband characteristics of §§3.1.1 and 3.1.2 and the frequency deviation of § 3.2.2, in addition to the following characteristics:

3.3.1 number and arrangement of the radio frequency channels;

3.3.2 wave polarization.

Interconnection at radio frequencies also requires that the frequency stability of the transmissions employed shall be within certain tolerances. Reference should be made to the valid C.C.I.R. Recommendations and to the Radio Regulations, Geneva, 1959.

---

* The choice and precise definition of a point of interconnection are shown in Fig. 1 of Recommendation 380.

** For multi-channel telephony system, the centre value of the intermediate frequency corresponds to the unmodulated carrier frequency.

REPORT 284 *

INTERCONNECTION OF AUXILIARY RADIO-RELAY SYSTEMS AT RADIO FREQUENCIES

(Study Programme 195A (IX))

(Geneva, 1963)

1. Frequency bands available

According to Recommendation 400, auxiliary radio channels can be provided either in the same band as the main system, or in a different band following the same route as the main system.

1.1 *Auxiliary systems operating in the same band as the main system*

The preferred characteristics of such auxiliary radio-relay systems are covered by Recommendation 389, which refers to systems operating in the 2, 4, 6 or 11 Gc/s bands. Several Administrations prefer such auxiliary channels.

1.2 *Auxiliary systems operating in a band other than that of the main system*

Frequencies are proposed in the band of 400–470 Mc/s and discussion showed that there would be frequencies available in the band of 2 Gc/s.

In the Radio Regulations, Geneva, 1959, only the bands 401–420 Mc/s and 450–470 Mc/s have been allocated to fixed (and mobile) service in all three Regions, with many restrictions set out in the appropriate footnotes. The 2 Gc/s band is also allocated to the fixed (and mobile) services in all three Regions, and frequencies may be available in the band 2550–2700 Mc/s.

Propagation conditions in the 400 Mc/s range are very stable, light-weight antennae and low-loss flexible coaxial cables simplify the construction of antennae, inexpensive crystal-controlled transmitters allow narrow spacing. Duplication of highly reliable transmitting tubes is feasible.

In the 2 Gc/s range, narrow-beam antennae are available with greater side-lobe attenuation than in the lower range. This property, and the fact that these waves are not normally propagated beyond the line of sight, reduces the number of frequency pairs necessary for a given network compared with that for the 400 Mc/s range.

It was stated, however, that in the latter range, a frequency offset of about 50 kc/s could double the available pairs of frequencies for a given radio-frequency band.

2. Necessary number of frequencies for auxiliary systems operating in a band other than that of the main system

It was stated that the necessary number of pairs of frequencies would depend on the number of radio-relay systems crossing the border between the Administrations concerned. With regard to the changing of frequencies between adjacent hops, the minimum requirement would be one or two pairs, but the number might often be greater, for instance, six pairs for more extended networks. With a baseband of, for example, 20 kc/s bandwidth, the spacing for the 400 Mc/s range with a frequency stability of 50×10^{-6} (Radio Regulations, Geneva, 1959) would be about 250 kc/s at crossing points and about 500 kc/s on parallel routes. For the 2 Gc/s range, a stability of 50×10^{-6} seems to be feasible (Radio Regulations, Geneva, 1959, give 300×10^{-6}); the corresponding figures would be about 0·5 Mc/s and 1 Mc/s respectively. For the sake of frequency conservation, the channel spacing should be reduced to the minimum practicable.

---

* This Report was adopted unanimously.

3. Characteristics to be specified

It was agreed that the most suitable form for transmission of the total baseband would be frequency modulation of the carrier *. Further characteristics to be specified are the frequency deviation, the pre- and de-emphasis and the polarization of radio-frequency signals.

3.1 *Frequency deviation*

In the 400 Mc/s range, a frequency deviation of 20 to 30 kc/s r.m.s. at a modulating frequency of 1 kc/s and a level of 0 dbm0 would be suitable. Information is not yet available for the other ranges.

3.2 *Pre-emphasis and de-emphasis*

In the 400 Mc/s range, pre-emphasis and de-emphasis corresponding to a time constant of $RC = 5$ μs would somewhat improve the signal-to-noise ratio. It was stated, however, that this point would be the subject of agreement between the Administrations concerned.

3.3 *Polarization*

If circumstances should require minimizing the interference to adjacent radio-frequency channel working in a specific station, or to co-channel working in different stations, the polarization of the radio-frequency signals should be chosen by agreement between the Administrations concerned.

REPORT 285 **

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Transmission, interference and interconnection

(Question 260 (IX))

(Geneva, 1963)

1. Introduction

This Report is based on consideration of systems with capacities from about 12 to 120 voice channels. Future developments may demonstrate the practicability of systems of greater capacity, but it is felt that limitation of present technology and natural phenomena prevent the compatibility of very wide-band tropospheric-scatter systems with high quality performance.

2. Transmission characteristics

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

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

Amplitude variation as a function of time is noted to consist of a rapid variation superimposed on a slow change. Rapid variations, which are basically caused by multipath phenomena, can be mitigated in many cases by diversity methods. The effects of slow variation may be minimized through use of high-power transmitting equipment, high-gain antennae,

---

* Amplitude modulation or a different type of modulation may be chosen by agreement between the Administrations concerned.

** This Report, which is an answer to Question 196 (IX), §3, was adopted unanimously.

very low-noise receiving techniques, low-loss feeders, adaptive message-loading techniques, improved detection and other system optimization practices, such as choice of radio carrier frequency and choice of modulation.

The variations in amplitude as a function of frequency consist essentially of two phenomena:

— a difference in mean signal strength as a function of radio carrier frequency;

— variation of signal-strength with frequency over relatively narrow bandwidths as a function of time, path characteristics, radio carrier-frequency range and antenna beamwidths.

The variation in the "long-term" mean signal strength as a function of frequency affects the selection of an operating frequency band. Considerations of path characteristics, antenna size and configuration, economic and technical aspects of components, may be used as factors in the choice of the optimum frequency range for a given application.

The aplitude-frequency and amplitude-time variations within a narrow band can affect the choice of radio-frequency range used and the antenna (beamwidth and gain) and modulation characteristics, as well as the choice of the services to be provided.

In fairly common circumstances, phase variations of many radians may be expected over short periods, introducing some frequency modulation due to propagation alone. Over long periods, the short-term average phase may vary even more, following changes in the dominance of such propagation mechanisms as diffraction, ducting, reflection by elevated layers, and tropospheric forward scatter.

Natural phenomena (such as multi-path), causing short-term phase variations usually contribute to short-term amplitude-time and amplitude-frequency variations as well.

The higher frequencies are usually preferred for shorter paths, limited antenna size and high information rates. Realization of high antenna gains at the upper frequencies can be impaired by wide mechanical tolerances, and will be reduced somewhat whenever the path antenna gain (see Recommendation 341 and Report 112) depends upon a scatter mechanism of propagation.

Assuming that a linear frequency-phase relation exists across the frequency band of a radio channel, there will still be variations with time in the phase of the received signal. Furthermore, as between different radio channels the phase will vary as a function of radio frequency. These effects are caused by the same natural phenomena referred to above, and can affect information quality and rate.

The deleterious effects of short-term phase-frequency and phase-time variations can be minimized by some of the following methods: selection of radio-frequency band, arrangement of baseband, modulation characteristics, orders of diversity and methods of combining used, antenna beamwidth employed and the use of adaptive message loading techniques.

The choice of a radio frequency band is influenced by the above-mentioned technical considerations, as well as by regulatory and interference aspects. In general lower frequency bands may be preferred for long paths, low information rates, limited antenna gain conditions.

3. Interference

Tropospheric-scatter systems have interference producing capabilities and susceptibilities not unlike those encountered in line-of-sight radio-relay systems. Differences are primarily due to the usually higher transmitting powers, narrower antenna beamwidths and more sensitive receivers encountered in tropospheric-scatter systems. This means that siting considerations are very important with scatter systems.

To minimize interference from a tropospheric-scatter radio-relay system, line-of-sight situations are usually avoided, as are areas where the diffracted signal will be strong. Under some circumstances, it may be impossible to avoid occasional interference from signals due to diffraction, strong layer reflection, or especially ducting.

To estimate expected co-channel interference, it is necessary to combine the path antenna gain and the propagation loss. The interfering field depends on the mean long-term loss and any additional fluctuations. At UHF and higher frequencies, the lowest observed extra-diffraction transmission loss values result from atmospheric focusing and ducting, either over sea or over land.

Antenna contributions may be analyzed in terms of an idealized azimuthal or "keyhole" pattern (see Fig. 1). In this example it is assumed that the antenna gain beyond about the second set of side-lobes does not exceed the equivalent of an isotropic antenna. The two patterns shown are for 2 Gc/s antennae, 2 m and 15 m in diameter, which are typical sizes for line-of-sight and tropospheric-scatter systems respectively.

Field strength may be combined with antenna gain (see Fig. 1) to yield azimuthal distance-interference patterns for various systems and combinations. In considering non-co-channel interference, account must also be taken of transmitter spectrum distribution and receiver pass-band characteristics.

Although it is not possible to recommend final channel arrangements, there is need to select frequencies in an orderly manner on a regional basis. In arriving at such agreements between Administrations, the guide-lines in Recommendation 302 and Report 286 should be observed.

Polarization discrimination is also suggested to aid the use of space diversity and the rejection of interference.

It has been general practice to engineer tropospheric-scatter systems on the high propagation attenuations exceeded only during small percentages of the time. It should be realized that under more favourable conditions, prevailing for the rest of the time, transmitter powers and antenna gains so justified can cause increased interference fields. It may be advisable under such conditions temporarily to reduce the transmitter power.

4. Interconnection

4.1 *Interconnection at baseband frequencies*

For interconnection at baseband frequencies, application of Recommendation 380 is suggested.

4.2 *Interconnection at intermediate-frequency*

Where interconnection at the intermediate frequency is desired, centre frequency, pass-band, impedance characteristics, levels, etc. should be specified.

Interconnection at the intermediate frequency is not as appropriate in tropospheric-scatter systems as in line-of-sight radio-relay systems. This is due to the following facts:

— increasing use of frequency compression techniques;

— limitations imposed by the use of diversity reception, particularly baseband combining;

— due to the poor carrier-to-noise ratios usually experienced, the deviation for each system is generally chosen as the optimum for that system, rather than using a standardized deviation; however, interconnection cannot be easily achieved unless all systems use the same deviation;

— the intermediate-frequency bandwidths, pre-emphasis, etc. are usually chosen as a function of the number of channels actually in use and a compromise is undesirable.

Whereas the above circumstances may not prohibit intermediate-frequency interconnection, its desirability is likely to become marginal in many instances.

Nevertheless, where intermediate-frequency interconnection is desired, for frequency-modulation systems the centre frequency, the voltage and impedance characteristics should be those specified in Recommendation 403 *.

4.3 *Interconnection at radio-frequencies*

Interconnection at radio-frequencies requires the specification of the carrier frequencies employed, baseband characteristics (such as number and allocation of channels, modulation and demodulation characteristics, pre-emphasis, pilots, channel levels), order and type of diversity and polarization used, antenna characteristics (gain, bearings and polarization), radio-frequency power levels, receiver sensitivities, and system pass-band characteristics.

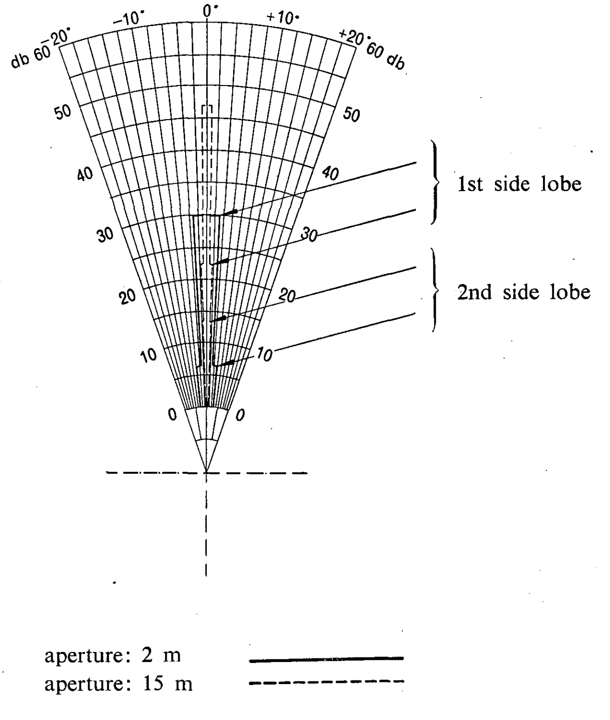


FIGURE 1

Pattern for an ideal parabolic antenna

(The example shown is for a frequency of 2 Gc/s)

* The interconnection frequency may be attained by single heterodyning, multiple mixing, multiplication (particularly in frequency compression receivers), a combination of these or similar techniques. Considerations of receiver noise figure and selectivity may also justify using double (or higher order) mixing. See Annex.

For the reasons given under § 4.2, as well as additional reasons (particularly noise, selectivity, and gain), interconnection at radio-frequency within a station is not desirable and there seems no purpose in preparing recommendations for such interconnection. Interconnection at radio-frequency over the air between two stations is nevertheless widely used.

ANNEX

THE CHOICE OF INTERMEDIATE FREQUENCIES FOR TROPOSPHERIC-SCATTER RECEIVERS

The following notes concern the choice of intermediate frequencies for tropospheric-scatter receivers of the angular modulation type only. For single-sideband equipment some of the considerations are different and are not considered here.

1. Choice of the first intermediate-frequency

When parametric amplifiers (or other low-noise input circuits) are used, the choice of intermediate frequency has no predominant influence on the noise factor of the receiver.

Otherwise, the choice of intermediate frequency becomes a compromise between the noise factor of the receiver and the radio-frequency filter losses. This may lead to the choice of a lower intermediate frequency than in the first case.

2. Double conversion receivers

In the interest of image rejection, as high a first intermediate frequency as possible should be used (consistent with noise figure requirements). However, there are a number of reasons why the use of a double conversion receiver is often desirable. These include the following factors:

- the large gain needed in a tropospheric-scatter receiver is sometimes difficult to obtain with only one intermediate-frequency;
- in a scatter receiver, the intermediate-frequency bandwidth is generally less than in a line-of-sight receiver carrying the same number of channels, to obtain the best compromise between threshold and intermodulation; hence, rather narrow intermediate-frequency bandwidths may be needed, which can be best obtained at a relatively low frequency;
- the intermediate-frequency bandwidth is often varied for different channel capacities to obtain the optimum compromise between threshold and intermodulation in each case. This can most economically be done by making the intermediate-frequency bandwidth suitable for the largest number of channels for which the set is to be used, and inserting a filter for lower capacities. These filters may be built more cheaply for a lower frequency.

In a receiver employing an intermediate-frequency combiner, it is necessary to have a voltage-variable oscillator in one or more of the receivers, which can be used to phase-lock the signals to one another, or to a common standard for effective combining. If this oscillator operates at a frequency below about 100 Mc/s, the use of relatively simple modulator techniques is possible. It can conveniently be the second local oscillator in a dual conversion receiver.

In a "Compression" type of receiver, a dual intermediate frequency is desirable to avoid the need for duplicating the microwave local oscillators for space or angle diversity, and is necessary to avoid the application of feedback over too long a loop.

For receivers using "phase lock" detectors, it is desirable to operate the detector at as low a frequency as possible. Although operation at frequencies of the order of 70 Mc/s is possible, there would be advantages from the receiver design standpoint if they could be operated at lower frequencies. If compression is combined with the phase-lock detector, the use of two intermediate frequencies is mandatory to avoid trying to apply feedback over a long path.

F. 2 - Radio-frequency channel arrangements

REPORT 286 *

TROPOSPHERIC-SCATTER SYSTEMS

Radio-frequency channel arrangements for systems using frequency modulation

(Study Programme 260A (IX))

(Geneva, 1963)

1. Introduction

Study Programme 260 A (IX) asks for a study of radio-frequency channel arrangements for tropospheric-scatter, radio-relay systems. The studies carried out so far give valuable information on the problems to be taken into account for establishing such a radio-frequency channel arrangement usable over a wide geographical area. The results obtained have made it evident that it is neither possible nor even desirable to fix preferred radio-frequency arrangements for such systems. On the contrary, the maximum amount of flexibility should be maintained in the design of such systems, so that their characteristics can best be adapted to current needs (See Report 285).

To simplify the design of equipment and to facilitate its operation, it is, however, desirable that studies of the necessary frequency arrangements in each case should be guided by certain basic rules.

2. Considerations on which a radio-frequency channel arrangement might be based

2.1 The high radiated power of tropospheric-scatter systems and the long range of this propagation method may give rise to serious interference at distances extending beyond national frontiers, for example 1000 km;

2.2 interference both between and within tropospheric-scatter systems can be minimized by the co-ordination of radio-frequency channel arrangements over a large geographical area;

2.3 the presence of high-power transmitters and very sensitive receivers in the same station makes protection against local interference very difficult, and as a result it is necessary to minimize such effects by a carefully planned arrangement of radio frequencies;

2.4 radio-frequency channel arrangements should provide for various capacities of FDM telephony (e.g. from 12 to 120 telephone channels) and perhaps also for television as appropriate;

2.5 with the frequency deviations likely to be employed, the bandwidth of emission may range from a fraction of 1 Mc/s to several Mc/s (perhaps up to 8 Mc/s for television);

2.6 to avoid undue interference between stations the minimum distance separating a receiving station from an interfering transmitting station operating on the same frequency may have to be large, for example 1000 km or more, depending on the power used, the characteristics, orientations and polarizations of the antennae;

2.7 if it is desired to make interconnections, it is recommended that use be made of the intermediate frequencies 35 and 70 Mc/s in conformity with Recommendation 403; see also Report 285;

* This Report, which replaces Report 136, was adopted unanimously.

2.8 it is important that the arrangement used be responsive to all operational requirements;

2.9 the arrangement used should be amenable to the use of diversity reception. When the system operates in dual-diversity, the avoidance of frequency diversity is recommended, as suggested by Recommendation 302, § 3.
Where frequency diversity must nevertheless be used in each direction of transmission, the diversity frequencies can either be very close together (for example those in adjacent channels), or separated by several tens of Mc/s. The radio-frequency channel arrangement must be compatible with such requirements;

2.10 the frequency bands usable by tropospheric-scatter multi-channel radio-relay systems between 100 Mc/s and 10 Gc/s have bandwidths ranging from a few Mc/s to more than 1 Gc/s. These bands are often taken from those allocated to the fixed and mobile services, according to regional and national regulations. The frequency plan must reflect this situation.

3. General indications to be followed

3.1 An appreciable reduction of the distance envisaged between stations likely to cause mutual interference can generally be realized, on condition that they can be operated on slightly different frequencies, the minimum useful frequency separation being about 0·5 to 1 Mc/s for narrow-band frequency-modulation systems * as well as for amplitude-modulation single-sideband systems;

3.2 interference resulting from frequencies produced at a single station (frequencies of transmitters, local oscillators, frequency-changers) is chiefly linked to the choise of intermediate frequency. It is, therefore, not wise to set up a channel arrangement without prior consideration of the value of the intermediate frequencies used.
The most troublesome interference can usually be avoided by choosing a separation between channels, such that the intermediate frequency can never be a multiple of this separation. This rule must be respected, particularly when the effective separations between channels are chosen as appropriate multiples of the unit step between 0·5 and 1 Mc/s as proposed in § 3.1;

3.3 to apply a single channel arrangement to several channels of various telephone capacities, a separation between channels in a station can be used which is a multiple of a frequency module. Typically, the radio frequency channel separation required for 60 and 120 channel systems could be respectively 3 to 5 times that required for 12 to 24 channel systems, the r.m.s. deviations used being chosen in conformity with Recommendation 404;

3.4 the first channel should be at a minimum distance from the end of the frequency band considered equal to approximately half the channel width;

3.5 at each station all transmitting frequencies should be in the same half of the band, and all receiving frequencies in the other half. The role of the two half-bands will be reversed in adjacent stations;

3.6 to minimize the problem of duplexing, the minimum frequency separation between transmitted and received signals on the same antenna should be of the order of:

— 40 Mc/s for systems operating at frequencies below 1000 Mc/s;

— 80 Mc/s for systems operating at frequencies above 1000 Mc/s.

The minimum frequency separation between transmitted and received signals at the same station, but not on the same antenna, should be of the order of:

— 25 Mc/s for systems operating at frequencies below 1000 Mc/s;

— 35 Mc/s for systems operating at frequencies above 1000 Mc/s.

Finally, the minimum separation between two transmitting frequencies, or two receiving frequencies at the same station, could be seven times the basic unit referred to in § 3.3;

---

* Special reference should be made to: MEDHURST, HICKS and GROSSET, Distortion in frequency-division-multiplex FM systems due to an interfering carrier. *Proc. I.E.E.* **105**, Part B, 282-292 (May 1958).
HAMER, R. and ACTON, R.A., Power spectrum of a carrier modulated in phase of frequency by white noise. *Electrical and Radio Engineer* **34**, 246-253 (July 1957).

3.7 taking account of the great number of usable channels, the variety of situations encountered in actual practice, and to keep the maximum flexibility in the use of frequencies, precise assignment of frequencies for interconnection should be the subject of an agreement between the Administrations affected.

REPORT 287 *

RADIO-RELAY SYSTEMS FOR TELEPHONY AND TELEVISION

Systems of capacity greater than 1800 telephone channels, or the equivalent

(Study Programme 192A (IX))

(Geneva, 1963)

1. The contributions to the Xth Plenary Assembly in reply to Study Programme 192 A (IX), gave details of the work carried out in various countries into the problems of the transmission of very wide-band frequency-modulated radio signals. These contributions lead to the consideration of the feasibility of, and the appropriate characteristics for, radio-relay systems with a capacity of 2700 telephone channels.

The following is a resumé of the contributions submitted to the C.C.I.R. Xth Plenary Assembly.

1.1 Experimental investigations carried out in Italy have shown that radio terminal and repeater equipment of 2700 channels can be realized using well-established techniques. Field tests over a typical radio section 51 km in length over the Po Valley have shown that distortion from multipath propagation does not appear to be a limiting factor so long as due care is taken in the choice of path length, clearance, etc. The tests indicated that a minimum radio-frequency carrier spacing of 36 Mc/s (about 3 times the highest baseband frequency) is required with a test-tone deviation of 140 kc/s r.m.s. per channel.

1.2 In the Federal Republic of Germany, tests transmissions have been carried out over two paths of 44 km and 60 km in length and of different topographical characteristics. In these tests, a 4 Gc/s test signal frequency-modulated by a 10 Mc/s sinusoid was employed and the relative phases of the separate beat signals between the upper and lower sidebands and the carrier were compared. The relative amplitudes of the two sidebands were also compared.

Although only limited quantitative data of the disturbing effects were obtained, it was considered that intermodulation noise and variations of the overall gain of a significant amount could occur unless due care were taken in the topographical planning of radio-relay links of a very high capacity.

1.3 Experience in Japan indicated that equipment for 2700 channel capacity transmissions may be designed using principles already established for lower capacity systems.

Propagation tests have also been carried out which indicate that in such systems high noise levels may be experienced over sea paths about 70–80 km long. However, the probability of occurrence of such distortion is thought likely to be small over land paths less than 50 km in length.

1.4 Work has been carried out in the United Kingdom into the evaluation of intermediate frequency techniques for very large capacity systems. Experiments were carried out using

* This Report was adopted unanimously.

an intermediate frequency of 210 Mc/s, as it was considered that the use of an intermediate frequency considerably higher than 70 Mc/s offered certain advantages for very high capacity systems. Tests showed that an intermediate frequency of 210 Mc/s was not too high to be practical for radio-relay systems and that the overall linearity of the intermediate-frequency equipment permitted a test-tone deviation of 200 kc/s r.m.s. to be used for 2700 channel systems.

In the light of the foregoing, it is essential that the desirable characteristics of 2700 channel systems shall be outlined in order that international standardization shall proceed as far as is reasonable at this stage without being unduly restrictive.

2. Baseband characteristics

To facilitate interconnection of 2700-channel radio systems with 12 Mc/s coaxial systems, the baseband limits should be in accordance with C.C.I.T.T. Recommendation G. 333. Recommendations 380, 398, 399 and 401 give provisional values for the input and output levels, baseband limits, continuity pilot frequency and white noise testing requirements for 2700 channels.

The continuity pilot deviation is undetermined as this is related to the final choice of test-tone deviation.

3. Radio-frequency channel arrangements

Preferred characteristics for a radio-frequency channelling plan for a radio-frequency band 680 Mc/s wide immediately above 6425 Mc/s (which is the upper limit of the band planned under Recommendation 383 have been determined and these are given in Recommendation 384.

A radio-frequency channel spacing of 40 Mc/s has been selected for the following reasons:

— a second radio-frequency channel arrangement for lower capacity systems may be derived, with 20 Mc/s channel spacing, which uses the same channel frequencies, together with an interleaved set of frequencies. This second set is suitable for use with an intermediate frequency of 70 Mc/s, as in Recommendation 403, for systems of up to a capacity of 1800 channels;

— it is suitable for use with two alternative values of intermediate frequency (100 and 140 Mc/s), the respective merits of which are discussed in the following section on intermediate frequency;

— the possibility of interference to radio-relay systems on parallel or crossing routes using an intermediate frequency of 70 Mc/s is greatly reduced;

— the requirements for cross-polarization discrimination between adjacent radio-frequency channels are relaxed and greater freedom is permitted in the choice of test-tone deviation higher than 140 kc/s r.m.s.

The preferred association of radio-frequency channels for 2700 channel systems when common transmit-receive antennae are used is dependent upon both the choice of relative polarizations and upon the value of intermediate frequency used. In general, it is advisable to avoid transmit-receive channel frequencies spaced by the intermediate frequency appearing on the same antenna but this problem has to be weighed against the difficulty of separating the two inner channel frequencies. Considering these factors, suggested polarization arrangements are shown in Fig. 1.

A frequency arrangement for lower capacity systems using a channel spacing of 20 Mc/s, which employs the same channel frequencies as the arrangement in Fig. 1, is shown in Fig. 2.

The need for an interleaved set of frequencies, displaced by 10 Mc/s from the main pattern, deserves further study. Such an arrangement might have advantages should a mixed arrangement of 960 and 2700 channel systems be used on the same route.

4. Auxiliary channels

It is customary, in devising radio-frequency channel arrangements for broadband systems, to provide for two pairs of auxiliary channel frequencies and some preliminary examination has been given to this problem. It seems likely that the values $f_o \pm 3$ and $f_o \pm 337$ Mc/s will prove to be the most suitable, although, in certain of the polarization arrangements, great difficulty may be experienced in filtering the two inner auxiliary channel frequencies. The proposed arrangement is included in Fig. 1.

An auxiliary channel arrangement with 20 Mc/s channel spacing is included in Fig. 2, and the suggested auxiliary channel frequencies are $f_o - 341$, $f_o - 19$, $f_o - 1$ and $f_o + 321$ Mc/s.

Further study is needed before preferred arrangements can be recommended.

5. Intermediate frequency

It is desirable, when devising radio-frequency channel arrangements for broadband systems, to choose an intermediate frequency which is an odd multiple of half the radio-frequency channel spacing, to minimize interference due to local oscillators. Hence, with an intermediate frequency of 70 Mc/s, a channel spacing of 20 Mc/s is satisfactory. In very wideband systems requiring the larger channel spacing of 40 Mc/s, intermediate frequencies of either 100 or 140 Mc/s are thought to be most suitable. It is not possible to establish a definite preference for one or other of the values at this stage, but factors involved in the choice are as follows:

- the lower value facilitates the early development of solid state IF equipment;
- the decreased percentage bandwidth is lower at the higher frequency so that it becomes easier to attain symmetry of the IF pass-band: nevertheless circuits are likely to be more stable at the lower frequency;
- radio-frequency filtration problems tend to be eased when a higher value of intermediate frequency is used.

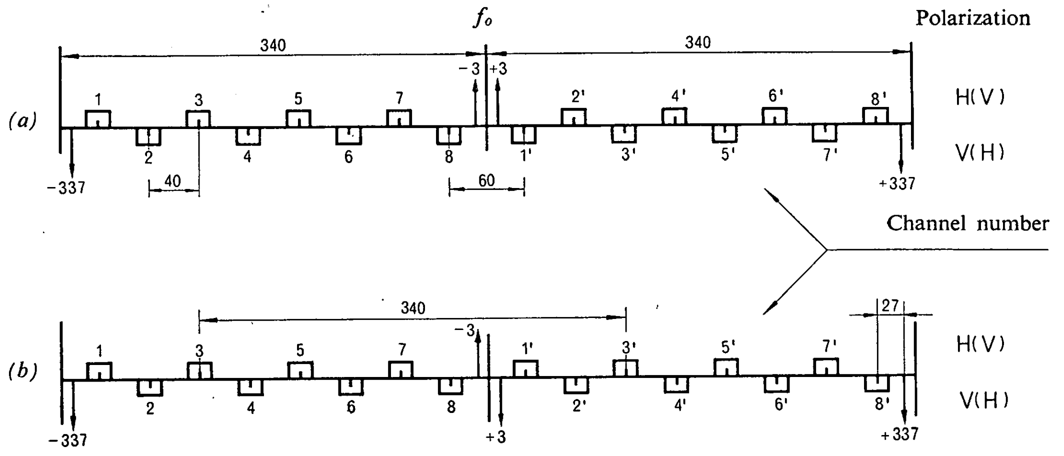
6. Deviation

With the rapid development of circuit techniques and components and the dearth of information on the likely contribution to intermodulation distortion due to propagation, it is difficult at this stage to decide on the value of deviation that will give the best balance between thermal and intermodulation noise. It is considered that a value of test-tone deviation between 100 and 200 kc/s r.m.s. will prove satisfactory; it is considered premature to define a preferred pre-emphasis characteristic, although the curve in Recommendation 275 should prove a useful starting point.

7. Conclusion

It is desirable at this stage to deliniate as far as possible the main parameters of a 2700 channel system so that, on the one hand, international standardization will be encouraged but that, on the other hand, the freedom of the designers shall not be unduly restricted. To this end, Recommendation 384 has been prepared which defines the essential radio-frequency channel characteristics. With regard to the other system parameters, it is proposed that further study should be restricted to the following alternatives and that other values should not be chosen unless there are particularly good reasons for doing so:

- intermediate frequency: either 100 or 140 Mc/s;
- r.m.s. test-tone deviation: either 100 kc/s, 140 kc/s or 200 kc/s.



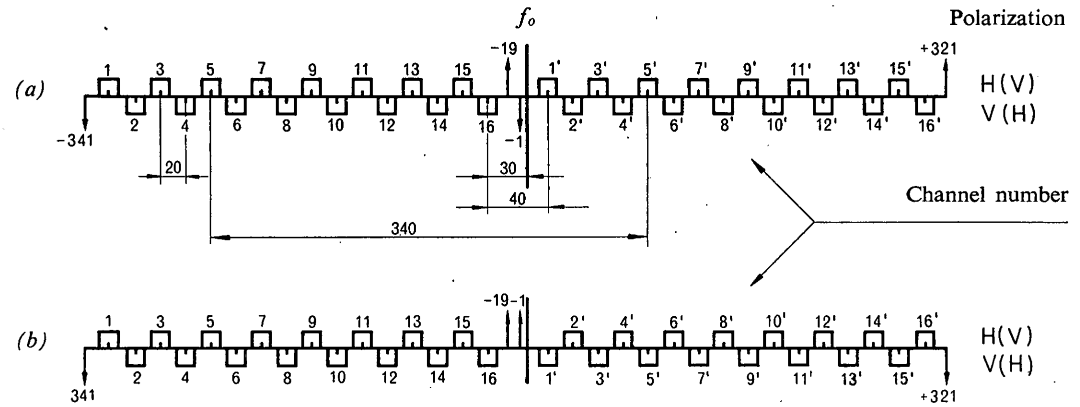
(a) Arrangement proposed for either:

— an antenna with single polarization and an IF of 100 Mc/s, or
— an antenna with double polarization and an IF of 140 Mc/s.

(b) Arrangement proposed for either:

— an antenna with single polarization and an IF of 140 Mc/s, or
— an antenna with double polarization and an IF of 100 Mc/s.

FIGURE 1
(All frequencies are in Mc/s)



(a) Arrangement proposed for antennae with single polarization

(b) Arrangement proposed for antennae with double po arization

FIGURE 2
(All frequencies are in Mc/s)

F. 3 - Hypothetical reference circuits and noise

REPORT 130 *

RADIO-RELAY SYSTEMS FOR TELEPHONY

Noise tolerable during very short periods of time on line-of-sight systems

(Study Programme 193A (IX))

(Los Angeles, 1959)

1. Method of specification

The maximum values of noise in telephone circuits on radio-relay systems should be specified in terms of:

— the mean psophometric noise in an hour;

— the psophometrically-weighted noise powers which may be exceeded only for specified small percentages of a month when the fading is severe, measured with an instrument which indicates the mean value over one minute or a quantity approximately equivalent to this value.

2. Time constant

Measurement in terms of the one-minute-mean power is favoured to facilitate the use of the opinion-rating method of assessing telephone conversations recommended by the C.C.I.T.T. Instruments having time constants of one minute are acceptable even though they do not precisely measure one-minute-mean values.

3. Short noise bursts

Information on the performance of line-of-sight radio-relay links suggests that it is not necessary to specify a limit to the number of high noise bursts of duration exceeding a given value and occurring in a given time, provided that limits are placed on the noise which may be exceeded only for small percentages of a month, and that noise due to power supplies and switching operations is excluded. It is desirable to stipulate in addition that the link should incorporate some form of diversity reception on sections in which the fading is unusually severe, e.g. due to the use of exceptionally long sections or to reflections from a water surface. The Annex gives some information on noise bursts in one country (United States of America); the magnitude and duration of noise bursts in other regions may be somewhat different due to the different meteorological conditions.

4. Traffic loading

It is recognized that the period of worst fading usually occurs at night, while the greatest traffic often occurs during the day. Whether advantage can be taken of this depends on the requirements that the system is intended to satisfy.

* This Report was adopted by correspondence without reservation.

5. Noise in parts of radio links

The noise power during substantial percentages of the time can, without great error, be considered proportional to the length of the circuit, for lengths exceeding about 250 km. There is some reason for assuming that intermodulation noise increases more rapidly with length than does basic noise. Nevertheless for lengths of circuit exceeding about 250 km, the error in assuming that noise for substantial percentages of time is proportional to length is small, and it is proposed, therefore, to make use of this law of proportionality in C.C.I.R. Recommendations.

When considering very small percentages of time for which high noise values may be exceeded, these percentages can be considered as proportional to circuit length for lengths of circuit exceeding 250 km and for values below 0·1% or in some cases below 1%.

The two working rules given above, i.e. linear-power-addition for large percentages of time and linear-percentage-addition for small percentages of time, are somewhat inaccurate between about 0·1% and 10% where the error may in extreme cases amount to 3 or 4 db. However, the rules are considered to be sufficiently accurate for most purposes. Greater accuracy can be obtained by detailed mathematical treatment which depends upon the particular monthly distribution curves involved. A method of approximation which can give useful accuracy in some cases has been discussed by B. B. Jacobsen (Proc. I.E.E., Part C, March 1958).

ANNEX

RELATIONSHIP BETWEEN SHORT-TERM AND LONG-TERM NOISE PERFORMANCE IN RADIO-RELAY SYSTEMS IN THE UNITED STATES OF AMERICA

1. The distribution of the duration of deep fades (and hence the resulting noise bursts) at the frequencies used in radio-relay systems appears to be log-normal. Such a distribution may be characterized by:

— its slope or its standard deviation, and

— one point on the curve, such as the median or the average duration.

2. From several series of tests, the standard deviation is approximately $\log_{10} 2{\cdot}7$, and appears to be substantially independent of frequency. This standard deviation has been observed in tests on individual paths and on systems comprising as many as 68 paths in tandem. It has been observed at different frequencies from 2 to 6 Gc/s. It has been observed in different regions which are subject to different fading influences and on paths with both adequate and inadequate clearance. A somewhat higher standard deviation appears to be associated with inadequate clearance, possibly because of an increased tendency towards obstruction fading.

The average duration is not as closely defined, and appears to be approximately inversely proportional to frequency. That is to say, at a given depth of fade at 2 Gc/s half as many fades twice as long as at 4 Gc/s would be expected. The total time of fading would be nearly the same, although this is only approximately true over frequency ranges greater than 2 to 1.

At 4 Gc/s an average duration of the order of 7 to 9 s has been observed for 30 db fades and of the order of 4 to 5 s for 40 db fades, in a limited series of tests on a system composed of 40 km paths.

The duration of fades is approximately inversely proportional to the length of the radio-frequency paths. The data quoted were observed on a system composed of paths approximately 40 km long in the North-Eastern United States of America. In other tests on paths approximately 70 km long in the Western United States of America, durations approximately 40–70 times as long were observed.

3. From these points, it is possible to relate the number and duration of the fades to the total time that a given depth of fade is exceeded in a long period of time, such as a month.

4. As a further example, consider a 4 Gc/s system with parameters such that a 40 db fade in any one section will cause the noise to exceed a given maximum level. Consider further that each section may be expected to fade 40 db or more for n seconds during the worst month * and consider that there are N sections in tandem, without diversity, so that the total time that a 40 db fade will be exceeded somewhere in the system ** is nN seconds during the worst month.

5. From § 2 and 4, the system of the example might be expected to experience $nN/4{\cdot}5$ or $0{\cdot}22\, nN$ fades exceeding 40 db during the worst month. The duration of these fades would be as outlined in § 2.

6. Fading differs from day to day and from hour to hour. The worst day will have more fades than an average day by some variable factor, and the worst hour will have more fades than the average hour by some still more variable factor. In one series of tests on a system 450 km long including 8 paths, the first factor was 6 and the second factor was 60. There is no information for other lengths of system or other numbers of paths.

7. The system of the example might, therefore, be expected to experience

$$\left(\frac{1}{30} \times 6\right) \times 0{\cdot}22\, nN = 0{\cdot}044\, nN$$

fades during the worst day of the worst month, and

$$\left(\frac{1}{30} \times \frac{1}{24} \times 60\right) \times 0{\cdot}22\, nN = 0{\cdot}018\, nN$$

fades during the worst hour of the worst month.

8. If the performance of a specified system is predicted using the methods of the example, it may be found that the performance does not meet the requirements of Recommendation 393. This demonstrates the need for avoiding the effects of fading by

— diversity operation,

— reducing the length of paths or the choice of more favourable sites,

— improving the fading margin by the use of higher power or higher gain antennae where these factors are at the disposal of the system designer.

9. The effects of deep fades may be substantially reduced by the use of some form of diversity reception, such as frequency diversity or space diversity. A limited series of tests has shown that approximately 5% of the total fading time beyond 40 db cannot be counteracted by frequency diversity of 100 Mc/s or more by vertical space diversity of 15 m or more at 4 Gc/s. The duration of the residual fades with diversity may be shorter than without diversity, by as much as 50%. No information is available on this point.

---

* For the North-Eastern United States and for paths about 40 km long, n may be taken as approximately 100. In other areas, and for other lengths of path, different values of n may be appropriate.

** The probability that 40 db fades will occur simultaneously in more than one of the N sections is very small. For shallower fades, such as 20 db, the probability of simultaneous fades is greater and may be appreciable.

10. With the foregoing as guidance as to the probable performance of a system during the worst hour and worst day of the worst month, it is sufficient to define the system by the long-term performance, i.e. the statistical distribution of noise during the worst month.

REPORT 288 *

NOISE IN CIRCUITS LONGER THAN 2500 km

(Question 193 (IX))

(Geneva, 1963)

1. The development of world-wide telecommunication networks involves specifying permissible limits for the mean value of circuit noise and for its variation with time at the end of a telephone circuit considerably longer than 2500 km. This matter has been studied initially by Special Joint Study Group C (C.C.I.T.T./C.C.I.R.), but as yet no final decisions have been reached. The following paragraphs summarize the advice of Study Group C as far as it is available and is relevant to radio-relay systems.

2. Joint Study Group C considers that there is no call to introduce new hypothetical reference circuits for radio-relay links.

3. However, it is to be noted that:

3.1 if real circuits, longer than 2500 km, are to be provided over plant which satisfies the requirements of Recommendation 393, one must expect that the mean psophometric power will be proportional to L (i.e., equal to $3\,L$ pW) and that the fraction of the time during which the noise power exceeds 47 500 pW will also be proportional to the length, i.e. $(L/2500) \times 0{\cdot}1\,\%$;

3.2 Nevertheless, by adopting special measures, such as suitably choosing the telephone channels on which very long circuits are set up, it is hoped that a fair proportion of these channels might have somewhat better performance (for example 2 pW/km or even less).

4. These special measures may, however, prove to be unnecessary and even undesirable, since it is to be expected both that demands for very long circuits will increase and that improvements in technique will take place. It may therefore be desirable, in the future, to reduce the noise objective on such circuits to less than 3 pW/km (2 pW/km or even less). This problem is under active study by Special Joint Study Group C (C.C.I.T.T./C.C.I.R.).

General Note. — All the figures for phosphometric power herein quoted represent an average over one hour. The noise objectives for shorter periods will require further study.

---

* This Report was adopted unanimously

F. 4 - Maintenance

REPORT 137 *

DURATION OF INTERRUPTIONS ON RADIO LINKS WHEN SWITCHING FROM NORMAL TO STAND-BY EQUIPMENT

(Question 197 (IX))

(Los Angeles, 1959)

1. Protection of radio-relay channels against interruptions due either to failure of equipment or to deep fading is usually supplied by automatically switched protection channels. Three general types of automatic switching arrangements are currently in use for the purpose. They are:

1.1 Multi-line switching, in which one protection channel serves two or more normal channels;

1.2 Single-line switching, in which one protection channel serves one normal channel;

1.3 Combining, in which the outputs of two parallel channels are combined at baseband or at intermediate frequency.

The specified requirements for time of operation of the three types differ; in general, the systems are required to operate as rapidly as developments permit.

2. Two types of interruption are recognized:

2.1 the *transfer time* of the switch element itself, which while operating may introduce a short-circuit, an open-circuit or double transmission, and

2.2 the *operate time* of the entire automatic switching system, from the instant that transmission is degraded sufficiently that switching is desirable to the instant that service is restored by completion of switching to the protection channel.

The specified limit for duration of an interruption of the first type is set by telegraph transmission, where interruptions of less than 1 ms will not cause errors on 50 baud AM or FM–VF (carrier) telegraphy. (It is also necessary to consider the level changes and phase changes associated with switching from one circuit to another, since these also can cause telegraph errors.) There is already a demand for data circuits which operate at much higher speed than 50 baud VF (carrier) telegraphy, and consequently, it is considered desirable to find means of reducing the switching interruption time to considerably below 1 ms.

3. There appears to be no hope, of reducing the operate time of the entire switching system to 1 ms. The various components of the total operate time are, for multi-line switching:

3.1 Time of recognition of fade or failure, at receiving end.

3.2 Time to construct a control signal to be sent to the transmitting end.

3.3 Transmission time of control signal to transmitting end.

---

* This Report, which was adopted unanimously, does not include interruptions due to power supply failures; this subject should be studied separately.

3.4 Recognition time at transmitting end.

3.5 Bridging time at transmitting end.

3.6 Transmission time of signals over protection line to receiving end.

3.7 Time to examine signal received over protection line.

3.8 Time to decide whether the switch should be operated.

3.9 Actual switch operation time.

4. By the natural laws of propagation, § 3.3 alone is usually 2 ms or more. Considering all the above items, and allowing 5 ms for margin, an objective of 35 ms seems practicable and appears to fulfill the following:

4.1 A barely perceptible interruption to voice.

4.2 A tolerable interruption to television—noticeable, but very seldom causing a failure of field synchronization.

4.3 A noticeable but not severe streak on phototelegraphy.

4.4 No seizure of common equipment in toll-dialling offices.

5. The effect of failures on the operate time of the entire automatic switching system will differ from that of fades. Failures usually interrupt transmission completely and suddenly, and service is not restored until the entire operate time has elapsed. With fading, transmission will probably continue to deteriorate but may not completely fail after the instant that request for switching is initiated. If the operate time and the noise level which will cause switching to be requested are properly proportioned to the maximum rate of increase in fading loss, it is possible to eliminate transmission errors due to fading. The maximum increase in fading loss on optical paths has been taken conservatively at 100 db per second, and if the operate time is 33 ms, the fading loss will increase 3 db during the interval between a request for switching and the completion of switching. If there is at least 3 db margin between the noise level causing a request for switching and the noise level that would produce transmission errors, no transmission errors will be caused by the fading, provided of course, that transmission over the protection channel is satisfactory so that switching actually takes place.

6. Single-line switching systems and combining systems operate much faster than multi-line switching systems because the normal and protection channels can be bridged permanently at the transmitting end so that there is no necessity to originate, transmit and recognise control signals. However, single-line switching systems cannot apparently be made fast enough to eliminate errors in 50 baud telegraph and data transmissions. For these services combining arrangements are preferable.

In some cases, stand-by equipment has been provided which can be switched to replace normal equipment which has failed. Generally, the objective is to complete switching as fast as the state of the art permits.

7. In summary, the following design objectives seem feasible at present:

7.1 *Transfer time:* 1 ms, which appears acceptable for most services; however, if high speed data transmissions are required, and even for certain types of VF (carrier) telegraphy, this value should be considerably reduced.

7.2 *Operate time:* 35 ms, which may cause errors in 50 baud telegraph transmission.

With systems now in service, the transfer time may be about 3 to 5 ms and the operate time may be 50 ms or more.

8. In conclusion, the switching systems must be such that interruptions due to operate time occur only in case of:

8.1 failure of normal equipment;

and that the interruption is limited to the transfer time in the two other cases:

8.2 failures in radio propagation;

8.3 switching over from normal to protection equipment for maintenance.

F. 5 - Characteristics

REPORT 289 *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY PREFERRED CHARACTERISTICS FOR THE TRANSMISSION OF MORE THAN ONE SOUND CHANNEL

Simultaneous transmission of television and a maximum of four sound channels

(Study Programme 194A (IX))

(Geneva, 1963)

1. Introduction

This mode of operation is only intended for systems with a capacity of 1800 telephone channels. According to Recommendation 271, and in conformity with the decisions of the C.C.I.R. Meeting of Experts, Cannes, 1961, a bandwidth of up to 6 Mc/s is envisaged for international television transmissions (e.g. Eurovision). As it is desired to make the separation between the highest video frequency and the sound channels sufficiently large, lest the filter necessary between the video and sound signals give rise to undue transients in the video channel, the space available in the baseband spectrum for accommodating the sound carriers is restricted approximately to the band 7 to 8·2 Mc/s. Only four sound channels of good quality may be accommodated in such a narrow band instead of six.

2. Baseband frequency arrangement for simultaneous transmission of television and four sound channels

2.1 *Frequency position of intermodulation products*

The sub-carriers of the four intended sound channels lie within a frequency octave, which implies they will be free from any quadratic non-linear distortion products. By careful arrangement, the third-power non-linear distortion products due to intermodulation between the sub-carriers, may be positioned off the sub-carrier frequencies, though some of them fall near the upper fringe of the video channel. Care should be taken that the third-power intermodulation product between the lowest sub-carrier and the continuity pilot is sufficiently spaced from a possible colour carrier at 4430 kc/s. It is further desirable that the third-order non-linear products between the sub-carriers should not be permitted to coincide with the frequency of the continuity pilot.

2.2 Taking account of considerations of § 2.1, the nominal frequencies for the four sub-carriers might be chosen as follows: 7000, 7360, 7740 and 8140 kc/s.

The third-order intermodulation products would, consequently, start at 5860 kc/s, the intermodulation product between the lowest sub-carrier on 7000 kc/s and the continuity pilot on 9023 kc/s would be at 4977 kc/s, which is well away from the colour carrier (4430 kc/s).

* This Report was adopted unanimously

3. Choice of the maximum frequency deviation of the sub-carriers

In § 2.2, an average spacing between the sub-carriers of 380 kc/s has been proposed. A convenient choice for the maximum frequency deviation of the sub-carriers would then be ±100 kc/s.

4. Choice of the frequency deviation of the IF and RF carriers produced by the sub-carriers

When choosing the frequency deviation of the main carrier frequency, account should be taken of the three main sources of noise:

— thermal noise,

— non-linear products falling into video channels,

— non-linear products falling into the sound channels.

As regards thermal noise, it will suffice to obtain a performance that is 12 db better than that for telephone channels equipped for long-distance operation. The improvement can be obtained by the use of a maximum signal deviation of the sub-carriers of ±100 kc/s, as proposed in § 3. It will be then more than sufficient, if the main carrier frequency deviation due to one sub-carrier is made equal to the nominal frequency deviation of a telephone channel occupying the same position in the baseband, taking into account the use of pre-emphasis.

It seems, however, that this value of deviation would fall somewhat short in respect to the intermodulation noise into the sound channel; this statement is based on experience with a sound channel in accordance with Recommendation 402; this applies still more to the present case, since the frequency deviation in § 3 above is smaller by a factor of 2 than the corresponding frequency deviation given in Recommendation 402.

In consequence, proposals for the frequency deviation of the main-carrier, would first require that values be specified for the deviation and pre-emphasis of the video signal. It has been suggested that the same pre-emphasis be used for systems designed for the simultaneous transmission of television and 600 telephone channels, or for television and several sound channels, as is used for systems loaded with 1800 telephone channels. A frequency deviation for television has been proposed which has, at the lower frequencies, the same value as that given in Recommendation 405. This results in a deviation at the highest video frequencies which is somewhat lower than that given in Recommendation 405 with pre-emphasis.

On the basis of the above assumptions, a provisional value for the main carrier frequency deviation is proposed which is 3 db larger than the nominal deviation for a telephone channel in the same baseband position. In this proposal, note has been taken of the fact that a system with a capacity of 1800 telephone channels must be more highly linear than a 960-channel system.

With the four sub-carriers and the television signal, the most pessimistic addition of the instantaneous peak frequency deviations gives ±3·8 Mc/s, while for a 1800 channel telephone system, the corresponding figure is ±6·2 Mc/s.

5. Characteristics of the multiplex equipment

The sub-carrier modulators and the network combining the sub-carriers with the video signal should be separate from the 1800 channel radio-relay equipment. The question remains to be studied, how to design the filters necessary for the separation of the video signal and the sound channels, to conform to all pertinent recommendations for television and sound channels of both the C.C.I.T.T. and the C.C.I.R.

6. Conclusions

The following transmission characteristics should be studied as preferred values:

6.1 Frequencies of the sub-carriers: 7000, 7360, 7740 and 8140 kc/s.

6.2 Maximum audio signal at a point of zero relative level * +9 db relative to 0·775 V r.m.s.

6.3 Audio bandwidth: 30 to 10 000 c/s (the upper limit may be increased, should there be evidence of need).

6.4 Maximum signal deviation of sub-carrier frequency: ±100 kc/s for the level defined in § 6.2.

6.5 Pre-emphasis in the sound channel needs further study.

6.6 Main carrier frequency deviation due to each of the four sub-carrier frequencies should be that corresponding to a power of +3 dbm0 in a telephone channel with the same baseband position, taking into account the use of pre-emphasis.

REPORT 290 **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred characteristics for the transmission of more than one sound channel Transmission of up to six sound channels

(Study Programme 194A (IX))

(Geneva, 1963)

1. Choice of a multiplex system for the transmission of several sound channels over a radio-relay channel

The work carried out within the scope of Study Programme 194 A(IX) should, for the time being, be confined to systems employing frequency-modulated sub-carriers.

2. Alternative use of a radio-relay system for the transmission of up to six sound channels

For the transmission of up to six sound channels on a radio-frequency carrier according to Study Programme 194 A(IX), two different solutions have been taken into consideration, as follows:

2.1 the use of a radio-relay system with a capacity of 960 or 600 telephone channels or less;

2.2 the use of a radio-relay system with a capacity of 1800 telephone channels, or the equivalent.

While the variant given in § 2.1 proves to be rather advantageous in respect of frequency economy, that in § 2.2 allows for a simple separation of the channels.

3. Alternative use of a radio-relay system with a capacity of 960 or 600 telephone channels or less

For the transmission of 6 sound channels on a radio-frequency carrier, it is not necessary to use wide-band systems with a capacity of 960 or 600 telephone channels;

---

* C.C.I.T.T. Recommendation J. 12 (Vol. III), Fig. 77. This defines the input and output levels for an international programme line and for an international programme link. It is the responsibility of the Administrations to choose the appropriate value for their special use.

** This Report was adopted unanimously

a baseband approximately 1·5 Mc/s wide as is found in radio-relay systems with a capacity of 300 telephone-channels would be sufficient. An added advantage would accrue, if the sound channel sub-carriers were placed in the baseband at frequencies below 1·5 Mc/s, because in this case, large phase shifts can be obtained at moderate frequency-shifts tending to a favourable signal-to-noise ratio. If it is nevertheless intended to transmit the 6 sound channels over a system with a capacity of 960 telephone channels, the same design parameters may be used.

3.1 *Channel arrangement in the baseband for the transmission of six programmes*

According to Recommendation 380, the baseband of a 300-channel system occupies a frequency band of 60 to 1300 kc/s. The frequency of the continuity pilot is given by Recommendation 401 as 1499 kc/s. It seems readily feasible therefore to accommodate six broadcast sound channels in the given baseband.

It is desirable to so distribute the sub-carriers in the sub-band that the quadratic and cubic harmonic distortion products fall into the gaps between the sub-carriers.

The following values are proposed when choosing sub-carriers:

90; 370; 610; 810; 1030 and 1290 kc/s.

With this arrangement we attain a minimum separation of 20 kc/s between third-order interference products produced by intermodulation of the sub-carriers and a carrier and a minimum separation of 50 kc/s between second-order interference products and a carrier. These values refer to the nominal values of the sub-carriers.

3.2 *Primary deviation for the sub-carriers*

A spacing of approximately 200 kc/s is proposed for the sub-carriers. The primary deviation of the sub-carriers should be

50 kc/s_{o-p} for the two lower carriers and

70 kc/s_{o-p} for the four upper carriers.

3.3 *Secondary deviation for the sub-carriers*

The over-all deviation for six sound channels should not exceed, or if possible, should be less than the peak deviation occuring when the radio-relay system is loaded with 300 telephone channels. The deviation at peak loading is 4 Mc/s_{o-p} according to page 53 of the C.C.I.T.T. Vol. III, and the channel deviation is 200 kc/s r.m.s. according to Recommendation 404.

It should now be examined whether it seems practicable to use the full peak deviation of 4 Mc/s_{o-p}, taking into account a deviation of 100 kc/s r.m.s. for the continuity pilot (Recommendation 401).

Using the parameters proposed in §§ 3.1 and 3.2, calculations show that to suppress the thermal noise, an over-all deviation of 1·7 Mc/s would suffice; corresponding to a single sound channel deviation of 200 kc/s r.m.s. By choosing low values of channel deviations, intermodulation between the six sub-carriers can be held to a minimum. Since with the sub-carriers positioned as given above, only third-power intermodulation products might give rise to trouble, these will be decreased by 2 × 6 db if, as proposed above, the frequency deviation is lowered from 34 to 17 Mc/s_{o-p}.

In the calculation of the signal-to-noise ratio, it is assumed that the six sub-carriers in the baseband have all the same level and that a pre-emphasis according to Recommendation 275 for 300 telephone channels is used in the radio-relay equipment. This proposal to use the same pre-emphasis as in telephone transmission, is of advantage in that it provides for nearly the same transmission quality in the six sound channels and in that it makes at the same time for a very simple switching technique from operation to reserve channel.

As has been mentioned above, basically the same parameter may be used in systems with a capacity of 960 telephone channels. In this case it is, however, proposed to use also the pre-emphasis of these systems for telephone transmission and to choose appropriate levels of the sub-carriers in the baseband, so that the secondary frequency deviation per sub-carrier corresponds to the frequency deviation per telephone channel in the same portion of the channel frequency pattern.

From the considerations given above, the secondary mean frequency deviation for any of the six sub-carriers will be 200 kc/s r.m.s., i.e. the same deviation as per telephone channel. The transmission of broadcast sound channels requires a signal-to-noise ratio approximately 12 db better than for telephone transmission. The necessary improvement in signal-to-noise ratio may be obtained by choosing an appropriate value for the primary frequency deviation.

The test methods for programme transmissions according to the procedure discussed above should still be studied with a view to defining exactly the conditions on which the desired transmission quality is attainable. Study of the questions dealt with should be continued in the light of these considerations.

3.4 *Levels in the baseband of the radio-relay equipment*

Pending future decisions, the levels and impedances in the baseband should be those given in Recommendation 380 for systems with a capacity of 300, 600 or 960 telephone channels even if such systems carry several broadcast sound channels instead of telephony. Thus, no difficulties would arise when switching from normal to reserve channels at the same time making for a more uniform design of radio-relay equipment.

3.5 *Parameters for the sound channel multiplex equipment*

The translation of, say, six broadcast sound channels (audio) into the baseband, by means of six frequency-modulated sub-carriers is not a task for the radio-relay system proper, which, e.g. as regards switching technique from normal to reserve, is not affected by the addition of the multiplexing equipment. Translation into the baseband must be effected in special modulators. If the characteristics for such baseband multiplex equipment were standardized on the lines set forth above, international connection would be feasible without affecting the present recommendations for radio-relay systems as regards switching from normal to reserve channels.

At the audio side, the characteristics of the multiplex equipment should be matched to the Recommendations of the C.C.I.T.T. for music lines, and at the baseband side, they should be matched to the baseband characteristics of radio-relay systems.

4. Alternative use of a radio-relay system with a capacity of 1800 telephone channels, or the equivalent

The use of a radio-relay system specialized for television with a video bandwidth of 10 Mc/s in accordance with Recommendation 270, is envisaged for the transmission of six high quality sound channels, when these channels are to be operated over the same route as one or several television channels.

The solution adopted by the French Administration in this case is explained in the following sub-paragraphs.

4.1 *Channel arrangement in the baseband for the transmission of six sound channels*

The bandwidth being sufficiently large, it will be possible to arrange the sub-carrier within a frequency octave. With this arrangement, the second order intermodulation products fall outside the band used. Effects of third-order intermodulation products are eliminated by an appropriate arrangement of the sub-carrier frequencies.

The frequencies of the sub-carriers are chosen as:
4260, 4940, 5600, 6290, 7010 and 7760 kc/s.

4.2 *Primary deviation for the sub-carriers*

The frequency spacing between the sub-carriers being 700 kc/s, the large primary deviation of these sub-carriers can be chosen without regard to any interference which might arise in the adjacent channels.

A deviation of 70 kc/s r.m.s. is used with a pre-emphasis which increases the relative level of the higher frequencies without noticeably decreasing the lower frequencies; the use of such a pre-emphasis results in good protection against the different sources of noise.

To simplify matters, the pre-emphasis characteristic adopted is that used in frequency modulation on VHF broadcasting transmitters. It is defined by Recommendation 412 for a *RC*-circuit with a time constant of 50 μs (75 μs in Canada and the U.S.A.).

TABLE I

Characteristics	Variant	
	§ 2.1	§ 2.2
Modulation system	FM-FM	FM-FM
Frequency positions of the sub-carriers (kc/s)	90, 370, 610, 810, 1030, 1290	4260, 4940, 5600, 6290, 7010, 7760
Nominal input impedance of the audio channel (Ω, balanced)	600	1500
Maximum audio signal (1) at a point of zero relative level (2) (db rel. 0·775 volts r.m.s.)	+9	+9 (in 600 Ω)
Audio bandwith (c/s)	30 to 10 000 (3)	40 to 15 000
Deviation of sub-carriers (kc/s r.m.s.) for a sinusoidal tone at maximum level given above	50	70 (at 800 c/s)
Pre-emphasis (μs) in the audio channel	50 (4) (75 in Canada and the U.S.A.)	50 (5) (75 in Canada and the U.S.A.)
Deviation of IF and RF carrier. The amplitude of the unmodulated sub-carrier should be such as to produce a deviation of the IF and RF carriers of: (mean value, kc/s r.m.s.)	200	600

(1) The input and output levels for an international programme line and an international programme link are defined by the C.C.I.T.T. (1). It is the responsibility of Administrations to choose the appropriate value for their special use.

(2) See C.C.I.T.T. Recommendation J. 13 (Vol. III), Fig. 77.

(3) The upper limit may be increased, should there be evidence of need.

(4) According to Recommendation 412. The reference frequency for the nominal deviation is still under study.

(5) According to Recommendation 412. The relative deviation of 0 db corresponds to a frequency of 800 c/s.

4.3 *Secondary deviation of the main carrier for each sub-carrier.*

The peak-to-peak frequency excursion being limited to about 10 Mc/s and taking into account the pre-emphasis in the baseband transmission (Recommendation 405), the r.m.s. value of the deviation for each sub-carrier (non-modulated) is about 600 kc/s.

4.4 *Interconnection at baseband frequencies.*

The characteristics for interconnection at baseband frequencies have been chosen such as to enable the multiplex signal to be transmitted over a radio-relay system in accordance with Recommendation 270. This arrangement makes for identical transmission characteristics in all channels, each of them being capable to serve as spare channel for any other without regard to baseband loading.

The multiplex equipment is foreign to the radio equipment proper: and the interconnection characteristics of the sound channel modulation conform to the C.C.I.T.T. Recommendations.

5. Comparison of the two variants.

The basic characteristics of the two variants in §§ 2.1 and 2.2 are given in Table I.

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

STUDY GROUP IX

(Radio-relay systems)

Terms of reference :

To study all aspects of radio-relay systems and equipment operating at frequencies above about 30 Mc/s, including systems using the tropospheric-scatter mode of propagation.

Chairman : Mr. E.O. DIETRICH (Federal Republic of Germany)

Vice-Chairman : Mr. J.H.H. MERRIMAN (United Kingdom)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP IX

1. The task of Study Group IX—in accordance with its terms of reference—is to study all aspects of radio-relay systems and equipment operating at frequencies above about 30 Mc/s including tropospheric-scatter systems.

2. As provided for in Recommendation 335, Recommendations by Study Group IX are intended for application to radio-relay systems for telephony to attain the transmission performance recommended by the C.C.I.T.T. for international circuits on metallic conductors.

2.1 The transmission performance of radio-relay systems for television should likewise be in accordance with the relevant Recommendations of the C.M.T.T.

3. Following closely the procedure adopted by the C.C.I.T.T. for cable systems, Study Group IX of the C.C.I.R. has set up hypothetical reference circuits for radio-relay systems and elaborated Recommendations for the noise allowable in such circuits, stating which values the noise power may attain for different percentages of the time if the operation is to meet the requirements stipulated by the C.C.I.T.T.

The study of the allowable noise in the hypothetical reference circuit and in real circuits also includes the requirements necessary for telegraphy transmission.

3.1 Similar Recommendations cover the allowable noise conditions in the hypothetical reference circuit for the transmission of monochrome television signals.

4. Resulting from the present state of development of techniques, only telephony systems using time-division multiplex and systems using frequency-division multiplex have been studied.

For systems using frequency-division multiplex the Recommendations are concerned with frequency-modulation only. They also take account of the use of pre-emphasis.

5. One of the main interests of Study Group IX has been the problem of international connection across national frontiers. From these studies a number of Recommendations have been established, with the aim of facilitating the interconnection of systems of different origin at radio frequencies, at intermediate frequencies or at baseband frequencies.

6. Besides working out agreements on baseband and intermediate-frequency characteristics, Recommendations for radio-frequency channel arrangements were necessary. Hence, channel arrangements for systems with a capacity of 12 to 2700 telephone channels, or the equivalent, were set up for the 2, 4, 6, 7, 8 and 11 Gc/s range. Still other Recommendations and Reports cover the channel arrangements for those service channels necessary for the operation of radio-relay systems in the different parts of the spectrum.

6.1 The standardization of radio-frequency channel arrangements is of great importance, since economical use of the frequency spectrum along national frontiers will only be feasible when the channel arrangements used in neighbouring countries are adapted to each other.

6.2 The establishment of Recommendations for radio-frequency channel arrangements for tropospheric-scatter systems proves particularly difficult. The frequencies for such systems must be very carefully chosen lest the high radiated power and the long range of this propagation mode may give rise to serious interference at distances extending beyond the national frontiers. Studies in this subject could not yet be concluded.

7. Since it is technically feasible to transmit the corresponding sound channel on a radio-relay system for television, the desirable characteristics for this type of operation were combined in a number of Recommendations, taking into account also the possibility of transmitting more than one sound channel.

8. Moreover, Study Group IX has dealt with maintenance problems and has worked out Recommendations for the measurement of the performance of radio-relay links with the help of a signal consisting of a continuous uniform spectrum. This method allows for the performance of radio-relay telephony systems using frequency-division multiplex to be measured under conditions closely approaching those of actual operation.

9. Among problems requiring further study, the following are worthy of mention:

— special questions of tropospheric-scatter systems;

— preferred characteristics for the transmission of colour television and the simultaneous transmission of colour television and other signals;

— noise due to fading or interference and very high noise peaks tolerable during very short periods of time;

— characteristics of systems for 2700 telephone channels.

10. Recently, new problems have arisen in connection with the coming into being of communication-satellite systems sharing the same frequency bands with line-of-sight radio-relay systems. The problems demand a very careful and intense study. In future, very close cooperation between Study Groups IX and IV seems to be indispensable.

OPINION 12 *

RADIO-RELAY SYSTEMS FOR TELEVISION

Maintenance procedures

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that Recommendation 290 gives the maintenance methods for radio-relay systems for telephony;

(b) that methods different from those used for telephony may have to be used for the maintenance of television radio links;

(c) that a joint C.C.I.R./C.C.I.T.T. Committee (C.M.T.T.) has been established to study television transmission;

IS UNANIMOUSLY OF THE OPINION

that the maintenance procedure for television radio-relay systems, in so far as it concerns the overall transmission performance, should be referred to the C.M.T.T., it being understood that the testing methods adopted should be the subject of agreement with the C.C.I.R.

Note. — The attention of the C.M.T.T. is drawn to the difficulties which may be produced by applying to radio-relay systems, test signals of high amplitude which can cause serious interference in adjacent radio channels.

OPINION 13 **

RADIO-RELAY SYSTEMS FOR TELEPHONY

C.C.I.T.T./C.C.I.R. Joint Working Party on circuit noise

(Questions 193 (IX) and 260 (IX))

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that a working party has been established by the C.C.I.T.T., with participation by C.C.I.R. representatives, to study circuit noise;

(b) that certain aspects of the questions under consideration by the C.C.I.R. might usefully be studied by this working party, that is to say:

---

* This Opinion was formerly designated "Resolution 54".

** This Opinion was formerly designated "Resolution 56"

— permissible noise power for the transmission of VF telegraphy or data (part of Question 193 (IX));

— permissible noise power for radio-relay systems using tropospheric-scatter propagation (part of Questions 193 (IX) and 260 (IX));

IS UNANIMOUSLY OF THE OPINION

1. that the working party on circuit noise established by the C.C.I.T.T. with participation by C.C.I.R. representatives be constituted as a C.C.I.T.T./C.C.I.R. Joint Working Party *;

2. that this Joint Working Party be responsible for the studies indicated in *(b)* above;

3. that the Director, C.C.I.T.T. be invited to be responsible for the convening, organization and secretariat of this Joint Working Party.

OPINION 14 **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred frequency bands and centre frequencies for radio-relay links for international connections

The C.C.I.R., (Los Angeles, 1959 — Geneva, 1963)

CONSIDERING

(a) that line-of-sight and near line-of-sight radio-relay links have already been established by many countries for international connections and that such networks are expanding;

(b) that some countries may be considering the use of tropospheric-scatter links for international connections;

(c) that the C.C.I.R. has recommended preferred radio-frequency interconnection arrangements for radio-relay links of capacity from 60 to 2700 telephone channels, or the equivalent (Annex I);

(d) that, for radio-frequency interconnection of links in international networks, agreement is necessary on specific radio frequencies as well as on the arrangement of radio channels within a band;

(e) that specific radio frequencies can readily be defined in terms of the centre frequency of the radio-frequency interconnection arrangement;

(f) that, for technical reasons, only certain preferred values of the centre frequency are acceptable in a given frequency band;

(g) that there are various aspects of radio-wave propagation and equipment design that lead to the choice of particular frequency bands for certain capacities and types of radio-relay system;

(h) that radio-relay links used for international connections must meet similar high standards of performance to those recommended by the C.C.I.T.T. for metallic circuits;

(i) that it is essential to avoid interference to radio-relay links used for international connections, either from other radio-relay links or from other radio services (including harmonics), operated in the same or other countries;

---

* This Working Party exists under the name "Special Study Group C".

** This Opinion replaces Resolution 55.

IS UNANIMOUSLY OF THE OPINION

that the attention of Administrative Radio Conferences be drawn to:

1. the technical advantages of international agreement on preferred frequency bands within which international line-of-sight and tropospheric-scatter radio-relay links may be established using the radio-frequency channel arrangements recommended by the C.C.I.R.;

2. the technical advantages of preferred values for the centre frequencies of bands for line-of-sight and tropospheric-scatter systems being established by international agreement;

3. the risk of interference between line-of-sight and tropospheric-scatter links if these operate in the same frequency band and in the same geographical zone;

4. the need to avoid interference to radio-relay links used for international connections from other radio services or harmonics radiated by them.

ANNEX I

C.C.I.R. RECOMMENDATIONS FOR PREFERRED RADIO-FREQUENCY CHANNEL ARRANGEMENTS FOR RADIO-RELAY SYSTEMS, USED FOR INTERNATIONAL CONNECTIONS (1) (2)

Recommendation	Maximum capacity of each radio carrier (Telephone channels or the equivalent)	Preferred centre frequency (3) f_0 (Mc/s)	Width of radio frequency band occupied (Mc/s)
283	60/120	1808 2000 2203	200 200 200
385	60/120/300	7575	300
279 and 382	300/1800	1903 2101 4003·5 (4)	400 400 400 (4)
383	600/1800	6175	500
384	960/2700	6770	680
386	300/960	8350	300
387	960	11 200	1000

(1) The Recommendations referred to above apply to line-of-sight and near line-of-sight systems. For tropospheric-scatter systems, it has not yet been possible to formulate preferred radio-frequency channel arrangements but the attention of the Administrative Radio Conference is drawn to Recommendation 388 and to Report 286.

(2) The attention of the Ordinary and Extraordinary Administrative Radio Conferences should also be drawn to Recommendation 389, Study Programme 195 A (IX) and to Report 284.

(3) Other centre frequencies may be used by agreement between the Administrations concerned.

(4) In some countries, mostly in a large part of Region 2 and in certain other areas, a reference frequency f_r = 3700 Mc/s is used at the lower edge of a band 500 Mc/s wide (see Annex to Recommendation 382).

RESOLUTION 17

SIGNAL AMPLITUDES IN INDIVIDUAL CHANNELS OF MULTI-CHANNEL TELEPHONE SYSTEMS

(Question 111)

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that Question 111 asks that a request for a study of the statistical distribution of the instantaneous signal amplitude in individual channels of multi-channel telephone systems be submitted to the C.C.I.T.T.;

(b) that after study, the C.C.I.T.T. has provided an answer in C.C.I.T.T. Recommendation G. 222 (Vol. III);

UNANIMOUSLY DECIDES

1. that the attention of Administrations who are interested in this Question be drawn to the answer provided by the C.C.I.T.T.;

2. that the study of Question 111 be terminated.

RESOLUTION 18

INFORMATION REQUIRED ON THE TRANSMISSION CHARACTERISTICS OF LINE SYSTEMS FOR USE IN THE DESIGN OF RADIO-RELAY SYSTEMS

(Question 112)

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that Question 112 asks that a request for study of the transmission characteristics of line systems for use in the design of radio-relay systems be submitted to the C.C.I.T.T.;

(b) that after study, the C.C.I.T.T. has provided an answer in C.C.I.T.T. Recommendation G. 222 (Note 1 to the NOTE) and G. 442 (Vol. III);

(c) that Recommendation 393 also provides a partial answer;

UNANIMOUSLY DECIDES

1. that the attention of Administrations who are interested in the Question be drawn to these answers;

2. that the study of Question 112 be terminated.

QUESTION 192 (IX) *

RADIO-RELAY SYSTEMS FOR TELEPHONY USING FREQUENCY-DIVISION MULTIPLEX

The C.C.I.R., (London, 1953 — Los Angeles, 1959)

CONSIDERING

(a) that a variety of types of multi-channel radio-relay systems operating at frequencies above about 30 Mc/s use frequency-division multiplex;

(b) that it is sometimes desirable to be able to interconnect systems of different types particularly on international circuits;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the radio or intermediate-frequency characteristics of frequency-division multiplex radio-relay systems operating at frequencies above about 30 Mc/s which it is essential to specify to enable two such systems to be interconnected;

2. what specifications should be drawn up for such characteristics and should be recommended as standards for radio-relay systems carrying frequency-division multiplex for use on international circuits and operating at frequencies above about 30 Mc/s?

STUDY PROGRAMME 192A (IX) **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Systems of a capacity greater than 1800 telephone channels, or the equivalent

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that there may be economic and operational advantages in the use of radio-relay systems with a capacity of substantially more than 1800 telephone channels or equivalent, on a single radio carrier;

(b) that very large capacity radio-relay systems may also be required in the future for the transmission of higher-definition television;

(c) that additional information is needed to establish the practical limits of capacity of such very large capacity systems;

UNANIMOUSLY DECIDES that the following studies be carried out:

1. the determination of optimum values for the system characteristics (including the baseband, intermediate-frequency and radio-frequency characteristics), to enable the maximum capacity in each radio-frequency carrier to be achieved;

---

* This Question replaces Question 93.

** This Study Programme was previously designated "Study Programme 157 (IX)".

2. the limitation on the maximum practicable capacity of the system due to the effects of multipath propagation.

QUESTION 193 (IX) *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Hypothetical reference circuits and circuit noise

The C.C.I.R., (London, 1953 — Los Angeles, 1959)

CONSIDERING

that the noise permissible in a radio-relay system may be expected to depend to some extent on the length of the system, and that it may, therefore, be desirable for design purposes to specify hypothetical reference circuits for radio-relay systems analogous to those specified by the C.C.I.T.T. for cable systems;

UNANIMOUSLY DECIDES that the following question should be studied:

the determination of:

— hypothetical reference circuits for the design of radio-relay systems,

— the elements appropriate to such circuits,

— the division of the permissible noise power amongst the various elements.

STUDY PROGRAMME 193A (IX) **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Noise tolerable during very short periods of time

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that, for radio-relay links, it is necessary to clarify how high noise levels occurring for short periods of time should be taken into consideration;

(b) that consideration must be given not only to the percentage of time during which high noise levels occur, but also to the duration of each burst of noise;

(c) that account should be taken of the fact that in radio-relay systems high noise-levels often occur at night when the traffic is particularly light;

(d) that examples of the distribution of noise with time in radio-relay systems are given in Recommendation 393 and Report 130 which also contain examples of the values of noise power likely to be experienced for short periods of time;

---

* This Question replaces Question 97, and also includes tropospheric-scatter systems.

** This Study Programme was formerly designated "Study Programme 158(IX)".

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. in what way should the maximum value of noise be specified when considering transmission on radio-relay systems;
2. what should be the time constant of the noise measuring apparatus;
3. should a limit be set to the number of high noise bursts, of a duration exceeding a given value, occurring in a given time;
4. in considering this problem, should account be taken of the fact that the traffic loading is greater during the day than during the night;
5 in what way can the maximum tolerable noise power for a part of a radio link be deduced from the maximum value of noise power tolerable of the complete radio link?

QUESTION 194 (IX) **

RADIO-RELAY SYSTEMS FOR TELEVISION

Preferred characteristics for the transmission of monochrome television

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that the study of preferred characteristics for radio-relay systems for multi-channel telephony is being pursued;

(b) that requirements for the transmission of monochrome television over long distances are given in Recommendation 421;

(c) that Recommendation 421 does not, however, include a consideration of the characteristics (other than at baseband frequencies) of radio-relay systems designed for the transmission of television;

(d) that it is preferable for the major intermediate-frequency and radio-frequency characteristics of international radio-relay systems to conform, as far as possible, with those for multi-channel telephony;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics of international radio-relay systems for television where they differ from those for telephony?

STUDY PROGRAMME 194A (IX) **

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred characteristics for the transmission of more than one sound channel

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that Recommendation 402 gives values for the preferred characteristics of a frequency-modulated sub-carrier for the transmission of a single sound channel on a radio-frequency carrier transmitting also a television signal;

* This Question replaces Question 146.

** This Study Programme was previously designated "Study Programme 159(IX)".

(b) that in certain circumstances up to six sound channels may be required over the same route as a television transmission;

(c) that radio-relay systems with a capacity of 600 or 960 telephone channels may be used to transmit a television signal *or* several sound channels on each radio-frequency carrier;

(d) that radio-relay systems with a capacity of 1800 telephone channels or the equivalent may be used to transmit a television signal *and* several sound channels on each radio-frequency carrier;

(e) that the sound channels provided by this means should meet the requirements of the C.C.I.T.T. for music circuits;

UNANIMOUSLY DECIDES that the following studies should be carried out:

the determination of the preferred characteristics for the provision of up to six sound channels in the following cases:

1. when the radio-frequency carrier transmitting the sound channels is used *alternatively* for television (radio-relay systems with a capacity of 600 or 960 telephone channels);

2. when the radio-frequency carrier transmitting the sound channels is used *simultaneously* for television (radio-relay systems with a capacity of 1800 telephone channels or the equivalent).

QUESTION 195 (IX) *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Service channels

The C.C.I.R., (Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that service channels are necessary for the maintenance of radio-relay systems;

(b) that it would be desirable to define the steps to be taken for the establishment of such service channels and for facilitating their international connection;

UNANIMOUSLY DECIDES that the following question should be studied:

1. in what form and by what means should the service channels required for the maintenance of radio-relay systems be established;

2. what are the characteristics, if any, to be specified with a view to permitting international connection of such service channels;

3. what are the preferred values of such characteristics?

---

* This Question replaces Question 147.

STUDY PROGRAMME 195A (IX) *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred characteristics for auxiliary radio-relay systems for the provision of service channels

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that an auxiliary radio-relay system may be required for the provision of service channels for the maintenance, supervision and control of radio-relay links;

(b) that this auxiliary system may be arranged by combining it with the main system, as is shown in Recommendation 389;

(c) that, on the other hand, it may be preferable to use an auxiliary radio-relay system quite independent of the main radio-relay system;

(d) that the frequency band concerned and the exact frequency allocation plan must be chosen carefully, to avoid interference with the main system;

(e) that the utmost reliability is essential for this auxiliary radio-relay system, because of the operational importance of the supervisory circuits;

(f) that some factors affecting the bandwidth that is required for these circuits are discussed in the Annex;

(g) that Recommendation 400 states the number and the function of the service channels that are required;

(h) that economy in the use of the spectrum is important;

UNANIMOUSLY DECIDES that the following study should be carried out:

determination of the characteristics (baseband, type of modulation and radio-frequency arrangement) for an auxiliary radio-relay system of high reliability.

ANNEX

In § *(e)*, it is pointed out that a high degree of reliability is required for service channels; consequently a stand-by auxiliary radio-frequency channel on each route is probably essential. These stand-by auxiliary channels could be provided on the same frequency as the main auxiliary channel or on a different frequency.

If the same frequency as the main auxiliary channel is used, the stand-by channel can be brought into circuit at any station by means of switches operated automatically by monitoring circuits on the equipment. The use of separate frequencies requires no monitoring circuits or switches and might therefore simplify the equipment and improve its reliability.

It sometimes occurs that a number of systems, each requiring supervisory circuits, converge at a point (including any connections with a local maintenance centre). On each route at such interconnection points, if the stand-by channel operates on a separate frequency, two pairs of frequencies in each direction of transmission will be required for the auxiliary radio-relay system. The same frequency can often be used simultaneously for two transmitters or two receivers in opposite directions, but this cannot be done at frequencies below about 1000 Mc/s.

* This Study Programme was previously designated "Study Programme 160(IX)".

The necessary spacing between adjacent frequency allocations at any station depends on the frequency stability of the equipment as well as on the modulation characteristics used. These factors should be considered in relation to all the frequency bands which might be used for this purpose ranging from about 8500 Mc/s down to 1000 Mc/s or even lower.

QUESTION 197 (IX) *

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Transmission interruptions

(Question No. 10 of the 3rd Study Group of the C.C.I.T.T., to be studied by the C.C.I.R. in cooperation with the 3rd and 4th Study Groups of the C.C.I.T.T.)

What is the duration of interruptions to transmission to be expected on radio links when switching from normal to stand-by equipment? (See Recommendation 305 of the C.C.I.R.)

Note. — It is necessary to distinguish the duration of breaks in transmission corresponding to the three following causes:

(a) failure of normal equipment,

(b) fading in radio-propagation indicated by the presence of excessive noise at a switching point of a radio link,

(c) change-over of the normal and stand-by equipment for maintenance of the radio link.

QUESTION 221 (IX) *

PROTECTION RATIOS FOR THE OPERATION OF COMMUNICATION SERVICES WITHIN THE CHANNELS OF A BROADCASTING SERVICE

(Adopted by correspondence, 1962)

The C.C.I.R.,

CONSIDERING

(a) that certain frequency bands may be used for television and sound broadcasting services in one country, and for communication services in another country;

(b) that Report 77 and Recommendation 418 deal only with the protection requirements between broadcasting transmissions;

DECIDES that the following question should be studied:

1. what is the protection ratio required by an AM or FM communication service as a function of its position within the frequency band occupied by a television or sound broadcasting transmission;

---

* This Question, which replaces Question 165, also includes tropospheric-scatter systems.

2. to what extent is the protection ratio affected by variations in picture content or sound programme material of the broadcast transmission;

3. television, pictures of certain kinds, particularly resolution-test waveforms, can result in peaks of energy higher than the energy level under normal programme conditions in portions of the occupied bandwidth. Is any allowance for this effect desirable and, if so, on what basis should it be made?

Note 1. — The study should, in the first instance, examine the protection ratio required for multi-channel frequency-modulation telephone systems, the capacity of which is normally not greater than 120 channels, sharing the television broadcast Bands IV and V.

Note 2. — For the purpose of this Question, protection ratio is defined as the minimum acceptable ratio of the wanted to the unwanted signals at the input to the radio-relay system receiver.

QUESTION 260 (IX)

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that tropospheric-scatter radio-relay systems have received acceptance and are increasingly being used operationally in many parts of the world;

(b) that it is desirable to determine the preferred characteristics of such systems needed to facilitate their international connection;

(c) that the frequency bands used by tropospheric-scatter radio-relay systems are often shared with line-of-sight radio-relay systems, other fixed and mobile, or broadcasting services;

UNANIMOUSLY DECIDES that the following question should be studied:

1. how do the characteristics of tropospheric-scatter propagation affect the design of radio-relay systems;

2. to what extent are systems employing this mode of propagation and operating on the same or on neighbouring frequencies liable to interfere with each other, with systems employing different modes of propagations as well as with other services?

STUDY PROGRAMME 260A (IX) **

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Radio-frequency channel arrangements

The C.C.I.R., *(Approved at Geneva, 1958)*

CONSIDERING

(a) that tropospheric-scatter radio-relay systems are already in service and that systems of this type may come into more extensive use in the future;

---

* This Question replaces Question 196.

** This Study Programme was previously designated "Study Programme 122(IX)".

(b) that such systems may use very high power (10 kW or even more, fed into high gain antennae);

(c) that tropospheric-scatter systems are capable of causing interference over wide areas and long distances, to systems of the same or of different type operating on the same or closely adjacent frequencies; and that such interference could frequently extend over national boundaries;

(d) that tropospheric-scatter systems may be particularly susceptible to interference from systems of the same or of different type, because of the low field strengths available at the receiving terminal;

(e) that distances between adjacent stations may vary widely, e.g. between about 100 and 400 km;

(f) that overshoot problems are likely to be more severe than with line-of-sight systems;

(g) that interference may be caused in directions other than that of the main beam;

(h) that most tropospheric-scatter systems are expected to provide not more than about 120 telephone channels; that many smaller systems may provide only 12 or 24 channels, but certain systems may transmit wideband information such as television;

(i) that the transmitting power used may differ considerably according to the distance to be covered, the number of channels to be transmitted, etc.;

(j) that at present frequency modulation of the radio-frequency carrier is most generally used, but that other types of modulation, e.g. single-sideband, may be introduced for some systems;

(k) that simultaneous transmission on two frequencies, to assist in the provision of quadruple diversity reception or for other reasons, while strongly deprecated in areas where the radio-frequency spectrum is likely to become congested, may be used in other areas;

(l) that the requirements for radio-frequency channel arrangements for tropospheric-scatter systems would seem from the above considerations to differ substantially from those for line-of-sight radio-relay systems or for other services;

DECIDES that the following studies should be carried out:

1. on what basis should radio-frequency channel arrangements for tropospheric-scatter systems be established;

2. what basic arrangements should be proposed?

Note. — This study should include consideration of the following points:

1. The extent to which radio-frequency channel arrangements must be considered in relation to a large geographical area rather than only to individual routes.

2. The especially difficult problem of avoiding interference to and from other systems.

3. The need to accommodate systems of differing channel capacity, power, type of modulation and type of service.

4. The transmitted bandwidths appropriate to such systems.

5. The appropriate frequency spacing or spacings between go and return channels on a given section of route.

6. The appropriate frequency spacing between two or more parallel channels along the same section of route.

7. The appropriate frequency spacing between systems installed in the same station for use on different routes.

8. The distances at which frequencies can be re-used without undesirable interference effects, both in the direction of the main beam and in other directions.

9. Whether the problem of radio-frequency channel arrangements might be substantially eased if intermediate frequencies (or the first intermediate frequency if a double-frequency change receiver is used), differing from those given in Recommendation 403, were to be used.

STUDY PROGRAMME 260B (IX)

TROPOSPHERIC-SCATTER RADIO-RELAY SYSTEMS

Diversity techniques

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that transmission processes relying on inhomogeneities in the atmosphere give, at the reception point, a wave which fluctuates very considerably in amplitude and phase, often resulting in appreciable impairment of the original signal;

(b) that such impairment can be greatly reduced by diversity techniques;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what means should preferably be used to obtain diversity benefits (antenna-spacing, frequency-spacing, difference in polarization, difference in incoming direction, time-diversity) and what is the minimum requisite difference in each case;

2. in what way must the received signals be combined to obtain the best possible resulting signal, due account being taken of the carrier frequency used, the nature of the transmitted signal, the bandwidth occupied by the spectrum of the modulated wave and of equipment complexity;

3. what influence does the use of diversity have on the transmission bandwidth, taking propagation into account;

4. what influence does the use of diversity have on interference that may be caused or suffered by the systems?

QUESTION 261 (IX)

RADIO-RELAY SYSTEMS FOR TELEVISION AND TELEPHONY

Preferred characteristics for the transmission of colour television and the simultaneous transmission of colour television and other signals

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(b) that the transmission of colour television signals over long distances is under study by the C.M.T.T.;

(b) that radio-relay systems will be required for the transmission of such signals alone or together with telephony or programme circuits;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the preferred characteristics of international radio-relay systems for colour television where they differ from those for monochrome television;

2. what are the preferred characteristics for radio-relay systems for the simultaneous transmission of colour television signals and telephony or programme circuits (radio-relay systems with a capacity of at least 1800 telephone channels, or the equivalent)?

Note. — In considering the preferred characteristics of mixed systems, advice is required on the following:

1. the maximum level and the characteristics of the noise and the signal residues liable to be present outside the television band offered for transmission;

2. the acceptable level of noise outside the television band, after transmission over the radio-relay system;

3. the noise levels corresponding to §§ 1 and 2 of this Note for a block of telephone channels transmitted above a television signal.

Sections 1 and 2 of this Note should be brought to the attention of the C.M.T.T., and § 3 to C.C.I.T.T. Study Group XV.

QUESTION 276 (IX) *

CHARACTERISTICS OF SIMPLE VHF OR UHF RADIO EQUIPMENT FOR USE ON TRUNK CONNECTIONS IN THE NEW AND DEVELOPING COUNTRIES

(Question No. 4 of the Plan Sub-committee for Asia, Geneva, 1963)

The Plan Sub-committee for Asia, (Geneva, 1963)

CONSIDERING

the expanding needs for extending communications to those areas in the new and developing countries which, due to terrain, climate or other reasons may not permit the use of landline, wire or cable;

REQUESTS the C.C.I.R. to study the following question:

1. what should be the broad characteristics and standards for simple and economic types of VHF or UHF equipment for trunk connections with the following basic requirements;

1.1 low power output, using only solid-state components;

---

* This Question was adopted unanimously by the Xth Plenary Assembly of the C.C.I.R., Geneva, 1963.

1.2 a small number of channels, say 6 to 12, or at the most 24;

1.3 low power consumption;

1.4 use of higher frequency deviation, to get a better noise figure to improve the signal-to-noise ratio;

1.5 ease of installation and maintenance;

2. what changes would be required in the characteristics and what would be the estimated percentage increase in cost of the basic equipment, if it is to be capable of being extended to cater for capacities of 120 to 240 channels at a later stage?

Explanatory note. — There is a need for developing simple types of trunk radio equipment with requirements such as to meet the expanding needs of new countries for trunk communications.

QUESTION 277 (IX)

SIMPLE SINGLE-CHANNEL RADIOTELEPHONY EQUIPMENT

(Question No. 5 of the Plan Sub-committee for Asia, Geneva, 1963)

The Plan Sub-committee for Asia, (Geneva, 1963)

REQUESTS the C.C.I.R. to study the following question:

what should be the recommendations for radio equipment that could provide, among other things, for the following:

— one speech telephone channel;
— transmitter-receivers, pole or cabinet mounted;
— low power consumption, using solid-state components;
— independence of local power supply;
— capability of being linked to the nearest headquarters station, which may be 20 to 30 miles away (30 to 50 km);
— use the simplest possible type of antenna with an inexpensive support;
— be unattended and capable of operation by a village Postmaster;
— require a minimum of technical maintenance?

Explanatory note. — It is very important to extend telecommunication facilities to those areas of the new and developing countries where the terrain and climatic conditions do not permit such facilities to be provided by wire or cable.

There is therefore an urgent need for this type of equipment, to connect remote areas, which have at present, no communication whatsoever. No equipment to meet such requirements is readily available in the world's markets. Something similar to the portable transistorized broadcast receiver developed in many countries may help a great deal.

---

* This Question was adopted unanimously at the Xth Plenary Assembly of the C.C.I.R., Geneva, 1963. It is also of interest to C.C.I.R. Study Groups I, II, III, X and XII.

QUESTION 278(IX) *

TWO-CHANNEL TIME-DIVERSITY TELEGRAPH SYSTEMS FOR USE ON RADIO-RELAY LINKS

(Question No. 6 of the Plan Sub-committee for Asia, Geneva, 1963)

The Plan Sub-committee for Asia, (Geneva, 1963)

CONSIDERING

the feasibility of using two channels in time-diversity for the improvement of telegraph transmission over radio-relay links;

REQUESTS the C.C.I.R. to study the following question:

1. what are the practical ways of making use of this technique.
2. what should be the characteristics of equipment using this technique?

Explanatory note. — In radio-relay systems, short duration interruptions due to fading of the signals or equipment interruptions can be tolerated in telephony, but result in mutilation of the received text in telegraphy. It is felt that the use of two channels operating in time-diversity (time delay) for the same transmission could provide a solution.

QUESTION 279(IX) **

TRANSMISSION PLANNING FOR RADIO-RELAY SYSTEMS IN THE NEW AND DEVELOPING COUNTRIES

(Question No. 13 of the Plan Sub-committee for Asia, Geneva, 1963)

The Plan Sub-committee for Asia, (Geneva, 1963)

REQUESTS the C.C.I.R. to study the following question:

1. what information can be given to guide developing countries in the basic transmission planning for radio-relay systems;
2. what are the major factors to be considered in determining the broad characteristics to be specified for this type of equipment?

Explanatory note. — Although a great deal of information has been written on this subject, it is only available through various articles, pamphlets and other miscellaneous publications. There is need for the production of a more comprehensive document, giving guidance on the basic transmission planning for cable-carrier and radio-relay systems, together with an adequate background to the fundamental questions of optimum signal levels in multi-channel systems and the planning of repeater sections to achieve specified signal-to-noise ratios.

The inclusion of a bibliography of published literature on this subject would also be valuable.

* This Question was adopted unanimously by the Xth Plenary Assembly of the C.C.I.R., Geneva, 1963. It is also of interest to C.C.I.R. Study Group III.

** This Question was adopted unanimously by the Xth Plenary Assembly of the C.C.I.R., Geneva, 1963. It is also relevant to the work of the Banks Working Party of the C.C.I.T.T. Study Group XI, dealing with Automatic Networks.

LIST OF DOCUMENTS OF THE Xth PLENARY ASSEMBLY CONCERNING STUDY GROUP IX

Doc.	Origin	Title	Reference	Other Study Groups concerned
9	Chairman, Study Group IX	Report by Chairman of Study Group IX (Mr. E. O. DIETRICH)	—	—
17	United Kingdom	Revision of Recommendation 277. Radio-relay systems for television. Pre-emphasis characteristics for frequency-modulation systems	Q. 194	—
65	United Kingdom	Radio-relay systems for telephony and television	S.P. 157	—
66	United Kingdom	Radio-relay systems for television and telephony	Q. 185 (V) Q. 192	V
67	United Kingdom	Radio-relay systems for television and telephony	S.P. 157	—
68	United Kingdom	Radio-relay systems for television and telephony	Q. 192	—
69	United Kingdom	C.C.I.R. Document IX/110 (Paris, 1962)	—	—
73	United States of America	Radio-relay systems employing tropospheric-scatter propagation	Draft Rep.	—
74	United States of America	Radio-relay systems for telephony using frequency-division multiplex	Draft Rep.	—
75	United States of America	Frequency sharing between communication-satellite systems and terrestrial radio services	Doc. IV/79-Rev.	IV
76	United States of America	Frequency sharing between communication-satellite systems and terrestrial radio services	Doc. IV/79-Rev.	IV
102	France	Radio-relay systems employing tropospheric-scatter propagation. Diversity reception.	Draft S.P.	—
103	France	Radio-relay systems using tropospheric-scatter propagation. Calculation of the mean noise power in frequency-modulation trans-horizon radio-relay systems	Q. 196 Rec. 287	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
112	United Kingdom	Mutual interference between active earth-satellite communication systems using frequency-modulation and terrestrial line-of-sight radio-relay systems sharing the 4 and 6 Gc/s bands. Derivation of necessary separation distances between satellite communication system ground-stations and line-of-sight radio-relay system stations	Q. 209 (IV) S.P. 174 (IV) Q. 192	IV
116	United Kingdom	Mutual interference between active earth-satellite communication systems and line-of-sight radio-relay systems sharing the 4 and 6 Gc/s band. Limitation of the transmitter powers for satellite and line-of-sight radio-relay systems	Q. 192 (IX) and 209 S.P. 174 (IV)	IV
119	Netherlands	Radio-relay systems for telephony using frequency-division multiplex. Characteristics of deep fades in microwave links	S.P. 158	—
123	Federal Republic of Germany	Radio-relay systems for television and telephony service channels	Q. 195 S.P. 160 Rec. 295	—
129	C.C.I.R. Secretariat	Bibliographic references in the volumes of the C.C.I.R.	—	I-XIV
131	Federal Republic of Germany	Radio-relay systems for television and telephony. Radio-relay systems with a capacity of 2700 channels. Measurements of phase distortion and selective fading when transmitting very broad frequency bands	S.P. 157	—
132	Federal Republic of Germany	Radio-relay systems for television and telephony. Radio-frequency channel arrangements in the 8 Gc/s band	Q. 192 (Doc. IX/114)	—
133	The Telephone Association of Canada	Noise on telephone circuits more than 2500 km long (Response to C.C.I.T.T. Question A/C)	C.C.I.T.T. Circ. 46 (Sp.C/XV)	—
137	Japan	Pre-emphasis characteristics for frequency-modulation systems. Draft Revision of Recommendation 277	Q. 194 Rec. 277	—
138	Japan	Radio-frequency channel arrangement for radio-relay systems operating in the 11 Gc/s band	Q. 192	—
139	Japan	Radio-relay systems having a capacity greater than 1800 voice channels or the equivalent	Draft Rep.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
140	Federal Republic of Germany	Radio-relay systems for telephony and television using frequency-division multiplex. Radio-frequency channel arrangements for radio-relay systems operating in the 11 Gc/s band	Q. 192 (Doc. IX/101)	—
143	Federal Republic of Germany	Radio-relay system for television and telephony. Alternative use of a telephone system for the transmission of up to six channels	Q. 194 S.P. 159 (Doc. IX/85)	—
154	Special Joint Study Group C (C.C.I.T.T./ C.C.I.R.)	Radio-relay systems for telephony using frequency-division multiplex. Allowable noise in the hypothetical reference circuit	Ann. 9/8	—
155	”	Termination of Questions 111 and 112	Ann. 9/16 and 9/17	—
156	”	Radio-relay systems for telephony using frequency-division multiplex. Noise in real circuits	Ann. 9/9	—
157	”	Radio-relay systems using tropospheric-scatter propagation. Allowable noise power in the hypothetical reference circuit for telephony transmission	Ann. 9/14	—
158	”	Radio-relay systems for telephony using frequency-division multiplex. Hypothetical reference circuit for radio-relay systems with a capacity of 12 to 60 telephone channels and of more than 60 telephone channels	Ann. 9/6 and 9/7	—
159	”	Observations on the method of noise measurement with a one-minute time constant	Doc. IX/90-Rev.	—
160	”	Communication satellite systems sharing the same frequency bands as line-of-sight radio-relay systems. Maximum allowable values of interference in a telephone channel	Doc. 51	IV
161	”	Noise limits for very long telephone circuits	—	IV
163	C.C.I.T.T.	Radio-relay systems using tropospheric-scatter propagation	—	—
164	C.C.I.T.T.	Effect of noise on telegraph transmission	—	III
168	Italy	Radio-relay system with a capacity of 2700 telephone channels or the equivalent. Investigation of the effects of multi-path propagation	S.P. 157, §2	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
173	C.C.I.T.T.	Radio-relay systems using forward-scatter techniques	C.C.I.T.T. Q. 11/XV	—
174	”	Radio-relay systems for television and telephony. Simultaneous transmission by the same radio-frequency carrier baseband arrangements	Rec. 271	—
175	”	Radio-relay systems for telephony using frequency-division multiplex. Interconnection at baseband frequencies	Rec. 269	—
176	”	Radio-relay systems for television and telephony	C.C.I.T.T. Q. 25/XV, 26/XV, 29/XV	—
187	”	Radio-relay systems for telephony using frequency-division multiplex. Measurement of performance with the help of a signal consisting of a continuous uniform spectrum	C.C.I.T.T. Q. 36/XV	—
219	United Kingdom	Draft amendment to Recommendation 278		—
220	United Kingdom	Draft amendment to Recommendation 280		—
239	U.S.S.R.	Draft amendment to Recommendation 272		—
243	Canada	Radio-relay systems for television and telephony	Q. 192 Rec. 278	—
247	The Telephone Association of Canada	Frequency sharing between communication satellite systems and terrestrial radio-relay systems	Q. 209 (IV), 214 (IV) S.P. 174 (IV), 179 (IV)	IV
253	Study Group IX	Calculation of noise in the overall hypothetical reference circuit for tropospheric-scatter systems	Draft Rep.	—
257	Canada	Radio-relay systems for television and telephony. Radio-frequency channel arrangements for 600 to 960 telephone channels, or the equivalent, operating in the 11 Gc/s band	Q. 192	—
288	Sub-Group IX-A	Radio-relay systems for television and telephony	Draft Rec.	—
289	Compañia Dominicana de Teléfonos	Radio-relay systems for telephony using frequency-division multiplex	Draft Rep.	—
294	Study Group IX	Definitions of hypothetical reference circuits	Draft Rec.	—
295	Study Group IX	Radio-relay systems using tropospheric-scatter propagation	Draft Rec.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
296	Study Group IX	Radio-relay systems using tropospheric-scatter propagation	Draft Rec.	—
297	Study Group IX	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
298	Study Group IX	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
299	Compañia Dominicana de Teléfonos	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
302	Study Group IX	Summary record of the first meeting	—	—
313	Sub-Group IX-B	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
314	Sub-Group IX-B	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
329	Sub-Group IX-B	Noise in circuits longer than 2500 km	Draft Rec.	—
333	Study Group X	Interconnection of radio-relay and line systems	Draft Rec.	—
334	Study Group IX	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
339	Sub-Group IX-D	Modifications to Annex 9/11 to Doc. 9	—	—
349	Sub-Group IX-A	Trans-horizon radio-relay systems	Draft Rev. of Rep. 136	—
351	Sub-Group IX-A	Proposed revision of Recommendation 274	Rec. 274	—
352	Sub-Group IX-A	Proposed revision of Recommendation 303	Rec. 303	—
355	Study Group IX	Radio-relay systems for telephony and television	Draft Rec.	—
365	Study Group IX	Radio-relay systems for telephony using frequency-division multiplex	Draft Rec.	—
378	Study Group IX	Summary record of the second meeting	—	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
381	Sub-Groups IX-A and IV-D	Communication satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	IV
402	Study Group IX	Radio-relay systems for telephony and television	Draft Rec.	—
416	Sub-Group IX-C	Radio-relay systems for television	Draft Rec.	—
418	Sub-Group IX-C	Radio-relay systems for television and telephony. Preferred characteristics for the transmission of more than one sound channel	Draft Rep.	—
419	Sub-Group IX-C	Radio-relay systems for television and telephony	Draft Rep.	—
423	Sub-Group IX-D	Draft amendment to Recommendation 292	—	—
424	Sub-Group IX-D	Amendments to Annex 9/12 to Doc. 9	—	—
425	Sub-Group IX-D	Draft amendment to Recommendation 293	—	—
426	Sub-Group IX-D	Amendments to Annex 9/10 to Doc. 9	—	—
432	Study Group IX	Radio-relay systems for telephony using time-division multiplex	Draft Rec.	—
439	Sub-Group IX-B	Draft revision of Doc. 295	—	—
444	Study Group IX	Radio-relay systems for television	Draft Rec.	—
448	Sub-Group IX-B	Trans-horizon radio-relay systems	Draft Rep.	—
455	Study Group IX	Addition to Doc. 2008	—	—
459	Sub-Groups IX-A and IV-D	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	IV
462	Study Group IX	Radio-relay systems for television and telephony	Draft Rec.	—
468	Study Group IX	Summary record of the third meeting	—	—
484	Study Group IX	Radio-relay systems for television and telephony	Draft Rec.	—
485	Study Group IX	Radio-relay systems for telephony and television	Draft Rep.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
486	Study Group IX	Proposed revision of Recommendation 303	—	—
487	Study Group IX	Proposed revision of Recommendation 274	—	—
492	Study Group IX	Radio-relay systems using the so-called tropospheric-scatter mode of propagation	Draft Rep.	—
522	Sub-Groups IX-A and IV-D	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	IV
525	Study Group IX	Summary record of the fourth meeting	—	—
548	Study Group IX	Radio-relay systems for television and telephony	Rev. of Docs. 484 and 485	—
580	Study Group IX	Summary record of the fifth meeting	—	—
584	Study Group IX	Radio-relay systems employing so-called tropospheric-scatter propagation	Draft Q.	—
586	Study Group IX	Radio-relay systems for television and telephony. Preferred characteristics for the transmission of colour television and the simultaneous transmission of colour television and other signals	Draft Q.	—
603	Study Group IX	Radio-relay systems for television and telephony	Draft Rec.	—
606	Study Group IX	Summary record of the sixth and last meeting	—	—
627	Study Group IX	Proposed revision of Resolution 55	—	—
2001	Drafting Committee	Radio-relay systems for telephony using frequency-division multiplex	Rec. 385	—
2002	,,	Signal amplitudes in individual channels of multi-channel telephony systems	Res. 17	—
2003	,,	Information required on the transmission characteristics of line systems for use in the design of radio-relay systems	Res. 18	—
2097	,,	Interconnection of auxiliary radio-relay systems at radio frequencies	Rep. 284	—
2098	,,	Radio-relay systems using tropospheric-scatter propagation	Rec. 396	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
2123	Drafting Committee	Radio-relay systems for television and telephony	Rec. 383	—
2124	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 392	—
2125	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 391	—
2126	”	Noise in circuits longer than 2500 km	Rep. 288	—
2127	”	Radio-relay systems for telephony and television	Rec. 386	—
2151	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 393	—
2152	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 395	—
2221	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 380	—
2222	”	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	(See Doc. 2247)	—
2223	”	Radio-relay systems for telephony using frequency-division multiplex	Rep. 283	—
2224	”	Radio-relay systems for telephony and television	Rec. 387	—
2225	”	Radio-relay systems for television	Rec. 402	—
2226	”	Radio-relay systems for television and telephony	Rep. 290	—
2227	”	Radio-relay systems for television and telephony	Rec. 401	—
2228	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 398	—
2229	”	Radio-relay systems for telephony using time-division multiplex	Rec. 394	—
2240	”	Radio-relay systems for television and telephony	Rec. 389	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
2241	Drafting Committee	Service channels for radio-relay systems	Rec. 400	—
2242	”	Radio-relay systems using tropospheric-scatter propagation	Rec. 399	—
2243	”	Radio-relay systems using tropospheric-scatter propagation	Rec. 388	—
2244	”	Radio-relay systems for telephony using frequency-division multiplex	Rec. 404	—
2246	”	Interconnection of radio-relay and line systems	Rec. 381	—
2247	”	Line-of-sight radio-relay systems sharing the same frequency bands as the satellite receivers of active earth-satellite communication systems	Rec. 406	—
2248	”	Radio-relay systems for television and telephony	Rec. 403	—
2299	”	Radio-relay systems for television and telephony	Rec. 384	—
2309	”	Definitions of hypothetical reference circuits	Rec. 390	—
2310	”	Radio-relay systems for telephony and television	Rep. 287	—
2312	”	Radio-relay systems employing tropospheric-scatter propagation	S.P. 260 B (IX)	—
2313	”	Radio-relay systems using tropospheric-scatter propagation	Rec. 397	—
2314	”	Radio-relay systems for television and telephony. Preferred characteristics for the transmission of more than one sound channel	Rep. 289	—
2315	”	Radio-relay systems for television	Rec. 405	—
2316	”	So-called tropospheric-scatter radio-relay systems	Rep. 285	—
2317	”	So-called tropospheric-scatter radio-relay systems	Q. 260 (IX)	—
2318	”	Radio-relay systems for television and telephony	Q. 261 (IX)	—
2383	”	Tropospheric-scatter systems	Rep. 286	—
2388	”	Radio-relay systems for television and telephony	Rec. 382	—
2394	”	Revision of Resolution 55	Op. 14	—

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

RECOMMENDATIONS OF SECTION L: SPACE SYSTEMS AND RADIOASTRONOMY

L.1 - General

RECOMMENDATION 259

SELECTION OF FREQUENCIES USED IN TELECOMMUNICATION WITH AND BETWEEN ARTIFICIAL EARTH SATELLITES AND OTHER SPACECRAFT

(Questions 168 and 169)

The C.C.I.R., (Los Angeles, 1959)

CONSIDERING

(a) that transmission of radio signals between the earth and artificial earth satellites and other spacecraft is now an established fact;

(b) that such extra-terrestrial objects may well be consecutively above different countries of the world, thus necessitating international collaboration;

(c) that radiocommunication between extra-terrestrial objects and the earth and among extra-terrestrial objects will be of importance;

(d) that such radiocommunication will be affected by the terrestrial troposphere and ionosphere, and by ionization, radio-frequency noise, and man-made interference in space, as well as by relative velocities;

(e) that the study of the effects of the ionosphere on such communications may be facilitated by comparison of HF signals with VHF or UHF signals since the ionospheric effects are larger at the lower frequencies;

(f) that while at present frequencies for communication with objects in extra-terrestrial space are being selected on the basis of particular communication requirements and technological capabilities, the inevitable increase in this type of communication is likely to lead to a chaotic situation in the radio spectrum;

(g) that no provision for such communication was made in the Table of Frequency Allocations (Atlantic City);

(h) that Report 205 presents a treatment of the technical factors affecting the selection of frequencies for telecommunication with and between spacecraft;

UNANIMOUSLY RECOMMENDS

1. that consideration be given to the provision of a number of small frequency-bands well spaced throughout the HF and higher bands for telecommunication services with and between spacecraft;

2. that for services involving communication among spacecraft in interplanetary space, additional consideration be given to the use of frequencies which do not significantly penetrate the terrestrial ionosphere or troposphere (roughly below 1 Mc/s or above 50 Gc/s respectively);

3. that special and particular consideration be given to the provision of at least two narrow frequency bands between 19 and 54 Mc/s to permit study of the effects of the ionosphere on communications passing through it;

4. that, in determining the widths of allocated bands, particular account be taken of Doppler shifts in frequency associated with high relative velocities.

Note by the Secretariat. — This Recommendation, prepared by the IXth Plenary Assembly, Los Angeles, 1959, was destined for the Administrative Radio Conference, Geneva, 1959. The Xth Plenary Assembly, Geneva, 1963 however, decided to maintain the text, and it has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

RECOMMENDATION 350 *

IDENTIFICATION OF RADIO EMISSIONS FROM SPACECRAFT

(Question 208)

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that satellites may be identified by visual observation, ephemeris (accurate prediction of physical location), the identifier or characteristics of the reflected or repeated earth station signal, and/or the characteristics of the satellite transmitted signal;

(b) that, for spacecraft other than satellites, the primary means of identification will normally be the signal characteristics, augmented by flight path data;

(c) that the techniques employed in spacecraft tracking are such that the transmission of conventional call signs is not normally essential for identification purposes;

(d) that call signs are not normally required by those using space systems;

(e) that Article 19, No. 737 of the Radio Regulations, Geneva, 1959, stipulates that a station shall be identified either by a call sign or other recognized means of identification, that such recognized means of identification may be one or more of the following necessary for complete identification: name of station, location of station, operating agency, official registration mark, flight identification number, characteristic signal, characteristic of emission, or other clearly distinguishing features recognized internationally;

UNANIMOUSLY RECOMMENDS

1. that, as regards the question of identification of radio emissions from spacecraft, Article 19, No. 737 of the Radio Regulations, Geneva, 1959, be considered adequate and applicable;

2. that Administrations be encouraged to exchange, to the maximum extent practicable, advance and current information relative to the identification of spacecraft (ephemeris and signal characteristics).

RECOMMENDATION 351 **

CESSATION OF RADIO EMISSIONS FROM SPACECRAFT

(Question 208)

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that the usable radio-frequency spectrum is a limited natural resource, within which all radio services must be satisfied;

* This Recommendation, which together with Recommendation 351 terminates the study of Question 208, has been brought to the attention of the Extraordinary Administration Radio Conference, Geneva, 1963.

** This Recommendation, which together with Recommendation 350 terminates the study of Question 208, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

(*b*) that, as regards the need for providing for cessation of radio emissions from spacecraft, the primary determination for each space project will be the likelihood of creating harmful interference to established terrestrial radio services as well as to other space operations;

(*c*) that spacecraft operations may be long-lived;

(*d*) that advances in technique, particularly as regards increased power radiated by space-station transmitters and improved receiver sensitivity of space and terrestrial systems, will progressively enhance the likelihood of harmful interference among spacecraft, including satellites, and between such vehicles and terrestrial radio services;

(*e*) that the administrative procedures for implementing the cessation of emissions from spacecraft is a matter for the Extraordinary Administrative Radio Conference, Geneva, 1963 to decide;

UNANIMOUSLY RECOMMENDS

that Administrations assure that spacecraft be capable of ceasing radio emissions by the use of appropriate devices, e.g. battery life, timing devices, ground command, or similar devices that will ensure positive cessation of emission.

L.2 - Communication satellites

RECOMMENDATION 352 *

ACTIVE COMMUNICATION-SATELLITE SYSTEMS FOR MULTIPLEX TELEPHONY AND/OR MONOCHROME TELEVISION

Hypothetical reference circuit for intercontinental systems

(Question 235 (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that it is desirable to establish a hypothetical reference circuit for active communication-satellite systems to afford guidance to designers of equipment and systems for use in intercontinental telephone and television networks;

(b) that with various types of active satellite systems, it is possible to arrange that the majority of intercontinental connections may be made with no more than one satellite link, if it is capable of spanning a great circle distance of at least 7500 km;

(c) that, to span the great circle distances of up to 25 000 km, required for a global system, it will be necessary to connect two, and occasionally three links in tandem;

(d) that the overall performance of each satellite link depends only to a small extent on the great circle distance between the earth stations;

(e) that provision for television standards conversion in a hypothetical reference circuit is undesirable;

UNANIMOUSLY RECOMMENDS

1. that a basic hypothetical reference circuit for active communication satellite systems should consist of one earth-satellite-earth link (see Fig. 1);

2. that the performance for at least a portion of intercontinental connections should take account of the need to connect two, and sometimes, three such links in tandem;

3. that this circuit should include one pair of modulation and demodulation equipments for translation from the baseband to the radio-frequency carrier, and from the radio-frequency carrier to the baseband respectively.

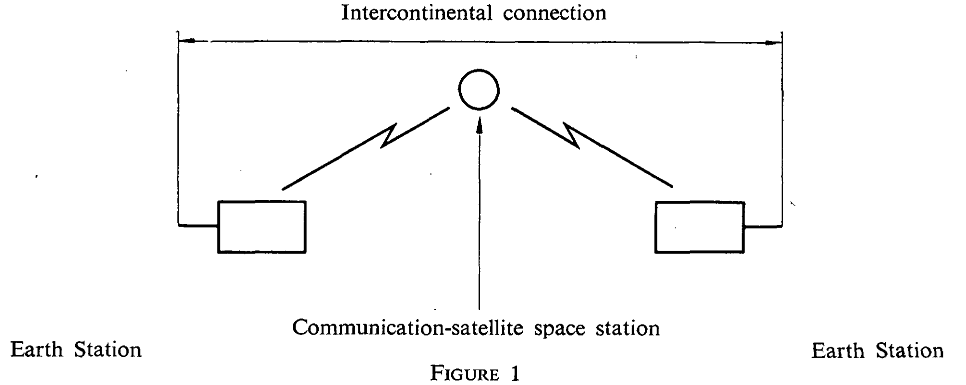


FIGURE 1
Basic hypothetical reference circuit

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

RECOMMENDATION 353 *

ACTIVE COMMUNICATION-SATELLITE SYSTEMS FOR FREQUENCY-DIVISION MULTIPLEX TELEPHONY

Allowable noise power in the basic hypothetical reference circuit

(Question 235 (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that the basic hypothetical reference circuit is intended as a guide to the design and construction of actual systems;

(b) that the costs of establishing and maintaining communication-satellite systems are critically dependent on the overall signal-to-noise performance requirements;

(c) that the total noise power in the basic hypothetical reference circuit should not be such as would affect appreciably conversation in most telephone calls or the transmission of telephone signalling;

(d) that the extent of fading cannot be determined fully until more experimental data are available, but is not expected to be appreciable in active communication-satellite systems;

(e) that there may be other sources of noise of short duration;

UNANIMOUSLY RECOMMENDS

1. that the psophometrically-weighted noise power at a point of zero relative level in any telephone circuit in the basic hypothetical reference circuit as defined in Recommendation 352, should not exceed the provisional values of 10 000 pW mean in any hour, and 80 000 pW, one-minute mean, for more than 0·2% of any month **;

2. that the higher noise levels that may be tolerated for very small percentages of the time should be the subject of further study;

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

Note 1. — Noise in the multiplex equipments is excluded from the above.

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

Note 3. — In applying the basic hypothetical reference circuit and the allowable circuit noise to the design of satellite and earth station equipment for a given overall signal-to-noise performance, the system characteristics preferred by the C.C.I.R., as found in its Recommendations, should be used where appropriate; where more than one value is recommended, the designer should indicate the value chosen; in the absence of preferred values, the designer should indicate the assumptions used.

---

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

** Subject to review in the light of experience and tests.

Note 4. — For frequency-division multiplex, it will be assumed that, during the busy hour, the signal can be represented by a uniform-spectrum signal, the mean absolute power-level of which, at a point of zero relative level, is equal to ($-15 + 10 \log_{10}N$) dbm for 240 channels or more, and ($-1 + 4 \log_{10}N$) * dbm for numbers of channels between 12 and 240, N being the number of both-way channels for which the communication-satellite system is to be designed.

Note 5. — It is not yet possible to make firm recommendations regarding requirements to be met if VF telegraphy and data transmission are required over telephone channels in a communication-satellite system.

Note 6. — The system should be designed to operate under the noise conditions specified, including periods of adverse propagation conditions such as those resulting from atmospheric absorption and increased noise temperatures due to rain.

RECOMMENDATION 354 **

ACTIVE COMMUNICATION-SATELLITE SYSTEMS FOR MONOCHROME TELEVISION

Video bandwidth and permissible noise in the hypothetical reference circuit

(Question 235 (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

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

(b) that the costs of establishing and maintaining active communication-satellite systems are critically dependent on the video bandwidth and the overall signal-to-noise ratio to be provided and these should, therefore, not be greater than is strictly necessary for acceptable transmission;

(c) that the total noise power in the hypothetical reference circuit should not reach a value that would prevent acceptable transmission of monochrome television signals;

(d) that the signal-to-noise ratio for a satellite intercontinental circuit should be comparable to, or greater than, the signal-to-noise ratio objectives specified for the continental networks to be interconnected (see Recommendation 421);

(e) that the extent of fading cannot be fully determined until more experimental data are available, but is not expected to be appreciable in an active communication-satellite system;

(f) that there may be other sources of short-duration noise;

(g) that the same satellite system may be required to accommodate either television or large numbers of telephone channels;

(h) that the video bandwidth and the permissible noise levels in the hypothetical reference circuit should accommodate television signals up to and including signals of the 625-line standard;

---

* This value is provisional for systems with less than 60 channels.

** This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 963.

UNANIMOUSLY RECOMMENDS

1. that, in the hypothetical reference circuit for active communication-satellite systems as defined in Recommendation 352, the nominal upper limit of the video bandwidth should be 5 Mc/s (equivalent noise bandwidth);

2. that the ratio of signal to weighted-noise for continuous random noise at the end of the hypothetical reference circuit, defined in Recommendation 352, evaluated in accordance with Notes 1 and 2 below, should be at least 55 db for 99% of the time;

3. that the question of the higher noise levels, that may occur for less than 1% of the time, should be the subject of further study.

Note 1. — The signal-to-noise ratio for continuous random noise is defined as the ratio (db) of the peak-to-peak amplitude of the picture signal, excluding synchronizing pulses, to the r.m.s. amplitude of the noise, within the range between 10 kc/s and the nominal upper limit of the video-frequency band f_c. The purpose of the lower frequency limit is to enable power supply hum and microphonic noise to be excluded from practical measurements.

Note 2. — The stated value of signal-to-noise ratio is that which shall apply when measured with the appropriate low-pass filter described in Annex II to Recommendation 421, with the appropriate weighting network * described in Annex III to the same Recommendation, and with an instrument having an "effective time constant" or "integrating time", in terms of power, of 1 s.

RECOMMENDATION 355 **

ACTIVE COMMUNICATION-SATELLITE SYSTEMS

Feasibility of sharing frequency bands with terrestrial radio services

(Question 235 (IV) and Study Programme 235A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that at the current state of technological development, active communication-satellite systems can most feasibly use frequencies between about 1 Gc/s and about 10 Gc/s;

(b) that since these frequencies are in extensive use for terrestrial radio services, possibilities exist for interference to and from stations in terrestrial services, on the one hand, and either earth or satellite stations on the other hand;

(c) that among the means for reducing, to permissible levels, interference between communication-satellite systems and terrestrial radio systems sharing the same frequency bands are:
- on the part of satellite stations, limitation of the power flux per unit area and the power flux per unit area per unit bandwidth produced at the surface of the earth;
- on the part of earth stations, limitation of the distance to terrestrial transmitters, appropriate to the technical characteristics concerned and to propagation factors;

---

* It is assumed that the weighting used would be appropriate to a television system with a video bandwidth of 5 Mc/s, as specified in Recommendation 421.

** This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

— on the part of stations in the terrestrial services, limitation of the distance to earth stations, appropriate to the technical characteristics concerned and to propagation factors, together with limitation of the total emitted power and the effective radiated power;

(d) that active communication-satellite systems can best share frequency bands with line-of-sight radio-relay systems, but that there may be considerable difficulty in sharing with certain other services, involving high power transmitters, highly sensitive receivers and changing areas of coverage;

UNANIMOUSLY RECOMMENDS

1. that if communication-satellite systems are to share the frequency bands between 1 Gc/s and 10 Gc/s with other services, such sharing be considered technically feasible under the provisions of Recommendations 356, 357, 358 and 406 in frequency bands allocated to the fixed service and occupied by line-of-sight radio-relay systems;

2. that questions of sharing with other services and the bases of such sharing should be studied further;

3. that the above be considered as provisional and subject to review at the XIth Plenary Assembly of the C.C.I.R.

RECOMMENDATION 356 *

COMMUNICATION-SATELLITE SYSTEMS SHARING THE SAME FREQUENCY BANDS AS LINE-OF-SIGHT RADIO-RELAY SYSTEMS

Maximum allowable values of interference in a telephone channel of a communication-satellite system

(Question 235 (IV), Study Programme 235A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that it may be necessary for communication-satellite systems to share the frequency bands used for line-of-sight radio-relay systems in the range 1 to 10 Gc/s;

(b) that mutual interference would increase the noise in both types of systems beyond that which would exist in the absence of frequency sharing;

(c) that it is desirable that the noise due to interference in the telephone channels of communication-satellite systems due to the transmitters of radio-relay systems should be a small fraction of the total noise in those systems set out in Recommendation 353;

(d) that it is necessary to specify the maximum allowable interference power in a telephone channel to determine the maximum transmitter power and effective radiated power of line-of sight radio-relay stations, and to determine whether specific locations for satellites earth stations and terrestrial radio-relay stations would be satisfactory;

---

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

(e) that it is unlikely that any given radio-frequency channel used by line-of-sight radio-relay receivers will be used for transmissions both from active communication-satellites and from earth stations;

UNANIMOUSLY RECOMMENDS

1. that communication-satellite systems sharing frequency bands with radio-relay systems be designed in such a manner that the interference noise power at zero relative level in any telephone channel of a basic hypothetical reference circuit of a communication-satellite system caused by the aggregate of the transmitters of radio-relay stations conforming to Recommendation 406 should not exceed:

1.1 1000 pW psophometrically-weighted mean power in any hour;

1.2 1000 pW psophometrically-weighted one minute mean power for more than 20% of any month;

1.3 80 000 pW psophometrically-weighted one minute mean power for more than 0·02% of any month;

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

Note 1. — Technical means and methods to meet the above objective are discussed in Report 209.

Note 2. — The above values are understood to be additive to those given in Recommendation 353.

Note 3. — All figures given are provisional and subject to revision in the light of later experience.

Note 4. — Joint Study Group C (C.C.I.T.T./C.C.I.R.) on circuit noise should be asked, through the Director, C.C.I.R., for their opinion on this Recommendation.

RECOMMENDATION 357 *

COMMUNICATION-SATELLITE SYSTEMS SHARING FREQUENCY BANDS WITH LINE-OF-SIGHT RADIO-RELAY SYSTEMS

Maximum allowable values of interference in a telephone channel of a radio-relay system

(Study Programme 235A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that it may be necessary for communication-satellite systems to share the frequency bands used for line-of-sight radio-relay systems in the range 1 to 10 Gc/s;

(b) that mutual interference would increase the noise in both types of system beyond that which would exist in the absence of frequency sharing;

(c) that it is desirable that the noise due to interference in the telephone channels of existing radio-relay systems from transmitters of satellites and earth stations should be a fraction of the total noise in those systems such that it would not be necessary to change the design objectives for radio-relay systems set out in Recommendation 393;

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

(d) that it is necessary to specify the maximum allowable interference power in a telephone channel, to determine the maximum power flux which can be allowed at the surface of the earth from communication-satellites and to determine whether specific locations for satellite earth stations and terrestrial radio-relay stations would be satisfactory;

(e) that it is unlikely that any given radio-frequency channel used by line-of-sight radio-relay systems will be used for transmissions both from active communication-satellites and from earth stations;

UNANIMOUSLY RECOMMENDS

1. that communication-satellite systems which share frequency bands with line-of-sight radio-relay systems, should be designed in such a manner that, in any telephone channel of a 2500 km hypothetical reference circuit for radio-relay systems, the interference noise power at a point of zero relative level, caused by the aggregate of earth stations and the transmitters of communication-satellite systems should not exceed;

1.1 1000 pW psophometrically-weighted mean value in any hour;

1.2 1000 pW psophometrically-weighted one minute mean power for more than 20% of any month;

1.3 50 000 pW psophometrically-weighted one minute mean power for more than 0·01% of any month;

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

Note 1. — The above values are understood to be additive to those given in Recommendation 393. It is further understood that the interference noise powers given above will not be concentrated in a single section of a radio-relay system, but will be distributed statistically among the sections.

Note 2. — Technical means required to meet the above objective are laid down in Recommendation 358.

Note 3. — All figures given are provisional and subject to revision in the light of later experience.

Note 4. — Joint Study Group C (C.C.I.T.T./C.C.I.R.) on circuit noise should be asked, through the Director, C.C.I.R., for their opinion on this Recommendation.

RECOMMENDATION 358 *

COMMUNICATION-SATELLITE SYSTEMS SHARING THE SAME FREQUENCY BANDS AS LINE-OF-SIGHT RADIO-RELAY SYSTEMS

Maximum allowable values of power flux density at the surface of the earth produced by communication satellites

(Question 235 (IV), Study Programme 235A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that in the interests of spectrum economy it would be advantageous for communication-satellite systems to share the frequency bands used for line-of-sight radio-relay systems in the range 1 to 10 Gc/s;

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva 1963.

(b) that, in the event of such sharing, it would be necessary to ensure that the power flux density set up at the surface of the Earth by satellite transmissions should not exceed values that would cause significant interference to line-of-sight radio-relay systems;

(c) that nevertheless any limitation of the power flux density set up at the surface of the Earth should not be such as to place undue restrictions on the design of communication-satellite systems;

(d) that a Recommendation as to the maximum allowable value of the power flux density that could be set up at the surface of the Earth by communication satellites may be of value for the technical guidance of the Extraordinary Administrative Radio Conference, Geneva, 1963, in accordance with Recommendation 36 of the Administrative Radio Conference, 1963, in accordance with Recommendation No. 36 of the Administrative Radio Conference, Geneva, 1959;

(e) that the maximum allowable value of the flux density will depend on the modulation characteristics of the satellite system, and a generally applicable value is required as well as values applicable to specific satellite systems;

(f) that for communication-satellite-systems using wide-deviation frequency modulation, a method of carrier energy-dispersal could be employed to reduce the radio-frequency power flux density measured in any 4 kc/s bandwidth, under conditions of low frequency deviation due to light loading from multi-channel telephone, or from television signals;

UNANIMOUSLY RECOMMENDS

1. that frequency sharing between communication-satellites and line-of-sight radio-relay systems be considered to be feasible under the conditions of §§ 2 or 3 below;

2. that for communication-satellite systems which use wide-deviation frequency modulation, the power flux density set up at the surface of the Earth by the emissions of a satellite should not exceed:

—130 dbW/m² for all angles of arrival,

and that signals radiated by a satellite should be continuously modulated by a suitable waveform if necessary, so that the power flux density measured in any 4 kc/s bandwidth particularly during periods of light loading should not exceed:

—149 dbW/m² per 4 kc/s for all angles of arrival;

3. that for communication-satellite systems using other types of modulation, the power flux density set up at the Earth's surface by the emissions of a satellite, measured in any 4 kc/s bandwidth, should not exceed:

—152 dbW/m² per 4 kc/s for all angles of arrival;

4. that the above be provisional pending further study *.

---

* Since this Recommendation has been made prior to the inception of the communication-satellite service, these provisional values should be reconsidered by the XIth Plenary Assembly of the C.C.I.R.

RECOMMENDATION 359 *

COMMUNICATION-SATELLITE SYSTEMS. AVOIDANCE OF INTERFERENCE BETWEEN EARTH STATIONS AND TERRESTRIAL RADIO STATIONS SHARING THE SAME FREQUENCY BANDS

Determination of the coordination distance

(Study Programme 235A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that, where earth stations and terrestrial stations share the same frequency bands, there is a possibility of interference, both as regards the earth station transmissions interfering with reception at terrestrial stations, and the terrestrial station transmissions interfering with reception at earth stations;

(b) that to avoid such interference, it will be desirable for the transmitting and receiving frequencies used by earth stations to be co-ordinated with the frequency usage by terrestrial services, which might be in a position either to receive interference from earth station transmissions or to cause interference to reception at earth stations;

(c) that this coordination will need to be established within an area surrounding the earth station and extending to the limits beyond which the possibility of mutual interference may be considered negligible;

(d) that this area may sometimes involve more than one Administration;

(e) that such mutual interference will depend upon several factors, including the transmitter powers, antennae gains along the interference paths, the nature of the intervening terrain, and the tolerable interference levels at the receivers;

(f) that the coordination of the preferred reference frequencies for the communication-satellite service with the frequencies used by terrestrial services may sometimes, especially for radio-relay systems, affect the whole area where such a system is used;

(g) that the possibility of interference will need to be examined in detail in each case, taking all factors into account;

(h) that, as a preliminary to this detailed examination, it is desirable to establish a method of determining, on the basis of broad assumptions, a coordination distance from the earth station, i.e. that distance within which mutual consultation between Administrations will be required and beyond which the possibility of interference may be regarded as negligible;

UNANIMOUSLY RECOMMENDS

1. that account be taken of the international coordination and planning which will be involved, if communication-satellite earth stations are to share frequency bands with terrestrial stations in nearby countries without undue mutual interference;

2. that the coordination distance for possible interference to terrestrial radio stations be determined by Administrations planning to establish earth stations on the basis of:

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

— the effective radiated powers likely to be used in various directions from the earth station;

— the maximum antenna gains and receiver sensitivities likely to be used at the terrestrial stations concerned;

3. that the coordination distances for possible interference to earth station reception be determined by Administrations planning to establish earth stations on the basis of:

— the expected range of effective radiated powers likely from terrestrial stations in the pertinent directions;

— the antenna and receiver characteristics likely to be used at the earth station concerned;

4. that the coordination distances in the above cases be determined on the basis of:

— the appropriate propagation data for overland and oversea paths given in Reports 243 and 244;

— interference powers in telephone channels in the baseband of receiving systems not exceeding the provisional values given in Recommendations 356 and 357;

— the procedure outlined in Report 209.

RECOMMENDATION 360 *

CRITERIA FOR SELECTION OF PREFERRED REFERENCE FREQUENCIES ** FOR COMMUNICATION-SATELLITE SYSTEMS SHARING FREQUENCY BANDS WITH LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(Question 235 (IV) and Study Programme 235A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that communication-satellite systems are expected to make an important contribution to the provision of world-wide and area communication;

(b) that spectrum economy would be enhanced by sharing frequency bands with terrestrial systems in the fixed services;

(c) that it can be demonstrated that, under suitably controlled conditions, sharing with terrestrial line-of-sight radio-relay systems is practicable;

(d) that a number of independent communication-satellite systems may be established, including low-capacity as well as high-capacity systems;

(e) that the selection of frequencies for use by communication-satellite systems requires international agreement so that interference between such systems and with other radio services may be minimized and the most effective use be made of the available frequency spectrum;

---

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

** The reference frequency is the frequency relative to which the specific frequency or frequencies assigned to a given communication-satellite system may be specified (No. 87 of the Radio Regulations, Geneva, 1959).

(f) that the preferred reference frequencies initially adopted will have a major influence on subsequent frequency usage;

(g) that the selection of preferred reference frequencies depends on the, as yet, undetermined technical characteristics of communication-satellite systems, as well as on the known technical characteristics of radio-relay systems;

(h) that the establishment of criteria for selection of preferred reference frequencies may be of assistance to the further work of the C.C.I.R., to Administrations concerned and to the Extraordinary Administrative Radio Conference, Geneva, 1963;

UNANIMOUSLY RECOMMENDS

1. that the designation of preferred reference frequencies should:

1.1 provide scope for the development and use, as necessary, of various types of communication-satellite system, e.g., using different orbits, types of satellites, methods of modulation and other technical characteristics;

1.2 allow for multi-station access, thereby enabling several earth stations to use a given satellite;

1.3 minimize interference between communication-satellite systems, and between communication-satellite systems and line-of-sight radio-relay systems to facilitate the planning of both types of system on a co-ordinated basis;

1.4 accommodate the long-term traffic requirements forecast for communication-satellite systems;

2. that the preferred reference frequencies should interleave as effectively as possible with the channel arrangements for line-of-sight radio-relay systems recognized in the Recommendations of the C.C.I.R.;

3. that there should be provision for high-capacity systems, low-capacity systems and systems using both large and small earth stations;

4. that the designation of preferred reference frequencies must be determined in the light of the decisions of the Extraordinary Administrative Radio Conference, 1963, Geneva, with regard to the frequency bands and directions of transmission adopted for the communication-satellite service.

L. 3 - Direct broacasting from satellites

No Recommendations in this sub-section

L. 4- Radionavigation by satellite

RECOMMENDATION 361 *

FREQUENCY REQUIREMENTS OF RADIONAVIGATION-SATELLITE SYSTEMS

(Question 242(IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that in view of the relatively low information rate likely to be required and in the interest of frequency-spectrum conservation, the use of narrow-band techniques appears to be suitable for radionavigation-satellite systems;

(b) that, for systems using satellites which are in motion relative to the earth's surface, the bandwidth requirements will be largely determined by the Doppler frequency shift and the accuracies of transmitter and receiver frequencies;

(c) that, for systems using satellites which are essentially stationary relative to the earth's surface, the bandwidth requirements will be largely determined by the modulation techniques which may be employed and the accuracies of transmitter and receiver frequencies;

(d) that antenna systems of individual radionavigation satellites should be designed to provide the maximum practicable coverage of the earth's surface;

(e) that there is a need to minimize the weight of the equipment in the satellite;

(f) that equipment and techniques are at present available, or may be available in the near future at frequencies in the VHF and UHF ranges (bands 8 and 9) up to about 1000 Mc/s, the lower frequencies being more suitable for low altitude systems;

(g) that it is possible in Doppler type systems to reduce errors caused by ionospheric refraction by the use of two frequencies well separated from each other, and that in this case, system design may be simplified by the use of harmonically related frequencies;

(h) that for systems based on the principle of directivity, the use of narrow beamwidth receiving antennae is required; that it is desirable to minimize the physical size of such antennae; and that for a given antenna size, the directivity and resulting accuracy increase with frequency;

(i) that for systems based on the principle of directivity, a study of desirable antenna size and the required accuracy indicates that frequencies above 10 Gc/s should be used; studies to date indicate that the atmospheric absorption due to water vapour and oxygen is significantly less in the region below 20 Gc/s and in a narrow region near 35 Gc/s;

(j) that this service would require a high degree of radio-frequency protection;

(k) that, in the interests of spectrum economy, it is desirable, and may prove feasible, to accommodate maintenance telemetering signals required for radionavigation-satellite systems on the radio-frequency channels provided for radio-navigation satellites;

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

UNANIMOUSLY RECOMMENDS

1. *that for Doppler, time measuring and path difference radionavigation satellite systems:*

1.1 these systems should preferably use narrow band techniques;

1.2 frequencies in the VHF and UHF ranges (bands 8 and 9) allocated for radionavigation systems are technically suitable;

1.3 frequencies which have not been allocated to radionavigation systems in bands 8 and 9 are also considered technically suitable for allocation to radionavigation-satellite systems;

1.4 where combination is feasible, the maintenance telemetering signals for radionavigation-satellite systems, be accommodated on frequency channels provided for radionavigation satellites;

1.5 consideration be given to the frequency requirements of these systems, preferably on a protected basis, with the provision of several harmonically related bands for Doppler systems;

2. *that for radio-sextant radionavigation systems*, frequencies of the order of 35 Gc/s are technically suitable. Where lower accuracy is acceptable, frequencies between 10 and 20 Gc/s may be used.

Note. — The question of frequency allocations should be considered by the appropriate conference (Extraordinary Administrative Radio Conference, Geneva, 1963 or others).

L. 5- Meteorological satellites

RECOMMENDATION 362 *

FREQUENCIES TECHNICALLY SUITABLE FOR METEOROLOGICAL SATELLITES

(Question 243 (IV), Study Programme 243A (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that meteorological satellites have demonstrated their value to mankind;

(b) that meteorological satellites will soon be operating in a routine manner as indicated in Report 217;

(c) that certain bands are now allocated internationally to the meteorological aids service;

(d) that certain of the frequency needs of meteorological satellites may be satisfied through the use of the meteorological aids allocations established at present;

UNANIMOUSLY RECOMMENDS

1. that bands 8, 9 and 10 are technically suitable for narrow-band and wide-band meteorological data transmission;

2. that as meteorological satellites become more fully developed, and taking due account of reliability requirements and economical use of the frequency spectrum, frequencies within the bands used for meteorological satellites will be technically suitable for tracking, maintenance telemetry and telecommand;

3. that frequencies allocated to the radiolocation service in bands 10 and 11 are technically suitable for use by the precipitation detection radar and cloud detection radar on board meteorological satellites.

---

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

L.6- Maintenance telemetering, tracking and telecommand

RECOMMENDATION 363 *

PREFERRED FREQUENCY BANDS FOR USE IN MAINTENANCE TELEMETERING, TRACKING AND TELECOMMAND OF DEVELOPMENTAL AND OPERATIONAL SATELLITES

(Question 237 (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that the frequencies technically suitable for maintenance telemetering, tracking and telecommand of developmental and operational radionavigation, meteorological and communication satellites lie in the range from 100 Mc/s to 10 Gc/s; the lower part of this range being generally more suitable for lower altitude earth-satellites and the higher part of this range being generally more suitable for higher altitude earth-satellites;

(b) that the integration of maintenance telemetering, tracking and telecommand links with data transmission and communication systems has many potential advantages such as system simplicity, efficient use of redundant modules, precision in tracking and efficient use of the spectrum;

UNANIMOUSLY RECOMMENDS

1. that bands of frequencies below 1 Gc/s, preferably below 600 Mc/s, are the most technically suitable for maintenance telemetering, tracking and telecommand of developmental and operational satellites;

2. that bands of frequencies between 1 and 10 Gc/s are also technically suitable for maintenance telemetering, precision tracking systems, tracking and telecommand for high altitude satellites; further that, because the frequency range is so broad, appropriate bands in the lower portion, centre portion and upper portion of this region be considered;

3. that bands of frequencies above about 10 Gc/s are technically suitable for maintenance telemetering, tracking and telecommand during the re-entry of satellites into the earth's atmosphere (see Report 222);

4. that, as systems such as meteorological, radionavigation and communication satellites become more fully developed, and taking due account of reliability requirements and economical use of the frequency spectrum, frequencies within the bands used for data transmission or communications be also used for maintenance telemetering, tracking and telecommand, where feasible.

---

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

L.7- Space research

RECOMMENDATION 364 *

TELECOMMUNICATION LINKS FOR NEAR-EARTH RESEARCH SATELLITES

Frequencies, bandwidths and interference criteria

(Questions 236 (IV), 237 (IV) and Study Programme 205 (VI))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that suitable operating frequencies, required radio-frequency bandwidths, and limiting interference criteria for near-earth satellite telecommunication links are determined by the technical considerations set forth in Reports 205, 218 and 219;

(b) that, based on past experience, it might be expected that from 20 to 30 active research near-earth satellites will be in orbit simultaneously;

(c) that radio frequencies from about 100 Mc/s to 10 Gc/s are suitable for near-earth satellite telecommunication links, and that the variety of functions and the conditions under which they must be performed divides this region into the following suitable regions: 100 to 300 Mc/s, 300 Mc/s to 1 Gc/s, and 1 to 10 Gc/s;

(d) that telemetering data links typically require radio-frequency bandwidths ranging from 10 kc/s to 3 Mc/s per link in the frequency range from 100 Mc/s to 10 Gc/s, with a preference for 10 kc/s in the lower portion, and 3 Mc/s in the upper portion; that wideband data and television links typically require radio-frequency bandwidths ranging from 50 kc/s to 20 Mc/s in the frequency range from 100 Mc/s to 10 Gc/s, with preference for 50 kc/s in the lower portion and 20 Mc/s in the upper portion of this range;

(e) that tracking links typically require radio-frequency bandwidths ranging from 10 kc/s to 3 Mc/s per link in the frequency range from 100 Mc/s to 10 Gc/s with a preference for 10 kc/s in the lower portion and 3 Mc/s in the upper portion of this range;

(f) that the operating noise temperatures of earth-station telemetering and tracking receiving systems, usually range from 30°K above 1 Gc/s to 3000°K at 0·1 Gc/s (equivalent to —214 dbW per c/s and —194 dbW per c/s);

(g) that earth station antennae for satellite communication do not normally use angles of elevation below 5°;

(h) that typical operating noise temperatures for receivers in spacecraft will be approximately 600°K (—171 dbW per kc/s) for near-earth research satellites, but measures can be taken to protect the spacecraft receiving system against interference approximately 10 db greater than this noise level;

(i) that telecommand can normally be satisfied by one data link channel per craft with radio-frequency bandwidths ranging from 10 kc/s at 0·1 Gc/s to 500 kc/s at 10 Gc/s, largely determined by the Doppler shift of 1×10^4 of the carrier frequency;

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

(j) that coding techniques and use of narrow beam antennae will make possible the control of several craft using the same radio-frequency telecommand channel;

(k) that for some sharing situations between near-earth reseach satellites and certain representative terrestrial services, separations of several hundreds of kilometres between the earth terminals may be required and that in many parts of the world separations of this magnitude are not readily attainable;

(l) that sharing among near-earth research satellites is desirable and feasible;

(m) that difficulties can be expected when sharing frequencies between near-earth research satellites and other services due to the technical problems of furnishing the required protection against terrestrial services;

UNANIMOUSLY RECOMMENDS

1. that the range between 100 and 300 Mc/s is technically suitable for near-earth research satellites with each satellite using radio-frequency bandwidths varying from 10 to 300 kc/s per link, for accomplishing telemetering, wideband data, tracking and telecommand functions;

2. that the range between 300 and 1000 Mc/s is technically suitable for near-earth research satellites with each satellite using radio-frequency bandwidths varying from 30 to 500 kc/s per link, for accomplishing telemetering, wideband data, tracking and telecommand function;

3. that the range between 1 and 10 Gc/s is technically suitable for near-earth research satellites with the following requirements:

— for tracking, 3 Mc/s per link;

— for telemetering, from 500 kc/s per line near 1 Gc/s to 3 Mc/s per link near 10 Gc/s;

— for wideband data links and television, 500 kc/s per link near 1 Gc/s to 20 Mc/s per link near 10 Gc/s; and

— for telecommand, 100 to 500 kc/s per link to be shared with tracking when feasible;

4. that consideration be given to the availability of coherently related frequencies spaced 6% to 10% of the higher frequency for precision tracking systems;

5. that sharing be accomplished to the maximum extent feasible among near-earth research satellites;

6. that the protection criterion for earth receiving sites be established as follows:

6.1 For frequencies greater than 1 Gc/s, the total time during which the density of the interference, in any single and all sets of bands 1 c/s wide, is greater than—200 dbW per c/s, shall not exceed 0·1% of the time; for frequencies less than 1 Gc/s, the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade;

7. that the protection criterion for receivers in space-craft be established as follows:

7.1 The total time during which the power density of the interference, in any single and all sets of bands 1 kc/s wide, is greater than approximately —161 dbW per kc/s, shall not exceed 0·1% of the time;

8. that note be taken of the difficulties to be expected in sharing between near-earth research satellites and stations in other services.

RECOMMENDATION 365 *

TELECOMMUNICATION LINKS FOR DEEP-SPACE RESEARCH

Frequencies, bandwidths and interference criteria

(Questions 236 (IV), 237 (IV) and Study Programme 205 (VI))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that suitable operating frequencies, required radio-frequency bandwidths, and limiting interference criteria for deep-space telecommunication links are determined by the technical considerations set forth in Reports 205, 218 and 220;

(b) that cosmic noise and man-made noise militate against the use of frequencies lower than 100 Mc/s and that atmospheric noise and absorption preclude the use of frequencies much higher than 10 Gc/s;

(c) that the precision tracking required for acceptable guidance of spacecraft to the moon and the planets and for manœuvres in their vicinity result in a preference for frequencies between 1 Gc/s and 10 Gc/s;

(d) that the typical operating noise temperatures of earth station receivers, operating at frequencies greater than 1 Gc/s, will be 25°K (—215 dbW per c/s) for most missions with design margins of less than 6 db; and that, for reception at frequencies less than 1 Gc/s, the system noise temperature is increased by cosmic noise approximately as the inverse of the square of the frequency;

(e) that the typical operating noise temperature of a receiver in a spacecraft operating at frequencies greater than 300 Mc/s will be 600°K (—201 dbW per c/s) with design margins of 6 to 10 db; and that for reception at frequencies less than 300 Mc/s, the system noise temperature is increased by cosmic noise approximately as the inverse of the square of the frequency;

(f) that water vapour in the atmosphere can produce significant degradation in the quality of deep-space communications, at frequencies higher than 4 Gc/s;

(g) that typical deep-space systems will use directional antennae both on the earth and on the spacecraft to transmit sufficient information. These antennae will have a surface precision of between 1 mm and 5 mm, regardless of diameter, so that frequencies between 1 and 10 Gc/s will generally be more suitable for efficient transmission;

(h) that Doppler shifts can be of the order of 1×10^{-4} of the carrier frequency;

(i) that interruptions in communications of more than 5 minutes per day could seriously affect the success of the mission;

(j) that real time television from the lunar surface is practical with frame rates, resolutions, and qualities comparable to commercial television on earth; that photographic facsimile from the nearer planets is similarly practical;

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva 1963.

(k) that it is practical and desirable to effect telemetering, data transmission, and tracking functions on the same space-earth link, and telecommand and tracking functions on the same earth-space link;

(l) that to effect precision tracking, a pair of coherently related frequencies with a separation ranging from 6% to 10% of the higher frequency is required;

(m) that the angular spacings of the moon and the planets are such that the same frequency may be used for probes at different celestial coordinates, but that different spacecraft in the vicinity of the same coordinates or in the antenna beamwidth may require different frequencies;

(n) that geographical separations which permit sharing between representative terrestrial services and deep-space research operations are typically several hundreds of kilometers, and may be greater than 500 km in the absence of terrain shielding; and that separations of this magnitude are not readily obtainable in many parts of the world; and that the spacecraft are visible over large areas of the globe;

(o) that considerable difficulties can be expected, when sharing frequencies between deep-space research operations and other operations, due to the technical problems of furnishing the required protection against both terrestrial and near-earth satellite transmissions;

(p) that although the exploration of deep space has just begun, certain recommendations are possible and necessary at this time;

UNANIMOUSLY RECOMMENDS

1. that frequencies for deep-space telecommunications links be located in the frequency band between 100 Mc/s and 10 Gc/s;

1.1 the band between 100 Mc/s and 1 Gc/s is generally more suitable for narrow band telemetering, tracking, and telecommand from launch to intermediate distances;

1.2 the band between 1 Gc/s and 6 Gc/s is generally more suitable for wideband telemetering, precision tracking, and telecommand from launch to extreme distances;

1.3 the band between 6 and 10 Gc/s is generally more suitable for very wideband telemetering and very precise tracking at various distances;

1.4 special consideration should be given to the availability of coherently related frequencies, spaced at 6% to 10% of the higher frequency, for precision tracking systems;

2. that spectrum space of the order of 2 to 4 Mc/s per link (due account being taken of the dependency of the radio-frequency bandwidth on the type of modulation used) is technically suitable for the transmission of wideband information for lunar flights;

3. that spectrum space of the order of 2 to 4 Mc/s per link is technically suitable for the transmission of wide bandwidths for precision tracking;

3.1 that tracking be time-multiplexed with lunar television or planetary facsimile where practicable;

4. that frequencies be shared among deep-space probes with different celestial coordinates but generally not with spacecraft with the same celestial coordinates;

5. that the protection criterion for earth receiving stations be established as follows:

5.1 for frequencies greater than 1 Gc/s, the total time during which the power density of the interference, in any single and all sets of bands 1 c/s wide, is greater than —221 dbW per c/s at the receiver input terminals, of a deep-space earth station shall not exceed 5 min. per day;

5.2 for frequencies less than 1 Gc/s, the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade;

6. that the protection criterion for spacecraft receivers be established as follows:

6.1 for frequencies greater than 300 Mc/s, the total time during which the power density of the interference, in any single and all sets of bands 1 kc/s wide, is greater than —171 dbW per 1 kc/s at the input terminals of the spacecraft receiver shall not exceed 5 min. per day;

6.2 for frequencies less than 300 Mc/s the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade;

7. that note be taken of the difficulties to be expected in sharing frequencies between deep-space research and other services.

RECOMMENDATION 366 *

TELECOMMUNICATION LINKS FOR MANNED RESEARCH SPACECRAFT

(Questions 236 (IV) and 237 (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that the frequencies, bandwidths, and interference protection criteria for manned research space flight telecommunication and tracking functions are generally similar to those of unmanned near-earth and deep-space flight (see Report 205, 218, 219, 220 and 222 and Recommendations 364, 365 and 367) with the following special considerations;

(b) that manned space flight has periods of launch, earth-space, mid-course manœuvres, terminal manœuvres, rendezvous, abort (premature termination) re-entry and recovery, which are in many respects similar to unmanned space flight, but due to safety-of-life considerations, are much more critical;

(c) that, in contrast with unmanned space flight, two-way voice communication is a vital part of manned space flight and is required to aid command and control, guidance, navigation and other telecommunication functions;

(d) that manned space flight will continue to be in the research phase for several years and, as such, can be expected to require the highest telecommunication and tracking reliability, high data-rate instrumentation such as television, and special telecommunication links for emergency purposes;

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

(e) that the presence of man aboard a spacecraft generally increases the information transmission per spacecraft by approximately 25% and that manned space flight operations often involve the use of compound (multi-stage) spacecraft, each part requiring separate telecommunication and tracking;

(f) that typical telecommunication links used for voice, telecommand, and telemetering require approximately 100 kc/s per link with links required for both directions and for two spacecraft engaged in such near-proximity operations as rendezvous, and that a need therefore can exist for approximately 500 kc/s of bandwidth per mission;

UNANIMOUSLY RECOMMENDS

1. that for most communication and tracking functions, manned research space flight be considered the same as unmanned near-earth and deep-space research flight with respect to frequency regions and interference protection criteria;

2. that frequencies in the HF range below 25 Mc/s are technically suitable for voice communication during the near-earth and recovery phases of manned space flight to extend the range beyond the normal line-of-sight propagation associated with higher frequencies;

3. that, to accommodate special requirements resulting from safety-of-life considerations, for reliable, line-of-sight, two-way telecommunication links having a bandwidth of as much as 500 kc/s per mission, the frequency range from about 20 Mc/s through the lower portion of band 9 (the frequency range from 100 to 600 Mc/s being generally most suitable, but lower frequencies being usable) is technically suitable;

4. that the protection criterion for the earth receiving stations be established as follows: for frequencies near 600 Mc/s, the total time during which the power density of the interference, in any single and all sets of bands 1 kc/s wide, is greater than —187 dbW per kc/s at the receiver input terminals of the earth station, shall not exceed 0·1% of the time; and that for frequencies less than 600 Mc/s, the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade;

5. that the protection criterion for receivers on manned spacecraft be established as follows: for frequencies greater than 300 Mc/s the total time during which the power density of the interference, in any single and all sets of bands 1 kc/s wide, is greater than —161 dbW per kc/s at the terminals of the space craft receiver shall not exceed 0·1% of the time; and that for frequencies less than 300 Mc/s, the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade;

6. that, when necessary for emergency purposes, manned space flight use the recognized emergency frequencies in accordance with the Radio Regulations, Geneva, 1959;

7. that the above considerations and recommendations apply only to the initial phases of manned space flight research, and *that a study be undertaken* to determine the possible impact of advanced manned space flight research missions such as space laboratories, cargo ferries, etc., it being quite probable that such missions will require world-wide frequency allocations.

RECOMMENDATION 367 *

FREQUENCY BANDS FOR RE-ENTRY COMMUNICATIONS

(Question 239 (IV))

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that spacecraft re-entering the earth's atmosphere are enveloped in a self-induced plasma;

(b) that electromagnetic radiations to and from the vehicle may suffer severe attenuation and other detrimental effects due to the existence of the plasma;

(c) that communications with, and tracking of, the vehicle may be imperative during the re-entry phase to ensure a successful mission;

(d) that the selection of frequency bands for re-entry communications and tracking is dictated partly by the parameters of the induced plasma;

(e) that the use of such bands requires international agreement, since the phases of re-entry flight may extend over one or more orbits of the earth;

(f) that the only proved solution to the re-entry communication problem to date involves the use of frequencies greater than the critical frequency of the plasma sheath;

(g) that critical frequencies of the plasma sheath can approach or exceed 10 Gc/s;

(h) that frequencies of 10 Gc/s and higher are affected appreciably by the earth's atmosphere;

(i) that the bands available at present for space reseach purposes above 15 Gc/s are technically suitable for some re-entry communications;

UNANIMOUSLY RECOMMENDS

that both the critical frequency of the plasma sheath and the atmospheric effects be considered in the selection of frequencies for re-entry communications (See Reports 205 and 222).

* This Recommendation has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva 1963.

L. 8- Radioastronomy

RECOMMENDATION 314 *

PROTECTION OF FREQUENCIES USED FOR RADIOASTRONOMICAL MEASUREMENTS

The C.C.I.R., (London, 1953 — Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that the development of radioastronomy has already led to major technological advances, particularly in receiving techniques, and to improved knowledge of fundamental radio-noise limitations of great importance to radiocommunication, and promises further important results;

(b) that protection from interference on certain frequencies is absolutely essential to the advancement of radioastronomy and the associated measurements;

(c) that, for the observation of known spectral lines, certain bands at specific frequencies are of particular importance;

(d) that account should be taken of the Doppler shifts of the lines, resulting from the motion of the sources, which are in general receding from the observer;

(e) that for other types of radioastronomical observations, a certain number of frequency bands are in use, the exact positions of which in the spectrum are not of critical importance;

(f) that the sensitivity of radioastronomical receiving equipment, which is still steadily improving, greatly exceeds the sensitivity of communications and radar equipment;

(g) that a considerable degree of protection can be achieved by appropriate frequency assignments on a national rather than an international basis;

(h) that, nevertheless, it is impracticable to afford adequate protection without some international agreement;

UNANIMOUSLY RECOMMENDS

1. that radioastronomers should be encouraged to choose sites as free as possible from interference;

2. that Administrations should afford all practicable protection to the frequencies used by radioastronomers in their own and neighbouring countries;

3. that particular care should be taken to give complete international protection from interference to observations of emissions known or thought to occur in the following bands:

Line	Line frequency (Mc/s)	Band to be protected (Mc/s)
Deuterium	327·4	322–329
Hydrogen	1420·4	1400–1427
OH	1667	1645–1675

4. that the bands allocated for standard frequency and time signal emissions at 2·5, 5·0, 10·0 and 20·0 Mc/s should not include anything other than the standard frequency and time signal emissions, thus permitting their use for reception in radioastronomy;

* This Recommendation, which replaces Recommendation 173, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

5. that consideration be given to securing adequate international protection of a number of narrow frequency bands throughout the spectrum above 30 Mc/s for the purpose of reception in radioastronomy (see Note);

6. that Administrations, in seeking to afford protection to particular radioastronomical observations, should take all practical steps to reduce to the absolute minimum amplitude harmonic radiations falling within the band of the frequencies to be protected for radioastronomy.

Note. — Radioastronomers in a number of countries have indicated their desire to use for this purpose one frequency band at each of the following approximate positions (not necessarily in harmonic relation):

Frequency (Mc/s)	Bandwidth (Mc/s)
40	± 0·75
80	± 1·0
160	± 2·0
640	± 2·5
2560	± 5·0
5120	± 10·0
10 240	± 10·0

L. 9 - Radar astronomy

No Recommendations in this sub-section

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

REPORTS OF SECTION L: SPACE SYSTEMS AND RADIOASTRONOMY

L.1 - General

REPORT 204 *

TERMS AND DEFINITIONS RELATING TO SPACE RADIOCOMMUNICATION

(Resolution 21)

(Geneva, 1963)

An agreed terminology relating to space radiocommunication does not at present exist and the practice followed by different countries and organizations varies considerably. It is evident that a consistent and clearly-defined terminology is essential if ambiguity and uncertainty are to be avoided in the preparation and interpretation of the documents of the C.C.I.R. **.

Recognizing that the definition of specific radio services and stations is a function of I.T.U. Administrative Radio Conferences, it is emphasized that the terminology and definitions contained herein are intended for the guidance of the C.C.I.R. They are not intended to prejudge the decisions taken in this regard by appropriate Administrative Radio Conferences in the future. It will be noted, in some instances, that the terminology suggested differs from that found in Article 1 of the Radio Regulations, Geneva, 1959.

A. Services, stations and functions

1. Space service ***

A radiocommunication service between space stations and earth stations, or between space stations, or between earth stations, when the signals are relayed by space stations or transmitted by reflection or by scattering from objects in space (excluding reflection or scattering from the earth's atmosphere).

2. Space station ***

A station in the space service, located on an object which is beyond or intended to go beyond the major portion of the earth's atmosphere.

3. Earth station ***

A station in the space service, located either on the surface of the earth (including on board a ship or a land vehicle) or on board an aircraft.

4. Communication-satellite service

A space service for radiocommunication between earth stations in which the signals are relayed by one or more space stations, or are transmitted by reflection or by scattering from objects in orbit around the earth.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

** The publication of these terminological data should forthwith add a degree of clarity and precision to space radio documents. The Working Group by correspondence set up by Resolution 21 within Study Group XIV with the assistance of the specialized collaborators of each of the other Study Groups, will be able to arrange these data and keep them up to date in view of their incorporation in the future Volume II of the "List of essential radio terms and definitions".

*** This definition represents a departure from definitions for the same or similar terms in Article 1 of the Radio Regulations' Geneva, 1959.

4.1 *Communication-satellite space station*
A space station in the communication-satellite service.

4.2 *Communication-satellite earth station*
An earth station in the communication-satellite service.

5. Meteorological-satellite service

A space service in which meteorological information obtained directly through instruments on board earth satellites is transmitted to earth stations from space stations on board such satellites.

5.1 *Meteorological-satellite space station*
A space station in the meteorological-satellite service.

5.2 *Meteorological-satellite earth station*
An earth station in the meteorological-satellite service.

6. Radionavigation-satellite service

A space service in which space stations on board earth satellites transmit information for the purposes of navigation.

6.1 *Radionavigation-satellite space station*
A space station in the radionavigation-satellite service.

6.2 *Radionavigation-satellite earth station*
An earth station in the radionavigation-satellite service.

7. Space research service

A space service in which spacecraft are used for research purposes.

7.1 *Space research space station*
A space station in the space research service.

7.2 *Space research earth station*
An earth station in the space research service.

8. Broadcasting-satellite service

A space service in which signals transmitted by space stations, or by reflection or by scattering from objects in orbit around the earth, are intended for direct reception by the general public.

8.1 *Broadcasting-satellite space station*
A space station in the broadcasting-satellite service.

8.2 *Broadcasting-satellite earth station*
An earth station in the broadcasting-satellite service.

9. Terrestrial services

A general term applied to any or all of the radio services as defined in Article 1 of the Radio Regulations, Geneva, 1959, other than space services.

10. (Space) telemetering

The use of telemetering for the transmission from a space station of measurements made in a spacecraft, including those relating to the functioning of the spacecraft.

10.1 *Maintenance telemetering*

Space telemetering relating only to the electrical, mechanical and/or environmental condition of a spacecraft and its equipment. This would include the telemetering of values of such parameters as fuel supply, power supply voltages, rate of battery charge or discharge, signal levels, temperature and pressure within a spacecraft and similar data unrelated to the radio service in which a spacecraft is designed to operate.

11. (Space) telecommand

The use of radio signals transmitted to a space station to initiate or terminate actions within the associated spacecraft.

12. (Space) tracking

Determination of the orbit, position, or velocity of an object by a continuous process of radiodetermination.

B. Terms relating to orbital characteristics

13. Orbit

The path in space followed by a satellite. (Normally, this is a path determined by the gravitational field of a primary body, such as the earth. To a first approximation, all orbits are simple conic sections, i.e., a circle, ellipse, parabola or hyperbola).

14. Circular orbit

An orbit in which the distance of the satellite from the centre of mass of the primary body is constant.

15. Elliptical orbit

A closed orbit in which the distance of the satellite from the centre of mass of the primary body is not constant.

16. Equatorial orbit

An orbit, the plane of which coincides with that of the equator of the primary body.

17. Polar orbit

An orbit, the plane of which is orthogonal to the equatorial plane and thus contains the polar axis of the primary body.

18. Inclined orbit

An orbit in a plane between those of the equatorial and polar orbits. The *angle of inclination* is measured between the plane of the orbit and the equatorial plane.

19. Apogee

The point of maximum altitude attained by a satellite in an elliptical orbit about the earth.

20. Perigee

The point of minimum altitude attained by a satellite in an elliptical orbit about the earth.

21. Random satellites

Satellites, the positions of which vary continuously relative to other satellites within the same system.

22. Station-keeping satellites

A satellite, the position of which, relative either to other satellites in the same system or to a point on earth, is maintained within given limits.

23. Attitude-stabilized satellite

A satellite designed to maintain one or more of its axes in a specified direction or directions, e.g., toward the centre of the earth or toward a fixed position in space.

24. Synchronous satellite

A satellite having an orbital period equal to the period of rotation of the primary body about its own axis.

25. Sub-synchronous satellite

A satellite having an orbital period which is an integral fraction of the period of rotation of the primary body about its own axis.

26. Stationary satellite

A synchronous satellite in a circular, equatorial orbit, moving in the direction of rotation of the primary body.

C. Miscellaneous terms

27. Active (communication) satellite

A communication satellite using a radio station on board the satellite.

28. Passive satellite

A satellite intended to relay radio signals by reflection or by scattering at the satellite. (This term encompasses ECHO-type balloons, orbiting dipoles, the moon, etc.)

29. Deep space

Space at lunar distances and beyond.

30. Satellite system

A system which provides a space service by means of a co-operating group of one or more earth stations and one or more associated satellite space stations or passive satellites.

31. Spacecraft

Any type of space vehicle, including earth satellites, deep-space probes, etc. whether manned or unmanned.

REPORT 205 *

FACTORS AFFECTING THE SELECTION OF FREQUENCIES FOR TELECOMMUNICATIONS WITH AND BETWEEN SPACECRAFT

(Question 239 (IV) and Study Programmes 191 (V), 204 (VI) and 205 (VI))

(Los Angeles, 1959 — Geneva, 1963)

1. Introduction

The purpose of this Report is to summarize the relationships between frequency and radio propagation and other technical factors which influence radiocommunication in space, to determine a basis for the selection of frequencies for communication between the earth and a spacecraft, or for communication between spacecraft.

Section 2 considers, in a general manner, the propagation factors affecting communication with spacecraft: §§ 3 and 4 apply this information to typical systems of communication with and between spacecraft respectively, and to examine the dependence of the signal and noise levels on frequency.

2. Factors affecting communication with spacecraft

Rapid advances in the use of spacecraft and expanded demands for communication has intensified the requirements for space communications. Usually, only modest transmitter powers are available in the spacecraft and, therefore, careful engineering of circuits for spacecraft is necessary, paying particular attention to the selection of radio-frequencies. The basis of selection of optimum frequencies may be: the available signal-to-noise ratio for a given transmitter power; the minimum probability of interference; or other considerations.

The discussion in this section considers, as its first objective, the way in which propagation effects control the signal strength and the noise level. However, it is recognized that the signal-to-noise ratio may not be the sole criterion of frequency selection, and some comments are made on refraction effects and other factors which may disturb the character of the signal and cause problems in location and tracking.

2.1 *Radio "windows"*

All communication between the earth and spacecraft must pass through the earth's atmosphere, including the troposphere and ionosphere. Communication between spacecraft will usually involve radio paths outside the influence of the lower atmosphere of the earth.

The atmosphere is frequency selective, allowing some frequencies to pass through readily while severely attenuating others. A range of frequencies in which waves penetrate the atmosphere readily is often called a "window".

Two principal ranges of frequencies pass readily through the atmosphere [1]. They are:

— the range between ionospheric critical frequencies and frequencies absorbed by rainfall and atmospheric gases (about 10 Mc/s to 20 Gc/s);

— the combined visial and infra-red ranges.

The atmosphere is known to be partially transparent in a third range, below about 300 kc/s [2]. Waves are propagated through the ionosphere in this range by what is sometimes called the whistler-mode. Propagation in this mode is not yet well understood. Since

* This Report, which replaces Report 115, was adopted unanimously. It has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963

the bandwidths required for most space applications are not available in this frequency range, it is not considered further in this Report.

The range 10 Mc/s to 20 Gc/s is of more immediate interest, particularly to the C.C.I.R., for the purposes of communication with spacecraft. The upper practical limit of this range may be below 10 Gc/s during heavy rainfall, and the lower limit may be above 70 Mc/s depending upon the degree of solar activity, the geographical position of the earth station and the geometry of the signal path. On the other hand, the "window" may extend from as low as 2 Mc/s for polar locations during the night [3], to as high as 50 Gc/s at locations at high altitude free from rain. Fig. 1 illustrates these general frequency limits.

Although the lower frequency-limit of the window is essentially limited by ionospheric influences, the use of frequencies near the lower limit of the window may be restricted by noise from extra-terrestrial or atmospheric sources. Interference problems may also be more difficult at these frequencies.

At higher frequencies, the main factors influencing the signal-to-noise ratio are:

— the signal power available under free-space propagation conditions,
— the absorption in the atmosphere,
— radiation from natural extra-terrestrial sources,
— thermal noise radiation arising from atmospheric absorption, and also from the earth via side-lobes in the directivity pattern of the antenna.

2.2 *Free-space propagation*

Although great distances are involved, the propagation medium in space is essentially transparent to radio waves over a wide range of frequencies and performance estimates for this range may be based on free-space propagation. The dependence on frequency of the input power to a receiver under free-space propagation conditions depends upon the type of antenna at the transmitter and the receiver. This dependence is shown by the following free-space propagation formula:

$$P_r = \left(\frac{\lambda}{4\pi}\right)^2 \left(\frac{P_t\, G_t\, G_r}{d^2}\right) = \left(\frac{c}{4\pi}\right)^2 \left(\frac{P_t\, G_t\, G_r}{f^2\, d^2}\right)$$

where

P_r = available power from the receiving antenna,

P_t = radiated power,

λ = wavelength in free-space,

f = frequency,

d = distance between transmitter and receiver,

G_t = power gain of the transmitting antenna, relative to an isotropic antenna,

G_r = power gain of the receiving antenna, relative to an isotropic antenna,

c = velocity of light in free-space.

If both the transmitting and receiving terminals of a free-space communication link use omnidirectional antennae or if the beamwidths at both terminals are fixed,

$$P_r \text{ is proportional to } \frac{P_t}{f^2 d^2}$$

so that the received power increases as the frequency is decreased.

If one terminal of a free-space communication link uses a directional antenna of fixed physical size and can operate with narrower and narrower beamwidths as the frequency is increased, while the other terminal uses an omnidirectional antenna or an antenna of fixed beamwidth, e.g. a directional antenna on the earth's surface (G_t = Const. f^2)* and an omnidirectional antenna on a spacecraft:

$$P_r \text{ is proportional to } \frac{P_t}{d^2}$$

so that the received power is independent of frequency.

If both terminals of a free-space communication link use directional antennae of fixed physical size and can operate with narrower and narrower beamwidths as frequency is increased, e.g. a directional antenna on the earth's surface and a directional antenna on a more elaborate spacecraft (G_t = Const. f^2 and G_r = Const. f^2) *:

$$P_r \text{ is proportional to } \frac{P_t f^2}{d^2}$$

so that the received power increases as the frequency is increased.

Fig. 2 illustrates the power available for free-space propagation when both the antenna at the earth station and the antenna at the space station have maximum physical size and minimum limitations on beamwidth. Within the "radio window", maximum available power depends on the operational requirements and antenna design which usually establish the physical size of the antenna and the limitations on beamwidth.

2.3 *Signal attenuation*

Actual propagation conditions may vary substantially from free-space conditions, particularly at frequencies near the edge of the radio "window", and it is necessary to correct for tropospheric and ionospheric effects to obtain a true estimate of the dependence on frequency. For higher frequencies this correction is primarily to take account of attenuation due to atmospheric gases, clouds and rainfall.

Fig. 3 indicates the attenuation of the signal for a vertical path in a clear atmosphere as a function of frequency. The curves are based on a theoretical estimate for an atmosphere typical of Washington, D.C. in August [4], and illustrates the frequency-dependence expected in a moderately humid area. Additional theoretical and experimental work is necessary to determine atmospheric absorption completely. The attenuation when the path is not vertical will be increased by a factor independent of frequency [5]; approximate values of this factor are given in Table I for various angles of elevation.

TABLE I

Effect of the angle of elevation on atmospheric absorption

Angle from the horizontal	0°	5°	7·5°	10°	30°	90°
Factor, by which the attenuation (in db) for a vertical path, must be multiplied	80	11	7	5	2	1

* In the direction of maximum antenna gain.

Fig. 4 shows the attenuation of the signal per 1 km of path due to rainfall, and to cloud and fog [6], [7]. Estimation of absorption due to rainfall is complicated by variation of drop size distributions for the same rainfall rate and by turbulence which may produce a different water content in the air than indicated by surface measurement. Fig. 4 applies to a typical drop size distribution in steady rainfall. It must however be remembered that the effective antenna noise temperature increases during rainfall; also changes of antenna impedance during heavy rainfall may further degrade the receiving conditions.

Estimation of the percentage of time for which a given attenuation occurs requires statistical information on the horizontal and vertical extent of rainstorms, and on cloud thickness and coverage. For example, an estimate based on statistics for Southern England for cloud [8] and rain, making assumptions concerning the dimensions of rainstorms, shows that the attenuation exceeded for 1% of the time is about 0·25 db due to rain and about 0·7 db due to cloud, taking the case of 5° elevation and a frequency of 4 Gc/s.

Near the low frequency edge of the window the absorption in the ionospheric D-, E- and F-regions increases with decreasing frequency. For most terrestrial locations even at 20 Mc/s this influence will rarely produce an attenuation greater than 1 db at vertical incidence or 6 db at low elevation angles. However, much larger values have been observed at high latitudes in the presence of aurorae, in particular during short-lived drop-outs [9]. The low frequency edge of the window is dependent on time and varies according to the local and regional ionospheric characteristics. Complicated ionospheric refraction and reflection phenomena can produce focusing and defocusing phenomena, in particular under conditions of scintillation (see § 2.5) and near the frequency limit of reflection [10].

2.4 *Refraction phenomena*

A radio ray passing through the lower atmosphere is bent by an amount depending on the angle of incidence and the thickness of the atmosphere traversed. The effect is largely independent of frequency, and its magnitude greatest at small angle of elevation. The magnitude of the bending is significant only for very small angles of elevation. Fig. 5 shows the average amount of bending versus apparent angle of arrival for two extreme types of atmosphere [11]. It is clear that the error in angle of arrival is very small for elevation angles greater than 5°, although it can be of the same order as the antenna beamwidths which are likely to be used for communication-satellite systems.

Ionospheric refraction also increases the apparent elevation, but it is important only near the low frequency edge of the window and decreases considerably with increasing frequency. It is essentially given by the Sellmeier dispersion formula [10]. The effect varies greatly according to the time-variations of the electron density and also with regional variations, the highest values being found in tropical regions. Anomalous effects occur frequently near the lower frequency limit of the window [10]. Ionospheric ducting may occur at altitudes below roughly 500 km and may be important at frequencies up to several hundred Mc/s [12].

2.5 *Scintillation and scatter*

Scintillation, i.e. fluctuation with time in the amplitude and direction of arrival of the signal, occurs when inhomogeneities in the refractive index are present which vary in time. The time variation results from motions of these inhomogeneities in the atmosphere or from motion of the spacecraft. Under these conditions there may be a lack of phase coherence so that typical phase effects (see § 2.6) cease to be well defined. Large aperture antennae will not realize their full plane wave gain under these circumstances so that an apparent attenuation is observed.

Tropospheric scintillation occurs mainly at very low angles of elevation. Measurements are, however, available which show that the effect is not negligible, even at higher angles of elevation, with high directivity antennae [13].

Ionospheric scintillations have been observed quite frequently related to auroral phenomena [10], [14]. Such observations have been reported on frequencies up to 1 Gc/s [15].

Scattering of energy over a wide range of angles may also occur. Although the attenuation and distortion of a signal resulting from this is generally quite negligible, the fraction of energy scattered may sometimes be a cause of interference.

2.6 *Phase effects*

A Doppler frequency-shift is produced if the path length of a radio link varies with time, giving a continuous change of phase. The received frequency f' is increased relative to the transmitted frequency f for a decreasing path length, and is decreased for an increasing path length. In the simplest case of free-space propagation the formula is

$$\frac{\Delta f}{f} = \frac{f'-f}{f} = -\frac{v_r}{c}$$

where v_r is the rate of change of path length and c is the velocity of light. The frequency shift Δf is a constant percentage of the transmitted frequency, and therefore increases with increasing frequency. For a low altitude satellite, the fractional change has a maximum value of up to 2×10^{-5}. The change is, however, greater for rockets and for satellites on take off and re-entry and, at times, also for space probes.

The Doppler effect gives frequency variations during the passage of a satellite which must be allowed for in considering frequency allocations for earth-space systems. Second-order difficulties may arise from the fact that the absolute frequency shift is not exactly constant throughout the frequency band occupid by the transmission.

Tropospheric refraction has only a negligible influence on Doppler shift. However, the ionospheric influence cannot be neglected near the lower frequency limit of the window, up to a few hundred Mc/s. This ionospheric influence is, again, variable with time and location. Considerable effects have been observed at frequencies below 100 Mc/s [10].

The Faraday effect appears as a consequence of double refraction in the ionosphere in the presence of the earth's magnetic field. This gives rise to a rotation of the plane of polarization of a linearly polarized plane wave. The effect depends on the electron density and on the strength and direction of the magnetic field. The total number of rotations is often several hundred in the vicinity of the lower frequency edge of the window. The Faraday rotation may occasionally reach a value as high as 150° at 1 Gc/s [16].

2.7 *Noise*

To determine optimum frequencies, the variation of background radio noise within the radio window must also be considered. This noise arises by radiation from natural terrestrial and extra-terrestrial sources, man-made noise, and by radiation from the absorbing atmosphere around the earth, and may be received in both the main and subsidiary lobes of the antenna. Radio noise is frequently described in terms of an effective antenna temperature.

Of the natural sources cosmic noise predominates at the lower edge of the radio window. Toward the upper edge, noise due to water vapour and oxygen absorption in the atmosphere becomes increasingly important.

There are three types of cosmic noise, namely a background radiation (mainly from the galaxy), radiation from point sources, and solar noise. The magnitude of the background cosmic noise decreases as the frequency is increased and becomes negligible in comparison with the receiver noise at frequencies above about 1 Gc/s [17]. The point sources are of very small angular width and are rarely intercepted by an earth station antenna.

The sun is also of small angular width and is rarely intercepted by an antenna beam. However, its apparent noise temperature may be very high and the noise received via side-lobes may be significant in some cases. Solar noise is dependent on the frequency and on the degree of solar activity. The apparent noise temperature of the quiet sun varies from almost 1 000 000° at 30 Mc/s to about 10 000° at 10 Gc/s. The amount of solar noise received by an antenna clearly depends on the apparent temperature of the sun, and on the fraction of the antenna beam intercepted by the sun.

In addition to noise from extra-terrestrial sources, noise also originates in the earth's atmosphere. When viewed through an absorbing region at a temperature T_1, the effective sky temperature due to a source at a temperature T_0, which fills the antenna beam, is given by

$$(1 - \alpha)\ T_1 + \alpha\ T_0$$

where α, the power transmission factor of the absorbing region, is related to the attenuation L, (db), by the formula

$$L = 10 \log_{10} (1/\alpha)$$

Fig. 6 shows the apparent sky noise temperature due to background cosmic noise and to atmospheric absorption as a function of elevation angle for the frequency range from 100 Mc/s to 40 Gc/s. This graph is for typical summer conditions but does not include the effects of cloud and rain. The two curves for cosmic noise correspond to the limiting cases with the antenna directed toward the maximum noise radiation, near the galactic center, and with the antenna directed toward the minimum noise radiation. In estimating antenna temperatures, the antenna pattern and radiation from the earth's surface must also be considered.

The noise due to absorption in cloud and rain may be calculated from the formula given above if the temperature and rate of attenuation and their distribution along the path are known. During heavy rain or dense fog, antenna temperatures at the highest frequencies considered here, will tend to approach the temperature of the atmosphere.

3. Communication with spacecraft

Fig. 7 combines some of the more important technical factors (on the basis of [4] and [18] to [24]) to illustrate the general frequency dependence of available signal and noise powers in a simple satellite system, namely an unstabilized satellite with an isotropic antenna 1000 km from an earth station which is located at sea level. The data refer to the link from space to earth which is thought to be generally the weaker one. It is assumed that the diameter of the antenna at the earth station is limited to 20 m and the minimum beamwidth is 0·2°. Under these conditions, the available signal power remains constant under clear atmospheric conditions up to the frequency at which the beamwidth limitation is reached (about 5 Gc/s). At higher frequencies the limiting beamwidth is used and there is a decrease in available signal power. There is also increase atmospheric absorption at the higher frequencies.

The noise power is estimated for a parabolic antenna in a moderately humid sea-level location (Washington D.C., August) and includes earth and solar-noise contributions from typical side lobes of a simple parabolic antenna. Careful design for side-lobe suppression will result in somewhat lower noise values. The same general frequency dependence holds for any fixed beamwidth antenna on the spacecraft.

Fig. 8 illustrates the relationship between the available signal and noise powers and the frequency in a more elaborate communication satellite system, namely a stabilized stationary satellite using an earth oriented directional antennae. For the circuit parameters assumed, the available carrier power increases with frequency until the beamwidth limitation of the satellite antenna is reached (20° beamwidth at about 2 Gc/s for a paraboloid 0·5 m in diameter); the available signal power is then essentially constant until the beamwidth limitation of the earth station is reached (0·2° beamwidth at about 6 Gc/s for a paraboloid 18 m in diameter). Beyond this frequency there is a decrease in available power as frequency is increased.

Fig. 9 illustrates the relationship between available signal and noise and the frequency in an elaborate stationary satellite system using very directive antennae with an elevated earth station in a moderately humid area (Washington D.C., August) and also in this area during moderate rainfall.

Fig. 10 illustrates the typical service area of a stationary satellite as a function of the angle of elevation for reception.

Fig. 11 shows the variation in service area at various altitudes of the satellite.

4. Communication between spacecraft

The choice of frequencies for radio links between spacecraft which is considered in this section, is determined largely by limitations on the spacecraft antennae as determined by the spacecraft mission, and by cosmic noise. When using simple omnidirectional antenna, solar noise is an important limiting factor. Three configurations are considered. The simplest uses omnidirectional antennae on both spacecraft. The second has directional antenna on one of the spacecraft and the most advanced has directional antennae on both.

For spacecraft to spacecraft communications, the controlling factors on system noise are cosmic and receiver noise. Cosmic noise decreases somewhat more rapidly than the square of the frequency as shown in Fig. 6. If the spacecraft are in the vicinity of the moon, the earth, or the other planets, the temperature and masking effects of these bodies must be included.

In calculating received power-levels for these systems, use can be made of the formulae in § 2.2 of this Report.

It is obvious that spacecraft having directional antennae will require high angular stability, so angular motions are small compared with the antenna beamwidth. Also, depending on the difficulty of search, acquisition and tracking of the signal being received, the beamwidth of the antenna may have to be larger than that determined only by spacecraft stability and maximum permissible antenna area. Thus both the gain and antenna area may be limited. Under these conditions, a particular transition frequency f_t, above which the system gain is limited by the minimum acceptable beamwidth and below which it is limited by the maximum area of the antenna, may be defined by the following relation:

$$\lambda_t^2 = \frac{c^2}{f_t^2} = \frac{4\pi A_m}{G_m}$$

where A_m = Maximum permissible antenna area;

G_m = Maximum permissible antenna gain, relative to an isotropic antenna;

λ_t = Free-space wavelength corresponding to the transition frequency.

The transition frequency 'f_t' is the one frequency at which the maximum permissible values of both antenna area and antenna gain may be used.

For the particular case of omnidirectional antennae on both spacecraft, the frequency variation of signal-to-noise ratio for receiver noise temperatures of 300°K and 1500°K is shown in Fig. 12. It is seen that for this configuration, there is a broad optimum operating region extending from about 10 Mc/s to 150 Mc/s or more, the low-frequency limit being determined by cosmic noise [18]. Much lower spacecraft receiver noise temperatures than those considered may eventually be achieved.

Similar curves are shown in Fig. 13 for a directional antenna on one of the spacecraft and an omnidirectional antenna on the other. The optimum frequency region depends on the transition frequency of the directional antenna. Above this frequency, the received signal decreases as the square of the frequency because of the beamwidth limitation. Below this frequency, the curves are controlled as before by the receiver noise temperature and the frequency variation of cosmic noise. It is seen from the diagram that when the transition frequency is very high, the optimum frequency region tends to broaden considerably.

For similar directional antennae on both spacecraft, the received power will decrease on each side of the transition frequency as the square of the frequency, if one disregards noise of cosmic origin. For systems presently envisaged, the optimum frequencies may lie anywhere in a range between about 1 and 30 Gc/s depending on maximum permissible antenna areas and antenna gains.

5. Summary

Communication between earth and space is possible within two broad frequency bands; about 10 Mc/s to 20 Gc/s and in the infra-red and optical regions. With the current state of development, the lower frequency band is of more immediate interest, particularly to the C.C.I.R. and has been considered in this Report.

The upper limit of the band considered is dependent upon tropospheric conditions and the lower limit depends upon ionospheric conditions and cosmic noise. The band, therefore, is not sharply defined, but is dependent upon geographical location and time of operation.

Within the band, the optimum frequency will depend upon the specific communication system.

For communication with spacecraft where the spacecraft has an omnidirectional antenna the available signal and noise powers are essentially constant over a broad frequency range. The practical upper frequency limit depends upon the minimum beamwidth which will permit acquisition and tracking at the earth station, as well as upon atmospheric conditions.

For communication systems using unstabilized spacecraft, the available signal-to-noise is constant over a broad frequency range with the practical upper frequency limit dependent upon maximum antenna size and minimum beamwidth limitations at the earth station.

As systems become more refined through stabilized spacecraft and the ability to use narrow-beam antennae, the upper frequency limit increases, and may extend to above 15 Gc/s for more elaborate systems if reception is not required at very low angles.

Optimum frequencies for communication between spacecraft depend upon whether omnidirectional or highly directional antennae are necessary to provide the service required. For omnidirectional antennae on both spacecraft, there is a broad optimum frequency region between about 10 Mc/s and 150 Mc/s [1]. For a directional antenna in one spacecraft, the desirable region lies between about 300 Mc/s and 3 Gc/s, and for directional antennae on both spacecraft between about 1 Gc/s and 30 Gc/s. These values may, however, be different if the effect of solar noise is important.

Bibliography

1. Haydon, G. W. Optimum frequencies for outer space communication. *J. Research NBS*, 64D, 105-109 (March-April, 1960).
2. Helliwell, R. A. and Morgan, M. G. Atmospheric whistlers. *Proc. IRE*, **47**, 200 (1959).
3. Zacharisen, D. H. World maps of F2 critical frequencies and maximum usable frequency factors, *NBS Technical Note* No. 2 (April, 1959).
4. Bean, B. R. and Abbott, R. Oxygen and water vapour absorption of radio waves in the atmosphere. *Geofisica pura e applicata*, Milano, **37**, 127-144 (1957).
5. Perlman, S., Kelley, L. C., Russell, W. T. Jr. and Stuart, W. D. Concerning optimum frequencies for space communication, *IRE*, **CS-7**, 167 (September, 1959).
6. Kerr, D. E. Propagation of short radio waves (McGraw-Hill Book Co., Inc. New York, N.Y. 1952).
7. Saxton, J. and Hopkins, H. S. *Proc. I.E.E.*, **98**, Pt. III, 26 (1951).
8. Jones. *Journal Royal Meteorological Society*, 65 (January, 1961).
9. Rawer, K. Effect of propagation in space communications. U.R.S.I. Symposium on Space Communication Research, Paris (1961).
10. Rawer, K. Propagation problems with space radio communications. *Journal of Research, NBS* Section D (1962).
11. Szulkin. Average radio-ray refraction in the lower atmosphere. *Proc. IRE*, **40** (5), 554 (1952).
12. Woyk, E. The refraction of radio waves by a spherical ionized layer. *Journal Atmo. Terr. Phys.*, **16**, 124-135 (1959).
13. Norton, K. A. et al. An experimental study of phase variations of line-of-sight microwave transmissions. *National Bureau of Standards* (U.S.A.), Monograph No. 33 (1961).
14. Aarons, J. et al. Atmospheric phenomena noted in simultaneous observations of 1958. *Planetary and space science*, **5**, 169-184 (1961).
15. Ko, H. G. Amplitude scintillation of a radio star at ultra high frequency. *Proc. IRE*, **48**, 1871-1880 (1960).
16. Ingalls, R. P. et al. A study of UHF space communication through an aurora using the moon as a reflector, 272-280 (1961).
17. Pierce and Kompfner. Transoceanic communication by means of satellites. *Proc. IRE*, **47**, 372 (1959).
18. Radioastronomy issue. *Proc. IRE*, **46** No. 1 (January, 1958).
19. Laitinen, P. O. and Haydon, G. W. Analysis and predictions of sky-wave field intensity. *Radio Propagation Agency Technical Report* No. 9 (August, 1950), U.S. Army Signal Radio Propagation Agency, Fort Monmouth, N.J.
20. Norton, K. A. Maximum range of a radar set. *Proc. IRE* (January, 1947).
21. Smith, G. O. Radio communications across space, ship to ship, and ship to planet. *Journal of the British Interplanetary Society*, Vol. **12,** 1, 13 (1953).
22. Castruccio, P. A. Communications and navigation techniques of interplanetary travel. *IRE* Transactions on aeronautical and navigational electronics (December, 1957).
23. Wheelon, A. D. Mid-course guidance techniques for space vehicles. National conference of aeronautical electronics (1958).
24. Mengel, J. T. Tracking the earth satellite and data transmission by radio. *Proc. IRE*, **44**, 755-760 (June, 1956).

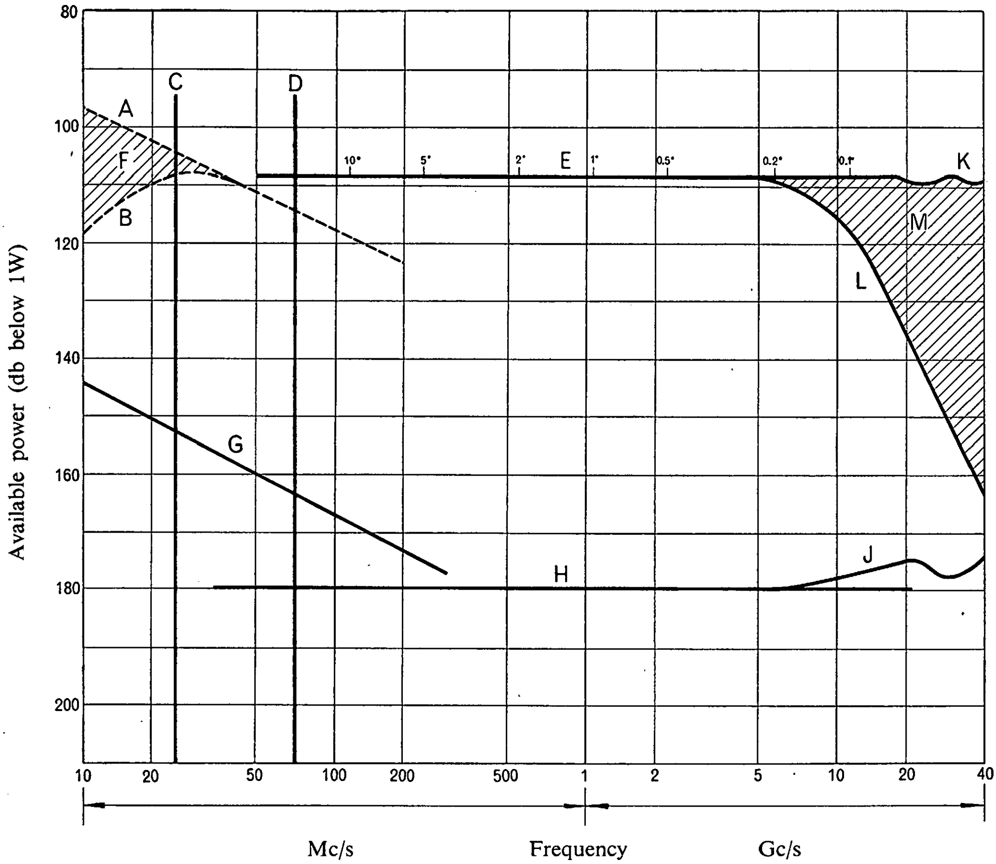


FIGURE 1

Chart illustrating the general frequency limits in a simple earth to spacecraft communication system

(Spacecraft: isotropic antenna, transmitter power, 1W, bandwidth, 1 kc/s, distance 1000 km)

Earth station antenna :

Paraboloid, diameter, 20 m, efficiency, 55% ——————

15 db gain above isotropic antenna — — — — —

A : Signal level during ideal night-time conditions (no absorption).
B : Typical signal level during day-time conditions assuming an angle of elevation of 5°.
C : Minimum frequency to assure penetration of earth's ionosphere: polar region-oblique path; tropical region-vertical path.
D : Minimum frequency to assure penetration of earth's ionosphere: tropical region-oblique path.
E : Beamwidth of paraboloid between half-power points.
F : Effect of ionspheric absorption.
G : Minimum cosmic noise. Maximum values will be found to be higher by about 15 db.
H : Noise level corresponding to a temperature of 70° K.
J : Noise due to absorption in a clear atmosphere, assuming an elevation angle of 5°.
K : Typical signal level for a vertical path in a clear atmosphere.
L : Typical signal level in heavy rain (16 mm/h), vertical depth 1 km, assuming an elevation angle of 5°.
M : Effect of varying atmospheric conditions and elevation angles.

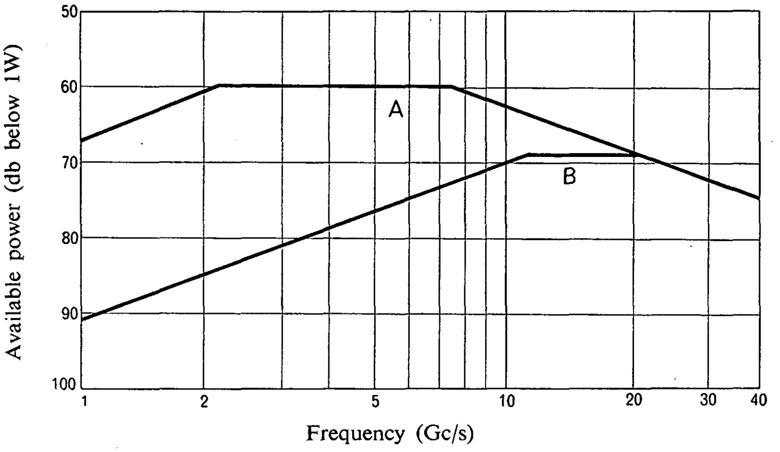


FIGURE 2

Variation of the available power, dictated by the physical size of antennae which have a fixed minimum beam-width requirement, as a function of frequency (1W - Free space — 1000 km)

Minimum beam-width: earth station antenna 0·1°
spacecraft antenna 1°

	A	B
Earth station antenna diameter limited to (m)	100	20
Spacecraft antenna diameter limited to (m)	3	1

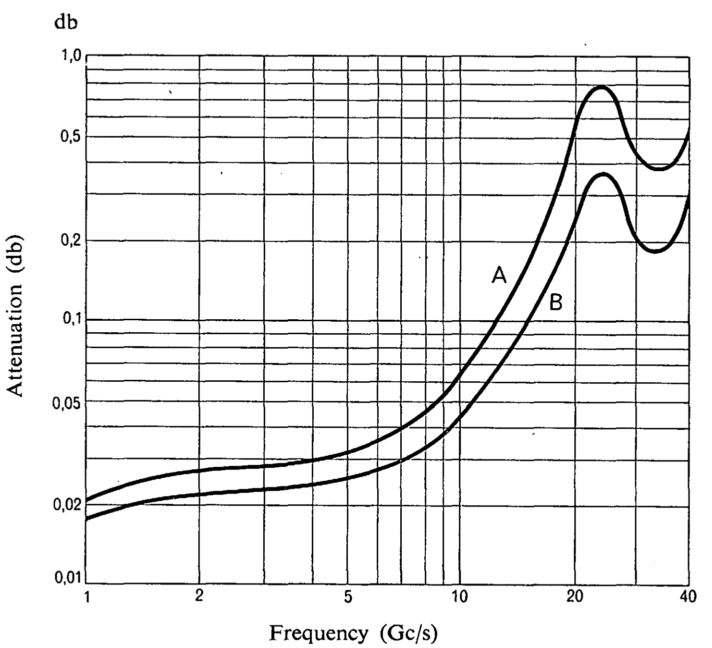


FIGURE 3

Theoretical one-way attenuation for a vertical path in a moderately humid area (Washington D.C. in August)

A: at sea-level
B: at 2 km above sea-level

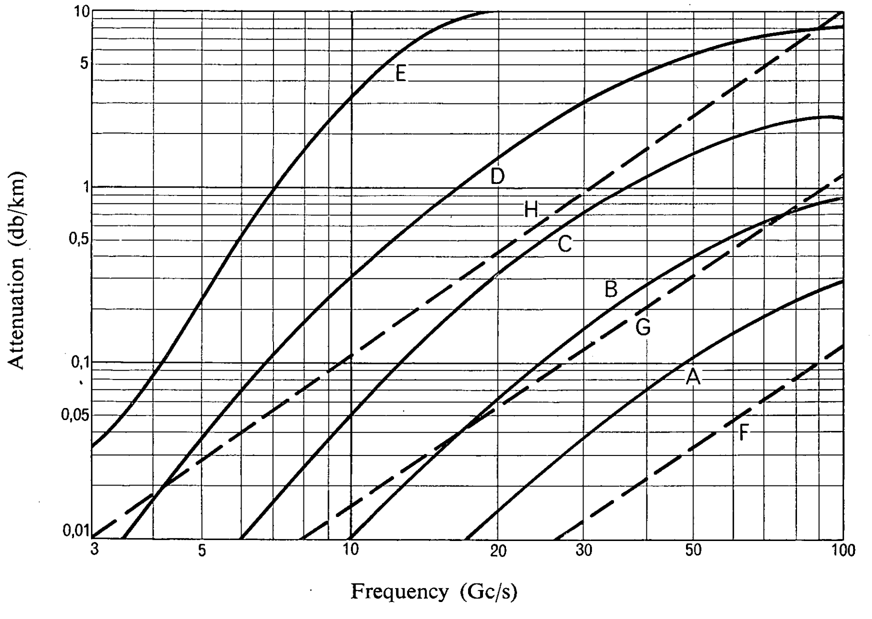
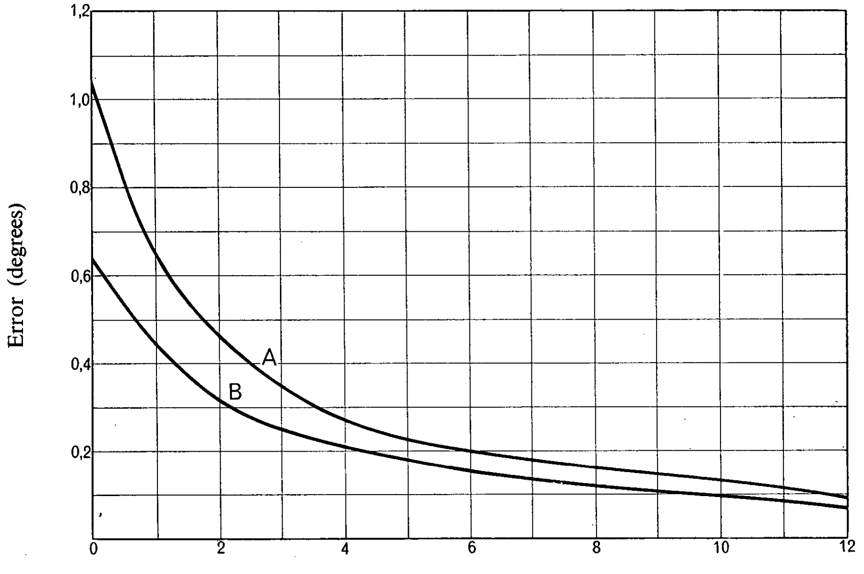


FIGURE 4

Attenuation due to precipitation

————————	Attenuation in rainfall of intensity:	*A*, 0·25 mm/hr (drizzle)
		B, 1 mm/hr (light rain)
		C, 4 mm/hr (moderate rain)
		D, 16 mm/hr (heavy rain)
		E, 100 mm/hr (very heavy rain)
— — — — —	Attenuation in fog or cloud:	*F*, 0·032 gm/m³ (visibility > 600 m)
		G, 0·32 gm/m³ (visibility about 120 m)
		H, 2·3 gm/m³ (visibility about 30 m)



Angle of elevation (degrees)

FIGURE 5

Error in angle of elevation due to tropospheric refraction

A : tropical maritime air
B : polar continental air

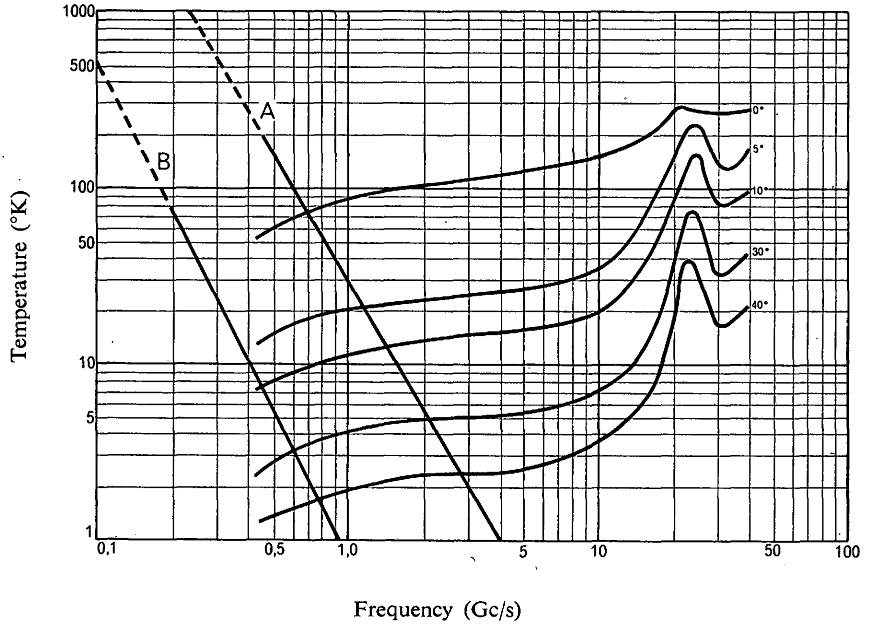


FIGURE 6

Apparent sky temperature due to background cosmic noise and atmospheric absorption for the angles of elevation indicated on the curves

A : maximum cosmic noise
B : minimum cosmic noise

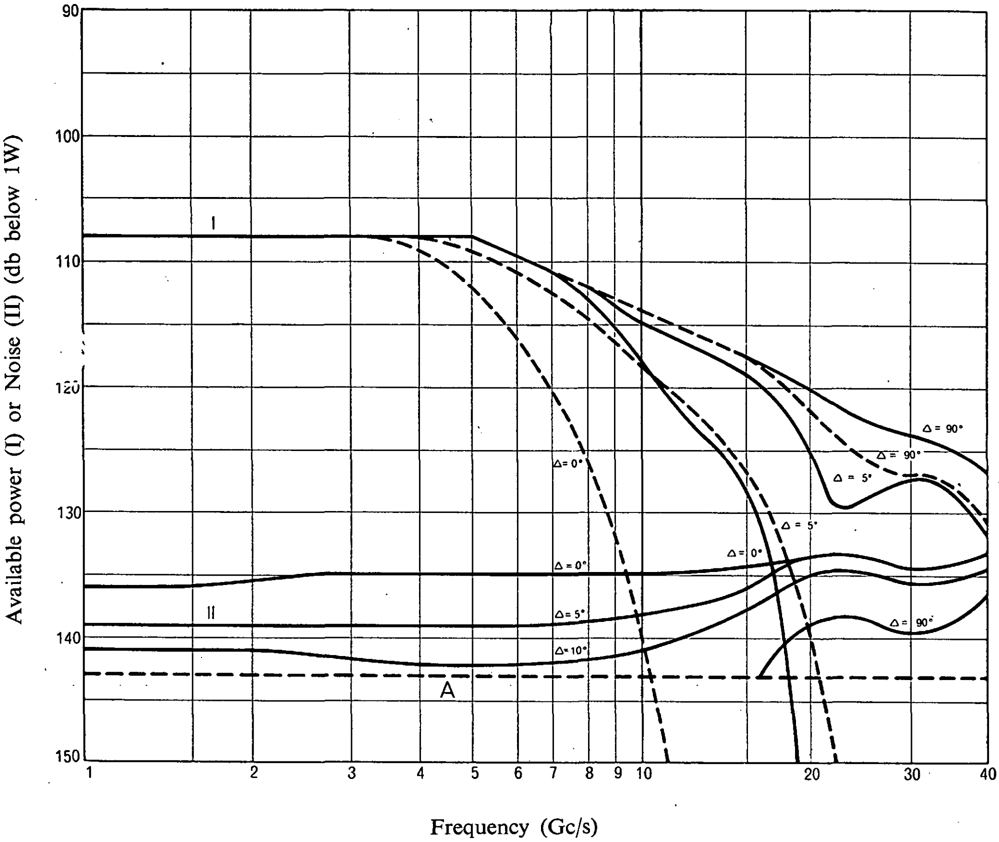


FIGURE 7

Theoretical signals and noise in a simple space radiocommunication system

Unstabilized satellite, 1000 km, 1W, earth terminal at sea-level

———————— Available signal, atmosphere typical of Washington D.C. in August

— — — — — Available signal, "Heavy" rainfall, 1 km in depth

Earth station antenna: maximum diameter, 20 m
minimum beamwidth 0·2°

Spacecraft antenna: isotropic

Bandwidth: 10 Mc/s

A : typical maser noise

Δ : angle of elevation of the earth-station antenna

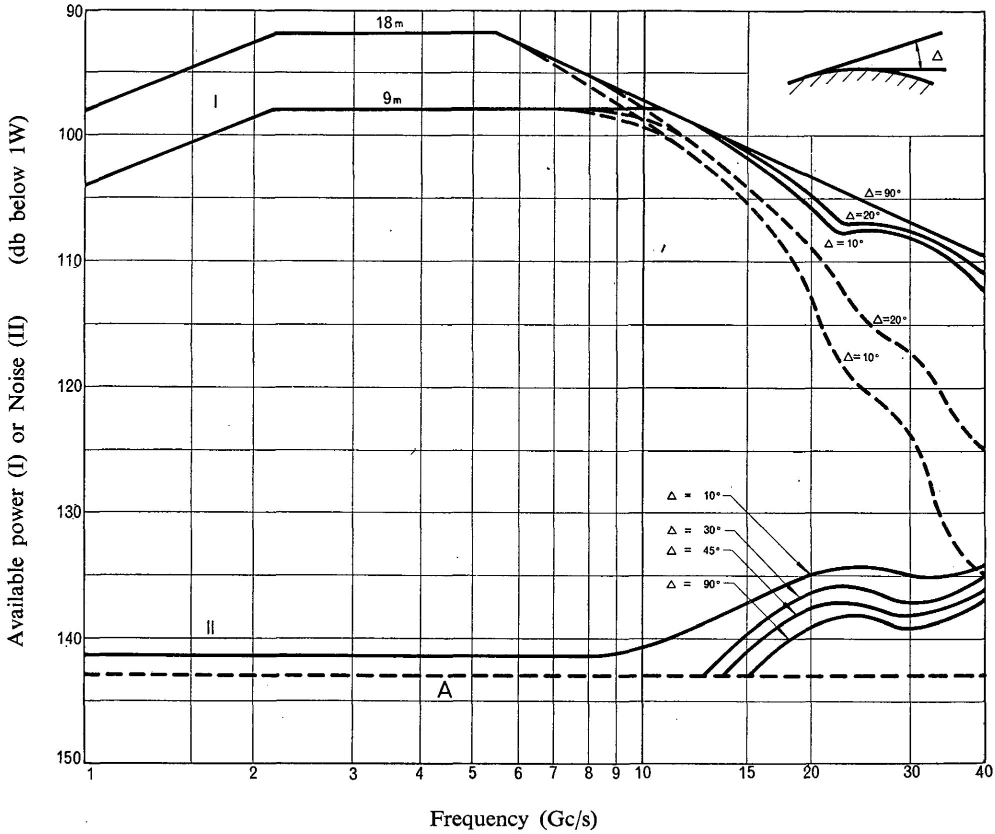


FIGURE 8

Theoretical signals and noise in a "typical" space radiocommunication system

Stabilized stationary, earth oriented, satellite, 2 kW, earth station at sea-level

——————— Available signal atmosphere typical of Washington D.C. in August

— — — — — — Available signal, "Heavy" rainfall, 1 km in depth

Earth station antennae: maximum diameters 18 m and 9 m
minimum beamwidth 0·2°

Spacecraft antenna: maximum diameter 5 m
minimum beamwidth 22°

Bandwidth: 10 Mc/s

A : Typical maser noise

Δ : Angle of elevation of the earth-station antenna

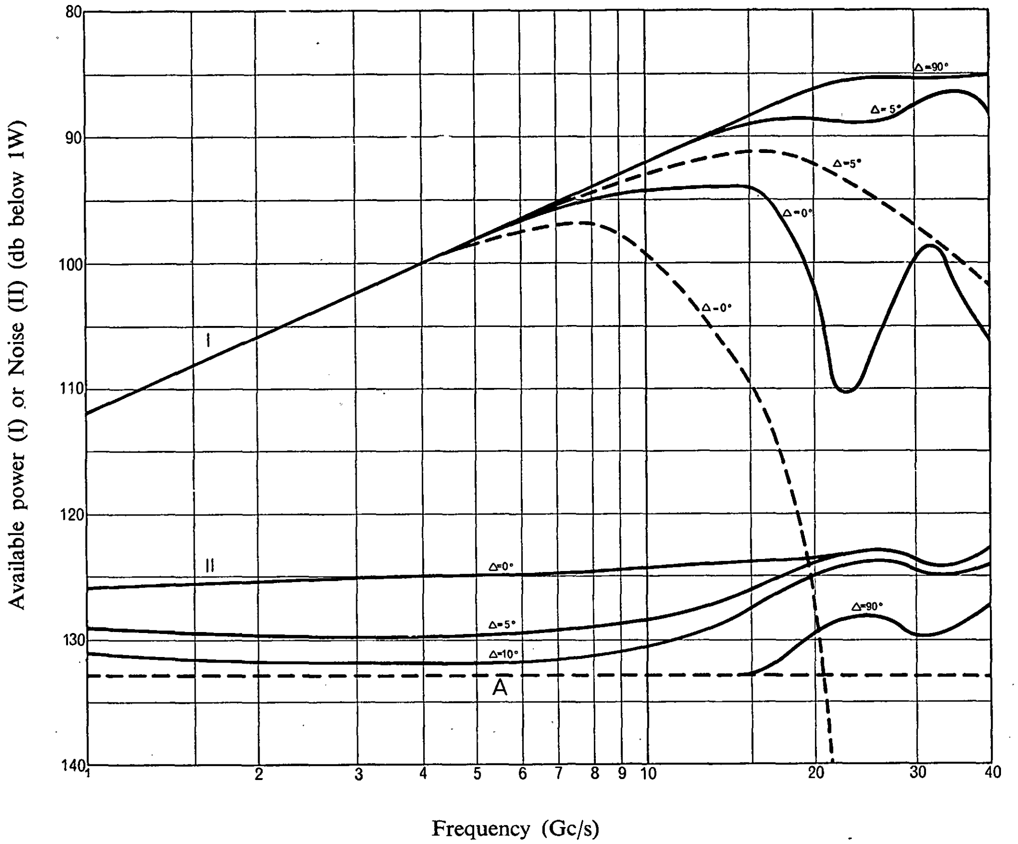


FIGURE 9

Theoretical signals and noise in a more elaborate space radiocommunication system

Stationary highly stabilized, earth oriented, satellite, 1W, earth station 2 km above sea-level

———————— Available signal, atmosphere typical of Washington D.C. in August

— — — — — — Available, "moderate" rainfall, 1 km in depth

Earth station antenna: maximum diameter, 20 m
minimum beamwidth, 0.05°

Spacecraft antenna: maximum diameter, 3 m
minimum beamwidth 0·2°

Bandwidth: 100 Mc/s

A : typical maser noise

Δ : angle of elevation of the earth-station antenna

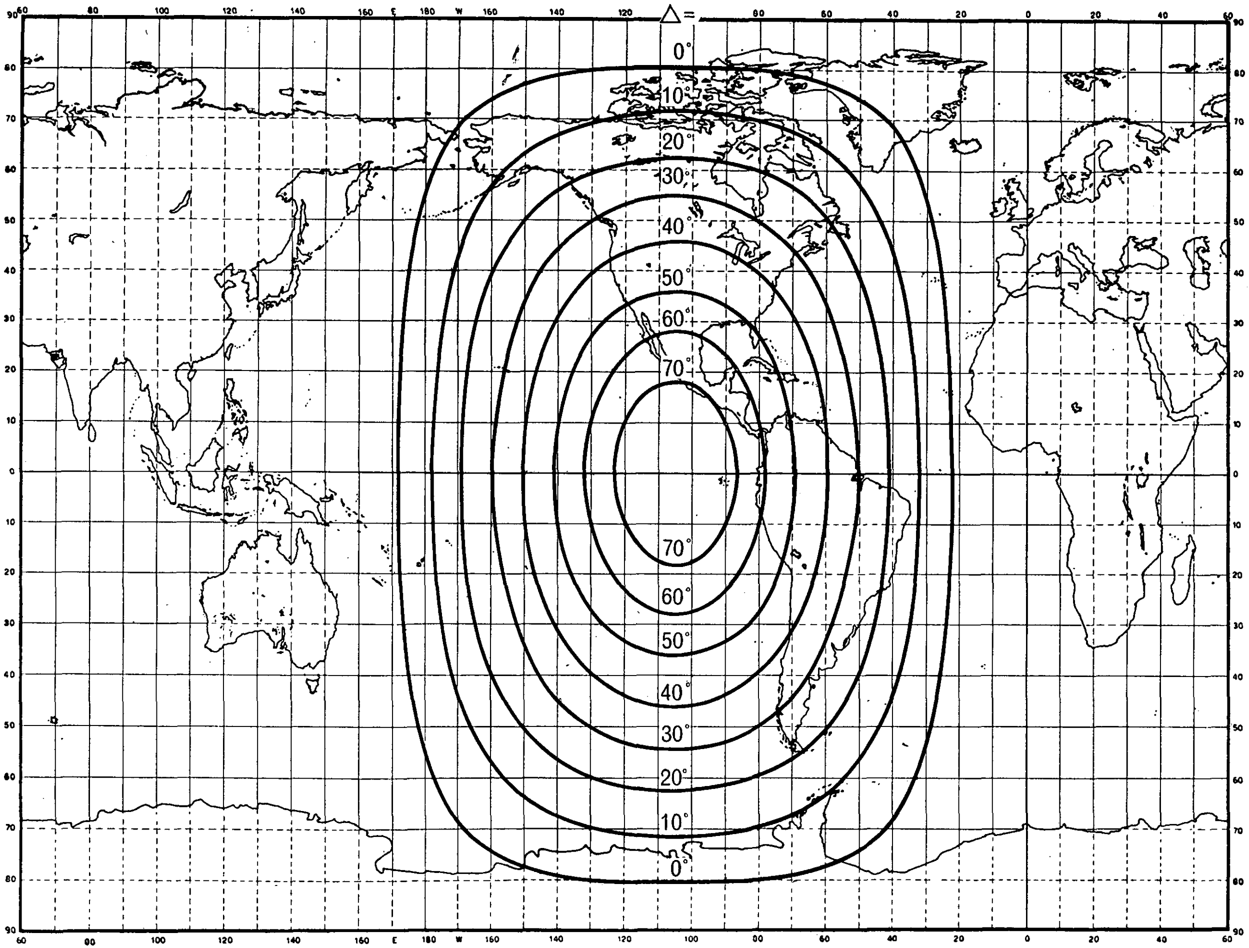


FIGURE 10

Chart showing a typical service area of a stationary satellite system

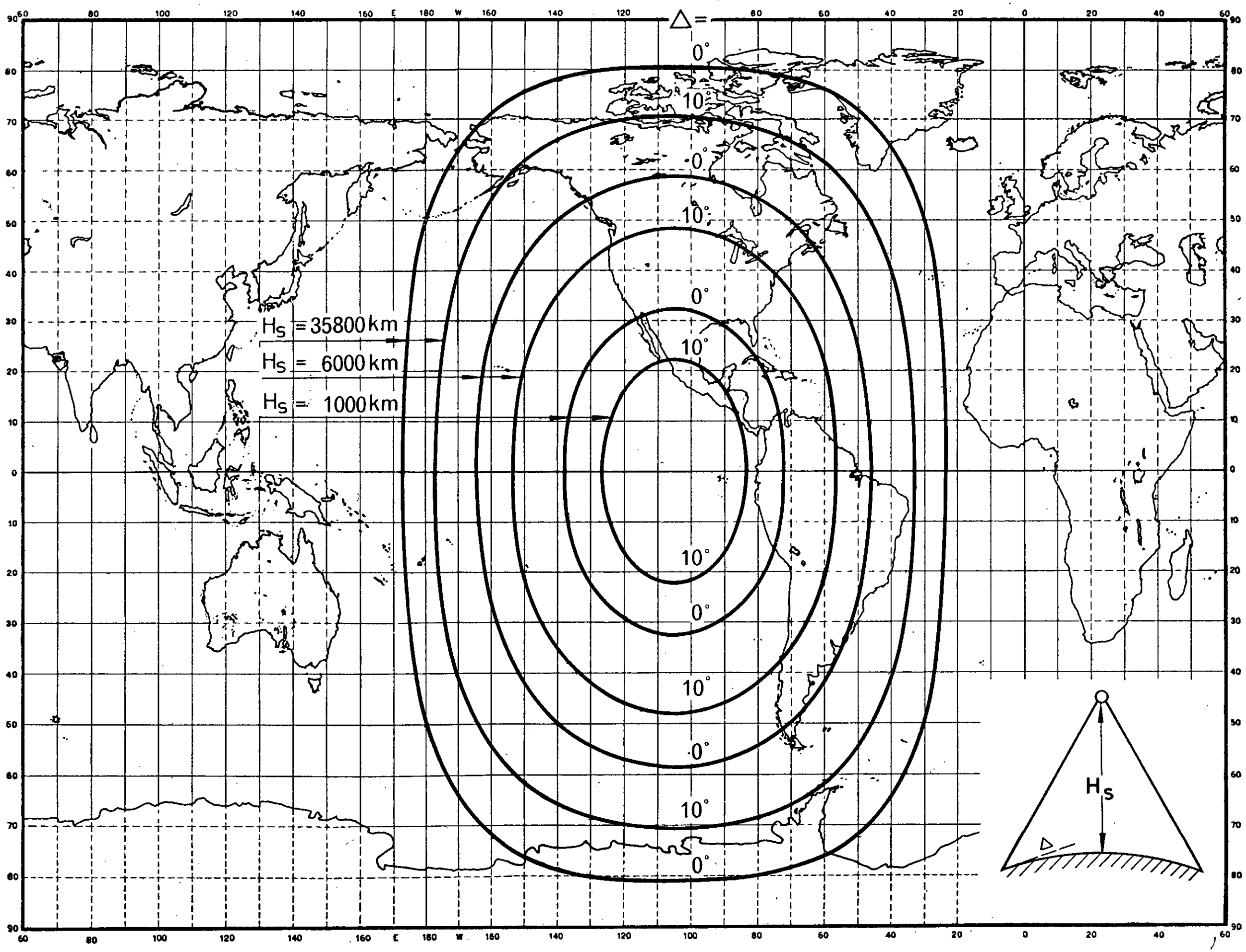


FIGURE 11

Chart showing the size of the typical service area as a function of the height of the satellite

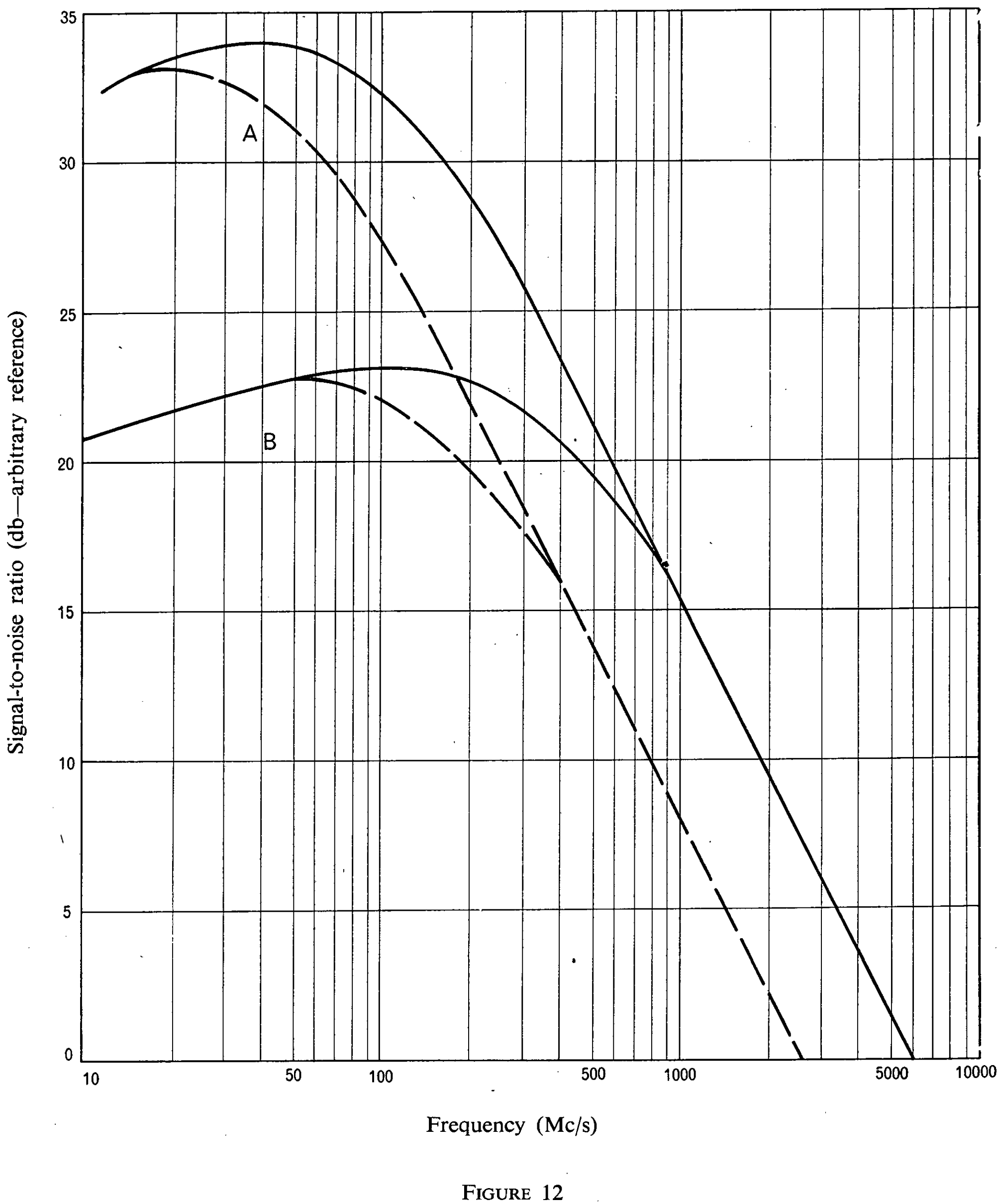


FIGURE 12

System signal-to-noise ratio for communication between spacecraft, both with omnidirectional antennae

——————— Receiver temperature 300°K

— — — — — — Receiver temperature 1500°K

A : minimum cosmic noise

B : maximum cosmic noise

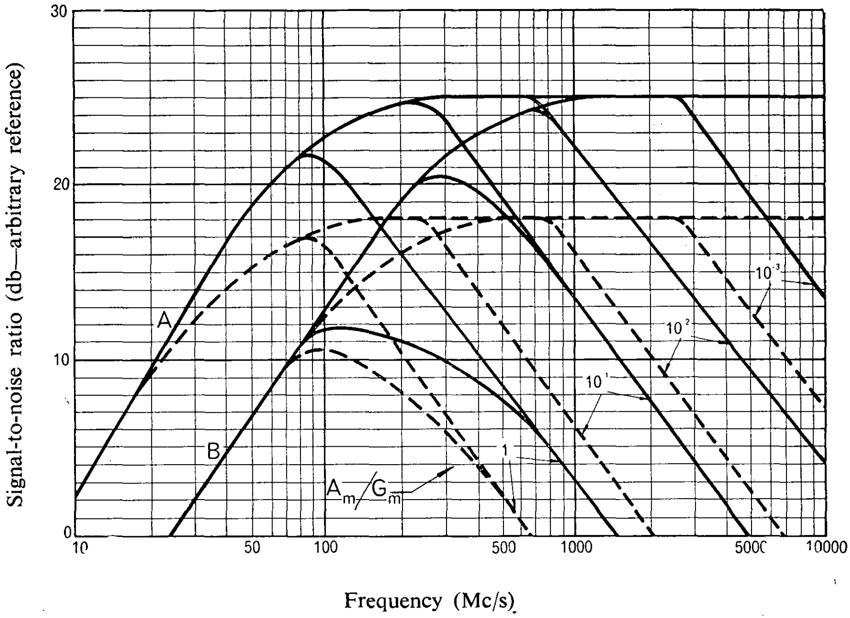


FIGURE 13

System signal-to-noise ratio for communication between spacecraft, one of which has a directional antenna

———————— Receiver temperature 300°K
— — — — — — Receiver temperature 1500°K
A: minimum cosmic noise
B: maximum cosmic noise

$$(A_m/G_m) = \frac{\text{maximum antenna surface (m}^2\text{)}}{\text{maximum antenna gain}}$$

L. 2 - Communication satellites

REPORT 206 *

COMMUNICATION-SATELLITE SYSTEMS

General considerations relating to the choice of orbit, satellite and type of system

(Question 235 (IV))

(Geneva, 1963)

1. Introduction

Various orbits and types of satellite have been proposed for communication-satellite systems; it is the aim of this Report to consider the characteristics, advantages and disadvantages of the various types of satellite system from the technical point of view. It should, however, be recognized that the choice of system or systems will depend not only on the technical factors involved, but also on operational, administrative and economic factors.

It is noted that, since the development of communication-satellite systems is necessarily an evolutionary process, and because all operational and transmission requirements may not be met by a single type of system, more than one system or type of system may eventually be incorporated into the world telecommunication network. The problems arising from the combination of communication-satellite systems on a technically compatible basis, so that they may be interconnected with one another and with other transmission systems, are outlined.

The use of communication-satellite systems in the world telecommunication network requires consideration of the type and volume of traffic (telephone, telegraph, data, television, etc.) to be accommodated, the routing of the traffic, the probable locations and capacities of earth stations and the overall performance required. Traffic aspects are a matter for the C.C.I.T.T./C.C.I.R. Plan Committee to consider; performance aspects of telegraphy, telephony and data transmission are matters for the C.C.I.T.T. to decide; the C.M.T.T. deals with television. These factors, nevertheless, have a marked influence on the design of communication-satellite systems: they determine, for example, the extent of the need for multi-station access, the capacities to be provided in satellites and the frequency requirements. The design of earth stations is also affected.

Finally, the present state of developments is reviewed, and an indication is given of matters requiring further study and investigation, with a broad indication of the possible time-scale of future developments.

2. Possible types of orbit

The possible orbits include circular and elliptical orbits in the equatorial and polar planes of the Earth, and orbits inclined at an angle to the equatorial plane.

The heights and periods of the orbits of interest for communication-satellite systems may be classified, for convenience, as follows:

— low-altitude orbits: heights from 1000 to 5000 km; periods from 2 to 4 hours (approx.);

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

— intermediate-altitude orbits: heights from 5000 to 20 000 km; periods from 4 to 12 hours (approx.);

— synchronous orbit: approximate height 36 000 km; period 24 hours.

The periods given are for circular orbits, and the heights are relative to the surface of the Earth.

It is assumed, with the synchronous orbit, that the satellites move from West to East, the period of 24 hours being the same as that of the rotation of the Earth on its axis. When such an orbit is in the equatorial plane of the Earth, the satellites are stationary since they appear to be motionless relative to observers on Earth. Synchronous inclined orbits are possible, but the satellites are then not stationary.

Sub-synchronous satellites have periods corresponding to an integral fraction of the period of rotation of the Earth; examples are as follows:

Approximate height (km)	20 000	14 000	10 500
Period (hr)	12	8	6

Random satellites are non-synchronous satellites, the height, orbital period, and orbital plane of which are established within a reasonable degree of accuracy, but which are not precisely controlled. Hence, there is relative motion, of a predominantly random value, between satellites.

Although orbits above the synchronous height of 36 000 km are possible, they have no significant advantages for communication-satellite systems.

Circular orbits in or near the equatorial plane of the Earth would have the advantage that perturbations of the orbits due to the oblateness of the Earth, and perturbations due to the Moon and Sun, are minimized, thus facilitating the use of station-keeping and attitude-stabilized satellites (see §§ 3.2 and 3.3).

Satellites in elliptical orbits move relatively slowly near apogee and are thus visible for longer times between certain pairs of suitably placed locations on the Earth, as compared with circular orbits of the same period; on the other hand the mutual visibility between other pairs of locations may be less. The elliptical orbit inclined at about 64° to the equator is of interest since the apogee remains at approximately the same latitude. These characteristics of elliptical orbits are of greater advantage for systems of regional, as opposed to world-wide, coverage; in the latter circumstance elliptical orbits show no special advantages and are at a disadvantage as regards satellite station-keeping. In addition, it would be difficult to use earthward-directed antennae efficiently on such satellites.

The higher orbits have the avantage of providing greater coverage of the Earth from each satellite, so that fewer satellites would be required for world-wide coverage. On the other hand, a more powerful rocket launcher would be required to put a given payload into the higher orbits. The use of circular equatorial, or near-equatorial, orbits in the West-to-East direction would enable larger payloads to be put into orbit than in the East-to-West direction, by taking advantage of the rotational velocity of the Earth. The use of only the equatorial plane with an equatorial launching site, as opposed to the multiple orbital planes required for polar or inclined orbit systems, would simplify the launching problem, provided that a satisfactory equatorial site is available.

To minimize the risk of damage to solar cells and other solid-state devices due to intense proton and electron radiation in the inner region of the Van Allen belt, it may be desirable, with a view to achieving long-life satellites, to avoid orbits passing through altitudes of from about 1500 to 5000 km in and near the equatorial plane, unless suitable radiation-resistant devices or screening methods can be devised.

The choice of orbital height is also important from the aspect of transmission delay over the earth-satellite-earth path (see Report 214).

3. Possible types of satellites

Satellites useful for communication may be classified as passive or active; stabilized or unstabilized; and random or station-keeping.

3.1 *Passive and active satellites*

Passive earth satellites may be either natural or made by man.

The only known natural satellite of the earth is the moon. Tests over a period of years have shown that, when time delay is not a controlling factor, e.g. telegraphy, the moon may be used successfully for transmission of information occupying a few kilocycles per second of bandwidth. The transmission losses encountered on an earth-moon-earth circuit are very large. Moreover, such a circuit is not continuously available.

Man-made satellites suitable for use in a passive satellite-communications system involve two principal approaches:

— comparatively large thin-walled structures which are inflatable in space;

— orbiting dipoles.

A passive satellite now in orbit is "Echo I". It was launched in 1960 into an approximately circular inclined orbit at an altitude of 1450 km and was inflated in space immediately after launch. It is a thin-walled 33 m diameter spheroid of aluminized mylar. In addition to other tests, it has been used to confirm propagation predictions and to demonstrate voice communications. Further launches and tests are to be made, using larger spherical passive structures which are less subject to deformation. Investigation also is continuing on methods of increasing the radio cross-section to mass ratio with the objective of improving the usefulness of passive satellites.

Consideration has been given to the placing of dipoles in suitable orbits. Being resonant, each dipole would reradiate signals which excite it. However, multi-path transmission from the various dipoles in the common volume illuminated by the transmitting and receiving antennae and Doppler shift effects, would place limitations on the use of this technique.

In general, passive satellites are less effective than active ones, because the overall transmission loss on the earth-satellite-earth path is appreciably greater than for active satellites.

In view of the high-powered earth station transmitters and limited overall transmission bandwidths characteristics of passive systems, attention now is being concentrated on active satellites for high-capacity systems.

3.2 *Attitude-stabilized satellites*

An attitude-stabilized satellite is designed to maintain one or more of its axes in a specified direction or directions, e.g. towards the centre of the earth or towards a fixed position in space. The simplest form of attitude stabilization is spin stabilization of the rotational axis. Spin stabilization may be passive (as in TELSTAR) or active (as in SYNCOM). In the latter case, pulsed gas jets can be used to correct both the spin axis and perturbations of the orbit. With active spin stabilization, a phased antenna array can produce an earth-directed antenna beam.

Three-axis stabilization of a non-spinning satellite permits directing conventional antennae toward the earth, and orienting solar cell panels toward the sun. Earth-directed satellite antennae provide gain which helps overcome the greater path loss associated with higher orbits. Without satellite antenna gain, more powerful transmitters and larger launching vehicles would be needed.

The development of techniques and equipment to provide attitude-stabilization systems of long life and high reliability present major problems. These problems may be somewhat reduced by use of circular equatorial orbits, due to the smaller perturbations experienced in such orbits.

Satellites which are not attitude-controlled or which are spin-stabilized are less complex, hence offering the advantages of simplicity in design and operation, and the probability of longer useful life in orbit.

3.3 *Random and station-keeping satellites*

Proposals have been made for the use of satellites distributed at random in a variety of orbits. Random satellites may be either active or passive, and could be attitude-controlled.

A station-keeping satellite is one the position of which, relative either to other satellites in the same system or to a point on earth, is maintained within given limits. Such satellites could be, and in general would be, attitude stabilized.

The advantages of random satellites as compared with station-keeping satellites would be greater simplicity of design and operation, and the probability of a longer useful life in orbit. On the other hand, fewer station-keeping satellites would be needed to provide a given quality of communication service, and simplify system operation.

4. Possible types of communication-satellite system

4.1 *Random satellite systems*

Broadband telecommunication by means of satellites similar to those which might be used in a random satellite system has now been successfully demonstrated and extensively tested. The extension from this stage to a world-wide operational system would not require the use of any basic new techniques or principles. This type of satellite system offers the means to proceed with an operational system at the earliest possible date.

An appreciable number of satellites, each carrying one or more broadband microwave repeaters, are needed to provide high continuity, world-wide service. However, useful service can be started with a small number of satellites, with the service being extended when needed by the addition of more satellites. Because of their simplicity, the individual satellites would be the cheapest of the various types and it is likely that three or more could be launched with a single rocket of current type.

For example, with some 12 to 18 such satellites, in orbit at heights of about 11 000 km, a substantial amount of telecommunication service would be possible. In fact, service would be available for 95 to 99% of the time between North America and Europe. With expansion to 48 random satellites, e.g., 24 in a polar orbit and 24 in a nearly equatorial orbit, service would be available over 99% of the time over most of the major communication routes of the world.

The above-mentioned possibilities could be achieved from existing launching sites. It may be noted that a random satellite system which includes polar orbits is the only one of the systems commonly proposed which is capable of complete world-wide area coverage. In a random satellite system, the statistical distribution of satellite positions is such that the failure of one, or a few, diminishes the reliability of service only a little.

The wide-band repeaters tested in random satellites are capable of carrying one broadband telecommunication channel or a number of narrower-band channels. This makes it possible to serve both large and small earth stations, or groups of stations, as desired.

The earth station antennae for a random satellite system must be able to follow the satellite across the sky, but experience has shown this to be easier than originally expected. Future stations can be simpler than today's experimental stations. Coordination between earth stations is required but, fortunately, the positions of satellites can be predicted in advance for extended periods. Information on satellite positions and their assignment to particular communication paths can be determined and shared among the earth stations well ahead of time.

The time delay introduced into communication links routed via random satellite systems at intermediate altitudes, will be substantially less than that of a stationary satellite and in some instances would be less than in a sub-synchronous satellite system.

4.2 *Sub-synchronous satellite systems*

Sub-synchronous satellite systems would use station-keeping satellites with orbital periods corresponding to an integral fraction of 24 hours, e.g., 6, 8 or 12 hours. Such systems enable antipodal distances to be spanned with maximum one-way transmission delays of some 300 ms. In the sub-synchronous system appreciably fewer satellites would be required for continuous service than would be needed for a random satellite system.

As an example, it may be noted that, using the 8-hour sub-synchronous equatorial orbit, 10 to 12 satellites could provide continuous coverage around the world between the latitudes 60° N and 60° S. If the orbital period is exactly 8 hours, each satellite would be visible to a given earth station twice per day at the same local times each day. The world-wide coverage of such a system could be divided into seven overlapping zones, each spanning about 70° of longitude and up to 4½ hours of local time. All stations in a given zone could use the same satellite at the same time, the period of use, one hour, of that satellite being denoted by an "active arc" for that zone. All the stations in a given zone would be in single-hop communication with each other, and most intercontinental connections could be established via not more than two satellite links joined in tandem via an interconnection earth station.

It is to be noted that the zoning principle would also be useful for television relaying, since each zone of some 4½ hours time difference corresponds approximately to a convenient maximum difference of time which could normally be accommodated by "live" television broadcasts. Each zone could, if desired, transmit different television programmes; on the other hand, world-wide television links could be established via interconnection earth stations.

A useful feature of such a system is that it would offer a measure of redundancy, although less than in a random system, which could be used if necessary, to provide partial but immediate compensation for the failure of one or more satellites. As a faulty satellite passes over each zone, many of the circuits within that zone could continue to operate by using adjacent satellites while they are traversing those parts of the orbit not normally regarded as active.

The choice of an orbital period of an integral fraction, e.g. one third of 24 hours, would be operationally convenient for the following reasons:

— when partial coverage is acceptable, e.g. in the initial stages of setting up a system, such partial converage would be available at fixed times of the day;

— additional satellites could be injected into a fully equipped system to cover peak traffic periods over specific areas of the world, e.g. over the transatlantic path;

— breaks in transmission due to the failure of a satellite would occur at the same time each day, thus facilitating the re-scheduling of traffic;

— the useful periods for each satellite and pair of co-operating stations would occur at the same time each day, thus facilitating regular hour-by-hour automatic switching from satellite to satellite.

The use of an orbit in the equatorial plane would facilitate satellite tracking, since the various satellites, when viewed from a given earth station, should follow identical tracks.

Since the range of azimuthal and elevation angles to be covered from a given earth station is limited, steerable antenna design is facilitated and terrain screening can be employed in varying degrees to minimize interference to and from terrestrial radio services.

The twelve satellites in such a system could use the same frequency assignments.

It is estimated on the basis of postal data for 1958, that, in a world-wide satellite system using the sub-synchronous 8-hour orbit, less than 18% of telephone connections would involve transmission delays of more than 250 ms and only 3% would involve mean delays exceeding 360 ms (see Report 214).

4.3 *Stationary satellite systems*

From a stationary satellite, the earth subtends an angle of approximately 17½ degrees, which corresponds to a maximum great-circle earth distance of approximately 17 000 km, assuming a minimum elevation of 5° for the earth station antenna. The corresponding area of the earth, from which a stationary satellite would be visible at an antenna elevation of 5° or more, is approximately a third of the earth's total area. All earth stations within this area could use this satellite continuously, without periodic hand-over from a setting satellite to a rising one, as will be required for satellites in any non-synchronous orbit. Moreover earth stations could use fixed directional antennae, having very limited beam-steerability. Such antennae can be simpler and less expensive than the multiple installations of steerable antennae which are needed with all other satellite systems.

The distance from a stationary satellite to its farthest earth stations will be about 42 000 km, requiring about 140 ms for propagation between such a station and the satellite. Thus, allowing for additional delay in associated terrestrial communication circuits, telephone conversations via a stationary satellite may have round trip delays of about 0·6 s.

To the extent that the satellite is stationary, this delay time is constant and Doppler frequency shifts would be negligible. The small amount of Doppler shift should facilitate the use of single-sideband modulation systems which, in turn, can facilitate flexibility of interconnection between earth stations.

The stationary satellite is also unique, in that the first such satellite can provide essentially uninterrupted service to earth stations located within a third of the earth's area. The first such satellite might be placed at longitude 50°, over the delta of the Amazon River, from where it could be used from all of South America, most of North America and Western Europe, a large part of Africa and even from parts of Greenland and Antarctica. A second such satellite might later be placed over the Indian Ocean, thus covering all of Europe and Africa, plus much of Asia. Additional satellites probably would be added to the stationary orbit, as needed, until they girdled the earth. Thus, in time, most earth stations could have access to two or more satellites, for long easterly or westerly routes. For example, with only two satellites at the locations mentioned above, stations in Europe and Western Africa would have access to both and would have one-hop coverage of about two-thirds of the earth.

To maintain a stationary satellite in a fairly precise position and to maintain its attitude so that the antennae are always pointing towards the earth, requires additional complexity over a random unstabilized satellite which could reduce reliability. Also, launch vehicles having greater thrust and more accurate guidance systems are required for orbital injection than are necessary for low or intermediate altitude random orbit systems. The extent of the problems, and the effort required to solve them, can only be determined as further experimentation is carried out.

4.4 *Integrated satellite systems*

Since the development of satellite systems will be an evolutionary process, it is likely that more than one system or type of system, will be used operationally in the world communication network, the earlier systems being of relatively simple design, and the later ones of greater complexity, providing increased satellite capacity and larger numbers of earth stations to accommodate expanding traffic requirements. Furthermore, transmission considerations, and in particular the problem of transmission delay, may indicate a need for both intermediate-altitude and stationary satellite systems.

It is convenient to use the term "sub-systems" to describe the individual elements forming part of an integrated communication-satellite system. For example, a stationary satellite system might form one such sub-system, and an intermediate-altitude system a second sub-system.

It is considered desirable, for the following reasons, that the various sub-systems be developed and established on a planned and integrated basis:

— to avoid mutual interference between the sub-systems;

— to achieve the maximum practicable degree of technical compatibility between the sub-systems;

— to ensure the possibility of interconnection, both between the sub-systems and with terrestrial transmission systems;

— to enable the capacities of satellites and earth stations to be increased as the traffic expands, with a minimum of additional equipment at earth stations;

— to avoid, as far as possible, obsolescence of earth station equipment and satellites.

The avoidance of mutual interference between sub-systems will require a suitable choice of radio-frequency channel assignements on an internationally agreed basis. It may also necessitate a selection of orbit configurations to minimize difficulties due to satellite eclipsing.

A degree of technical compatibility between sub-systems would help to minimize the amount of equipment of different designs required at earth stations and avoid equipment obsolescence. For example, steerable antennae provided to accommodate random satellites or the limited range of azimuthal and elevation angles needed for an intermediate-altitude equatorial orbit satellite system could also be used for a stationary satellite system. In another example, satellites in different sub-systems might use similar modulation characteristics so that earth station transmitting and receiving equipments would be interchangeable.

The interconnection of communication satellite sub-systems with one another, and with terrestrial transmission systems, will be facilitated by compatible standards of transmission performance and of baseband characteristics, e.g. of the video bandwidth for television and the multiplexing arrangements for multi-channel telephony and telegraphy.

Attention will also be needed to the problem of accommodating traffic growth and providing for increased numbers of earth stations, without involving obsolescence either of earth station equipment or of satellites. In this connection there would be advantages in replacing satellites which have failed by satellites of increased capacity, but of compatible design, in the same orbits.

5. Communication-satellite systems in the international telecommunication network

5.1 *General considerations*

The expansion of the international telecommunication network on a world-wide basis is proceeding at a rapid pace. Terrestrial-type plant will provide for this expansion during the next few years at present rates of growth. It is envisaged, however, that a sharp increase in these rates of growth is probable, particularly with improved service and automatic operation of the telephone and telegraph circuits. The large blocks of international circuits, which will be required, could be supplied by a communication-satellite system or systems. These will supplement the facilities already available between major traffic centres. In addition to the requirement for large groups of trunks between major traffic centres, it is envisaged that communication-satellite systems will provide access to remote points in the world having relatively low traffic density. Such facilities, it is hoped, will thus supplement the present HF radio network facilities and give a significant improvement in the quality of service.

The C.C.I.T.T. will consider, at its next Plenary Assembly in 1964, plans which have been developed for a world-wide telephone network employing semi-automatic and automatic type operation. This involves a numbering plan, a routing plan and a transmission plan for such world-wide service. The international circuits required for the plan will join together the national networks throughout the world in a global telecommunications network. Communication-satellite systems could be an important contributor to these facilities, particularly for the very long international circuits between continents. At the same time the C.C.I.T.T. plan will set up requirements and limits which should be met by the communication-satellite facilities for the world-wide service.

It is possible that the unique features of communication-satellite systems may suggest alternative arrangements of the world plan. As presently envisaged by the C.C.I.T.T., this is a hierarchy of world switching centres through which traffic is routed to its destination. Communication-satellite systems could provide direct access to widely separated points throughout the world, possibly by-passing many of these switching points. However, it is too early to estimate the significance of such factors in the world routing plan, but they clearly will require study.

The estimates of the international traffic and its routing, requested by the C.C.I.R. from the C.C.I.T.T. / C.C.I.R. Plan Committee, will provide a basis for communication-satellite system planning.

5.2 *Performance of satellite systems*

A large background of experience in telecommunications has been built up throughout the world, based on terrestrial systems. This experience has been brought together and made available through the constituent organs of the I.T.U. Circuits derived from communication-satellite systems should conform to these recommendations so that they can be used in international connections on a world-wide scale.

While various types of circuits derived from terrestrial systems differ considerably in their characteristics, a fact which is recognized and accepted, the circuits derived from communication-satellite systems will have some unique characteristics. These arise primarily from the great distances traversed by the signals in going from earth to satellite and back to earth. The time delay involved in transmission via satellites is very large, compared to terrestrial systems, and introduces new and significant problems (see Report 214). It is important to note that the problem does not arise to any significant extent with one-way transmission systems such as are involved in point-to-point telegraph, and facsimile services. Performance characteristics of satellite circuits with respect to noise, transmission loss and stability are similar to terrestrial circuits and do not present unusual problems.

5.3 *Routing and multiple access*

The world routing plan of the C.C.I.T.T. for telephony proposes a hierarchy of international switching points through which traffic is routed to its destination. These international traffic centres (CT) are of three grades designated CT1, CT2, and CT3 respectively. The highest ranking centres (CT1) are completely interconnected by direct international circuits. Since the number of CT1 centres will be small (possibly 8 to 10), the circuits interconnecting them will be very long intercontinental facilities. Each CT1 will serve a region and will be connected to lower ranking CT2 centres. Since each CT1 region will be of continental proportions the circuits from CT2 to CT1 may also be very long.

Communication-satellite systems will provide circuits of the length and in the quantity required for the interconnection of major traffic centres such as CT1's. It would also be expected that they could provide many of the CT2 to CT1 circuits. In addition to these basic circuits, the routing plan would include and encourage the provision of direct circuits between any two points having sufficient traffic volume. These latter circuits would by-pass some switching points and thus provide better service. Such direct circuits could also be provided by communication-satellite systems.

The proposals which have been made for communication-satellite systems having multiple access and facilities for interconnection offer a very effective means of obtaining circuits of the types indicated above. Such systems make it easier to justify direct circuits between points of low traffic density with consequent improvement in service. However, it is important to note that the facilities for interconnection referred to simply provides direct point-to-point circuits, as required, in a more economical manner. Communication-satellites are unlikely to provide for some time to come the complex functions usually associated with a telephone switching apparatus such as a major traffic centre (CT) would have.

6. Future developments

6.1 *Present state of development*

Since 1958, the technology of communication-satellites has been explored with projects involving active satellite systems, such as SCORE, COURIER, TELSTAR and RELAY and those involving passive systems, such as "Echo I" and "Westford". In addition, a considerable amount of effort has been devoted to studies, space research projects, and equipment development programmes, which have contributed to the advancement of communication-satellite technology. Since satellite communications are, in effect, another form of the broad area of communications, much of the technological advancement achieved by work in such areas as line-of-sight radio-relay and tropospheric-scatter can be applied.

In general, the following significant technical achievements have been demonstrated, either under actual environmental conditions or under simulated laboratory conditions:

— the ability to launch and inject useful payload weights into precise circular or elliptical inclined orbits;

— the ability to pass useful information bandwidths through communication-satellites, including telephony, telegraphy, wideband data and television;

— the ability to design and build long-life, reliable components capable of withstanding the launch and orbital environment, including light-weight high-efficiency radio frequency power amplifiers in the frequency range up to 10 Gc/s and having a power output up to about 10 W;

— the ability to design and build large highly accurate antenna structures capable of oper; ation up to 10 Gc/s, and capable of automatically tracking satellites with high precision-

— the ability to design and build receivers having very low inherent noise in the frequency range up to 10 Gc/s and beyond.

6.2 *Additional information required*

While past work has advanced the technology to the point where the feasibility of satellite communication systems has been demonstrated, considerable work remains to be done to assure the development of an economic operational system, including:

— to obtain information on the location, type and strength of damaging radiation and its variation with time;

— to increase further the life expectancy of satellites through circuit design techniques, mechanical design improvements and component improvements;

— to achieve reliable control and stabilization of attitude;

— to achieve reliable positional control in orbit;

— to develop accurate and reliable methods of launching multiple satellites with a single launch vehicle;

— to develop reliable methods of placing heavy pay-loads into precise, high equatorial orbits;

— to obtain information on the significance of time delay due to long transmission paths, and appropriate corrective measures for echo;

— to develop methods of controlling the flow of information and the use of facilities, particularly in systems with facilities for multi-station access and interconnection.

Other developments which would contribute to improvement of operational communication satellite systems include:

— ion engines for better attitude- and station-keeping, and possibly, injection into orbit;

— nuclear power supplies;

— electronically steerable antennae;

— improvements in radio-frequency power amplifiers;

— inter-satellite relaying

6.3 *General time scale*

Much information on the above problems will be obtained during the course of experiments planned or being carried out at the present time. For example, the SYNCOM programme will explore means of placing pay-loads into synchronous equatorial orbits and will use spin-stabilization of the satellite while obtaining the advantages of a directive antenna. Additionally, a number of scientific satellites will be launched during the next two years to investigate the radiation problem.

Generally speaking, it is probable that developmental launches, as distinguished from experimental launches, designed to lead to an operational satellite communication system of the random type or spin-stabilized stationary type will not begin until 1965. Developmental launches leading to fully stabilized stationary or suitably phased sub-synchronous operational satellite communication systems will probably not begin before 1967. At the present stage of development, any estimate of time scale is highly dependent on such variables as technological break-throughs and unforeseen development problems.

REPORT 207 *

ACTIVE COMMUNICATION-SATELLITE EXPERIMENTS

Preliminary results of tests and demonstrations

(Question 235 (IV))

(Geneva, 1963)

1. Introduction

The active satellite TELSTAR, designed and constructed by the Bell Telephone Laboratories, was successfully launched by the United States National Aeronautics and Space Administration (N.A.S.A.), on 10 July, 1962. Three earth stations, situated respectively at Andover (U.S.A.), Goonhilly Downs (United Kingdom), and Pleumeur Bodou (France), took part in the first transmission tests via this satellite and the station at Fucino (Italy) took part later.

Subsequently, N.A.S.A.'s active satellite RELAY, built for them by R.C.A., was put into orbit on 13 December, 1962, when a further successful series of tests was made in which the stations at Nutley (U.S.A.) and Rio de Janeiro (Brazil) took part, in addition to the four already mentioned.

Although the results described in this Report were obtained with TELSTAR, similar results were obtained with RELAY, commencing at the beginning of 1963, but they are not included in this Report.

Other projects, such as SYNCOM, are expected to be carried out in the near future.

2. The Telstar satellite, its orbit, and the cooperating earth-stations

2.1. *The* TELSTAR *satellite*

The TELSTAR satellite was launched into an elliptical orbit with a perigee of 950 km and an apogee of 5700 km, the orbital plane making an angle of about 45° with the equatorial plane. The orbit obtained is very close to the one planned.

Spherical in shape, and weighing about 80 kg, the satellite receives frequency-modulated signals at about 4 Gc/s and, after amplification and frequency-change, retransmits them at about 6 Gc/s with a power of about 2 W. The antennae are omnidirectional around the spin axis, with nulls in the radiation pattern along the axis. Two beacons, operating at 136 and 4080 Mc/s, are used to acquire and track the satellite. The power supply is provided by solar cells which cover the outer walls of the satellite. In addition to the telecommunication tests, it has also been possible to make measurements of a scientific nature concerning the space environment.

2.2 *The Andover and Pleumeur Bodou earth-stations*

Each of these stations has a steerable horn antenna weighing about 350 tons with a circular aperture 20 m in diameter, protected by a weather-proof radome 65 m in diameter. The antenna has particularly low noise characteristics and a very narrow beam. Each station is equipped for acquisition tracking on 136 Mc/s and precision tracking on 4080 Mc/s. The antenna can be directed from separate tracking antennae, from computed predictions of satellite path, by automatic tracking, or by a combination of these methods.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

2.3 *Goonhilly earth-station*

The Goonhilly antenna consists of a steerable parabolic reflector with a diameter of 25 m, the moving part weighing about 870 tons. The source of illumination is situated in the plane of the aperture and it is so designed as to ensure both good directivity and good protection against noise. The heavy, robust structure of the antenna has made it possible to dispense with a radome, but it nevertheless can operate under winds of up to 100 km an hour. The steering of the antenna is programmed from perforated tape, fine correction of the beam direction being produced by movement of the feed near the focus using the 4080 Mc/s beacon signal.

3. Summary of the results obtained

3.1 *Propagation and noise*

The strength of the signal received is close to the calculated values. From the time of acquisition and until an angle of elevation of about 3° is reached, the signal power fluctuates considerably; for angles of elevation above about 5° operation is very satisfactory and stable.

According to the measurements made at Pleumeur Bodou, the equivalent temperature of the system, measured at the zenith before and after each passage of the satellite is, on average, 34°K. In 90% of cases, it does not exceed 40°K and in 99% of cases it is less than 80°K. In good weather the noise temperature, for an elevation of 3°, is 2·5 db above the temperature at the zenith. Measurements at Andover have shown similar results.

3.2 *Orbital prediction and tracking*

The accuracy of the data supplied by the N.A.S.A. to the various stations has steadily improved since the launching of the satellite and is now a few minutes of arc; it is thus possible to programme the steering of an antenna with a beam aperture of 10 minutes of arc. The auto-tracking systems of the Andover and Pleumeur Bodou antennae have a steering accuracy of the order of one minute of arc.

3.3 *Modulation method*

The tests have confirmed the value of wide-deviation frequency modulation, the radio frequency bandwidth of the signal being about 20 Mc/s and the baseband about 5 Mc/s wide.

3.4 *Transmission tests*

3.4.1 *Telephony tests*

High-capacity telephony tests were made by loading the system with noise equivalent to 600 channels; in this way it was possible to measure the thermal and intermodulation noise of the system. The measurements showed that the performance of the system was very satisfactory and revealed the advantages of pre-emphasis.

Thermal and intermodulation noise tests were also made on a 12-channel two-way basis. These tests were also satisfactory and many subjective demonstrations have been carried out.

In addition, operation with a greatly simplified earth station with a small antenna, providing a single telephone channel, has been demonstrated.

3.4.2 *Television tests*

The television transmission tests provided spectacular demonstrations. Shortly after the satellite went into orbit, television pictures were transmitted and shown on the networks of the various countries taking part in the tests. Numerous technical tests were then made, giving proof of the excellent transmission performance of the circuit for television test signals.

Colour television tests with the N.T.S.C. system were made from Goonhilly and Andover, these also gave satisfactory results.

3.4.3 *Telegraphy and data transmission*

Tests have been made with many different low speed and high speed telegraph and data signals. Here again, the transmissions were successful. As an example, only one error occurred in a data transmission at great speed (875 000 bits/second) lasting 20 minutes (i.e. 10^9 bits).

3.4.4 *Phototelegraphy tests*

Phototelegraph transmissions were successfully made and a study was carried out of the effect of variations in group delay.

3.5 *Scientific experiments*

Apart from its strictly telecommunication results, TELSTAR has provided much scientific data, such as:

— measurement of proton and electron fluxes of various energies; these measurements gave detailed information on the structure of the inner Van Allen belt and its variation with time;

— measurement of the effect of radiation on solar cells, diodes and transistors of various types, protected by shielding of different thicknesses.

4. General conclusions

Tests with the experimental active communication satellite TELSTAR have shown that it is capable of transmitting the wide range of types of signal that are in common use and that the performance in all cases approaches the appropriate international standards.

The tests have also shown the possibility of accurately predicting the position of a satellite and of satisfactory tracking with very large antennae. At the experimental stations, this has been possible as soon as the satellite elevation is more than about 5° above the horizon.

Although evidence as to the life of the satellite is necessarily incomplete, the deterioration of the satellite power supply due to radiation damage has remained within limits suggesting a life of two years or more.

More recent experiments with the satellite RELAY have confirmed the above conclusions. They have also made it possible to extend the scope of the tests to a larger number of earth stations, to a new frequency band (2 Gc/s) and to demonstrate further the feasibility of medium-capacity earth stations, using smaller antennae (some 10 m in diameter) and relatively low-cost earth station equipment.

REPORT 208 *

ACTIVE COMMUNICATION-SATELLITE SYSTEMS FOR FREQUENCY-DIVISION MULTIPLEX TELEPHONY AND MONOCHROME TELEVISION

Form of the basic hypothetical reference circuit and allowable noise standards; video bandwidth and sound channel for television

(Question 235 (IV))

(Geneva, 1963)

1. Form of the basic hypothetical reference circuit

As an aid to the designers of active communication-satellite systems, it is desirable to establish basic hypothetical reference circuits and the allowable noise powers for frequency-division multiplex telephony and monochrome television.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

It has been found possible to recommend a common basic hypothetical reference circuit for both frequency-division multiplex telephony and monochrome television, based on a single satellite link (earth station-satellite-earth station) (see Recommendation 352). In arriving at this Recommendation, the following factors have been taken into account.

1.1 Active communication-satellite systems for intercontinental connections are likely to use orbital heights in the range from about 8000 to 36 000 km, including the stationary-satellite system at an orbital height of 36 000 km. In these circumstances, the majority of intercontinental connections, both for telephony and television, could be made by a single satellite link, since it would be capable of spanning great-circle distances of up to at least 7500 km. However, a global satellite system will need to span great-circle distances of up to at least 25 000 km for a proportion of intercontinental telephone connections, and for some television connections. Since the stationary satellite system is limited to a maximum great-circle distance of about 17 000 km, it may be desirable for telephony to extend such a satellite link by terrestrial links to span the longer distances. With lower orbital heights, e.g. in the range 8000 to 15 000 km, two, or sometimes three, satellite links in tandem may be needed to span great-circle distances up to 25 000 km. It is to be noted that considerations of transmission delay in telephony may require the selection of orbital heights and number of satellite links, to reduce the delay to values acceptable to the users of long-distance connections.

1.2 Transmission delay is not significant for television and transmission via two satellite links in tandem at stationary or intermediate orbital height would be possible and necessary for the longer distances up to 25 000 km.

2. Allowable noise standards.

2.1 *General considerations.*

It is clearly essential that the allowable noise standards for active communication-satellite systems should be commensurate with those adopted for other long-distance transmission systems; in this connection the general principles established by the Joint C.C.I.T.T./C.C.I.R. Special Study Group C on circuit noise for telephony, and the C.M.T.T. for long-distance television transmission are particularly relevant.

However, there are certain characteristics of satellite communication systems which should be mentioned.

The radio path length (earth to satellite to earth) between any two earth stations will depend on the satellite orbit employed, and may vary with time. However, in any specific communication-satellite system, the variation of the path loss between satellite and earth station will not exceed a few decibels, irrespective of the great-circle distances between co-operating earth stations or the position of the satellite in its orbit within the range of mutual visibility to the earth stations. It may therefore be concluded, that the noise performance will not vary by more than a few decibels with the distance between the earth stations.

The limited experience thus far available suggests that there is comparatively little signal fading on communication-satellite links for wave directions exceeding a few degrees in elevation and for radio-frequencies up to at least 6 Gc/s. However, rain, cloud, snow and sleet may, at times, cause the noise level to increase by several decibels, the increase being greater for frequencies above about 6 Gc/s. Thus, the noise level at the output of a satellite link will be stable and low most of the time, with increases of a few decibels for a small percentage of time, subject to a seasonal variation. Detailed and comprehensive experimental data of noise performance are not yet available; for this reason the allowable noise for small percentages of time must be regarded as provisional until such data have been obtained. Furthermore, the noise levels exceeded for very small percentages of time (e.g. less than 0·2% of the time), cannot be stated at this time and require further study.

2.2 *Allowable noise in the basic hypothetical reference circuit: frequency-division multiplex telephony*

The following points, in addition to the general considerations mentioned above, have been taken into account when preparing Recommendation 353:

2.2.1 the maximum value of 10 000 pW (psophometrically-weighted) for the mean noise in any hour in any telephone circuit of the basic hypothetical reference circuit would correspond to 1·3 pW/km on a 7500 km great-circle distance or 0·65 pW/km on a 15 000 km great-circle distance and would thus compare favourably with other long-distance transmission media;

2.2.2 the value of 80 000 pW (psophometrically-weighted) for the one minute-mean value, exceeded for less than 0·2% of any month, in any telephone circuit in the basic hypothetical reference circuit, is based on Recommendation 393 for line-of-sight radio-relay systems and allows for the seasonal variation of noise: however, this value must be regarded as provisional until additional experimental data are available;

2.2.3 with two satellite links in tandem, such as may be required for spanning great-circle distances up to about 25 000 km, the mean noise in any hour would be 20 000 pW and the value of 80 000 pW be exceeded for less than $2 \times 0{\cdot}2\% = 0{\cdot}4\%$ of a month.

2.3 *Allowable noise in the basic hypothetical reference circuit: monochrome television*

Recommendation 421 indicates that, for a 2500 km hypothetical reference circuit corresponding to an international television circuit used for the transmission of 625-line television signals in a 5 Mc/s video bandwidth, the signal-to-weighted noise ratio should exceed 52 db for all except 1% of the time, the signal being the peak-to-peak value (excluding synchronizing pulses), and the noise being the weighted r.m.s. value measured on an instrument with an effective time constant in terms of power of one second.

For the basic hypothetical reference circuit for active communication-satellite systems (see Recommendation 352), comprising a single satellite link, it is recommended that, for 625-line signals with a 5 Mc/s video bandwith, an overall signal-to-weighted noise ratio of 55 db be adopted (see Recommendation 354). The weighting factors for uniform and triangular spectrum random noise are given in Recommendation 421 for various television systems.

With two satellite links in tandem, the signal-to-weighted noise ratio would then be 52 db.

3. Video bandwidth in the basic hypothetical reference circuit

The following points have been taken into account in preparing a Recommendation on the nominal upper limit of the video frequency band in an active communication-satellite system for television:

— the video bandwidth should be adequate for acceptable transmission of television signals up to and including 625-line standards;

— the need, for economic reasons, to provide a video bandwidth, no wider than is strictly necessary;

— the desirability that the width of the baseband for television should be compatible with that for high capacity frequency-division multiplex telephony.

Taking these factors into account it is recommended that the nominal upper limit of the video band in the basic hypothetical reference circuit for monochrome television be 5 Mc/s. However, in view of the desirability of providing for the future transmission of colour television signals with a chrominance sub-carrier of about 4·43 Mc/s, it is suggested that the designers of satellite communication systems bear in mind the possible need for a video bandwidth slightly wider than 5 Mc/s, e.g. of 5·5 or even 6 Mc/s, should this be economically practicable.

4. Simultaneous tramission of a sound channel and a television picture

To avoid excessive differences in transmission delay between a television picture signal and the corresponding sound signal, there will often be advantages in transmitting both over the same satellite link. In this event, a wider baseband may be needed, to accommodate the sound signal (e.g. on a separate sub-carrier in the baseband). Alternatively, the sound signal might be transmitted by time-division multiplex with the video signal, e.g. using the synchronizing pulses or the blanking intervals without the need for a wider baseband. However, occasion may arise where the sound may be transmitted by some other means, e.g. by submarine cable, a land-line circuit or by another satellite or radio channel, and undesirable differences between sound and picture could arise. The attention of the C.M.T.T. is drawn to the problem, so that suitable values of the relative transmission delay for sound and picture may be established (see Question 270 (C.M.T.T.)).

REPORT 209 *

COMMUNICATION-SATELLITE SYSTEMS

Frequency sharing between communication-satellite systems and terrestrial services

(Question 235 (IV))

(Geneva, 1963)

1. Introduction

It would appear that communication-satellite systems may well require a very large amount of spectrum space to meet future traffic requirements. However, that part of the radio-frequency spectrum between about 1 and 10 Gc/s, technically most suitable for such systems, is already widely used for terrestrial services. It follows that the problem of finding sufficient spectrum space for communication-satellite systems would be greatly facilitated if it were possible to share frequency bands with other compatible services. Such sharing would have to be based on mutually acceptable standards of protection against interference with some allowance for future developments in the services concerned.

The four basic criteria (*a*, *b*, *c* and *d*, see Fig. 1) which determine the technical feasibility of sharing frequencies between communication-satellite systems (both active and passive) and terrestrial systems are as follows:

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

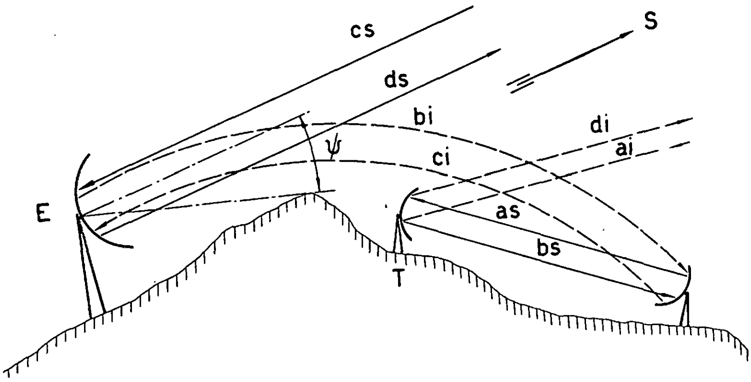


Figure 1 *(a)—Elevation*

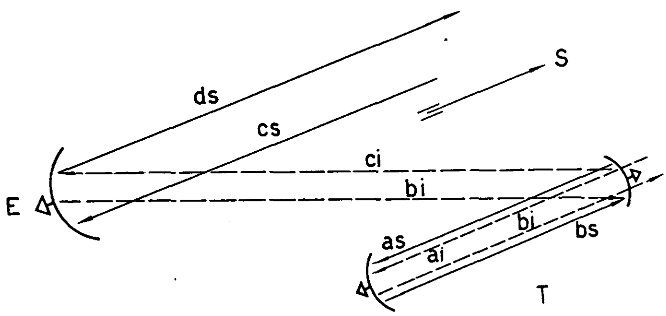


Figure 1 *(b)—Plan*

FIGURE 1

Four examples of interference (a, b, c and d) with an earth-space communication at an angle of elevation Ψ

—— s ——→ : Wanted signal path
- - - - i - - - → : Unwanted signal path
⇉——————→ S : Direction of space station
E : Earth station
T : Terrestrial system

a—at a terrestrial receiver, the signals from the satellite must not cause harmful interference to the terrestrial service;

b—at a terrestrial receiver, the signals from satellite earth stations must not cause harmful interference to the terrestrial service;

c—at a satellite-system earth station, signals from terrestrial stations must not cause harmful interference to the reception of signals from satellites;

d—at a satellite receiver, signals from terrestrial stations must not cause harmful interference to the reception of signals from satellite-system earth stations.

This Report discusses the principles upon which such frequency sharing could be based.

2. Principles upon which frequency sharing could be based

2.1 *Use of technically suitable bands on a compatible basis*

Examination of the frequency spectrum reveals that, considering the present state of development, the most suitable frequencies for first generation communication-satellite systems lie between about 1 and 10 Gc/s. The use of frequencies above 10 Gc/s is not precluded for future systems, but will depend upon further study.

Within the range 1 to 10 Gc/s, the variation of transmission loss, atmospheric noise and absorption, cosmic and rain noise, and present techniques have led to suggestions that frequencies between about 2 and 8 Gc/s may be used for the satellite-to-earth path in some active systems. Since greater transmitter power will be available at the earth terminal, the earth-to-satellite path could be operated between about 1 and 10 Gc/s.

Since satellites will be visible over large portions of the earth's surface, the frequencies chosen for the communication-satellite service must be available for sharing on a worldwide basis.

2.2 *Compatibility*

The most suitable frequencies for sharing in the range 1 to 10 Gc/s are those now employed by line-of-sight radio-relay systems in the fixed service. As such systems use relatively low radiated power with highly directional antennae, the probability of interference between the services will be at a minimum. Considerable control, as pointed out later, is possible in the siting of stations for either of the sharing services so that interference between earth and terrestrial stations can be minimized. Interference between satellite stations and these terrestrial stations may be mitigated by appropriate limitation of power levels in both services.

A determination of whether sharing is possible between two particular stations depends on the following factors:

2.2.1 the permissible interference either in a telephone or in a television channel, at the output of the receiver subject to this interference;

2.2.2 the ratio of the powers of the wanted signal and the unwanted signal, at the input to the receiver, which will just result in the permissible interference at the output of the receiver;

2.2.3 the power of the interfering transmitter;

2.2.4 the transmission loss along the unwanted signal propagation path, including effective antenna gain, and basic transmission loss;

2.2.5 the power of the wanted transmitter;

2.2.6 the transmission loss along the wanted signal propagation path, including effective antenna gain, and basic transmission loss.

2.3 *Adequate spacing and protection of earth and terrestrial stations*

This section describes appropriate methods for siting earth and terrestrial stations so as to ensure:

— that signals from the earth-station will not cause harmful interference to the terrestrial service;

— that signals from the terrestrial station will not cause harmful interference to signals received at the earth station from the satellite.

These potential interference situations are examples *b* and *c*, respectively, as shown on Fig. 1 and it is evident from this figure, that the propagation path for the unwanted signal will usually be a beyond-the-horizon path, but may, in certain situations, be a line-of-sight path. On the other hand, the propagation paths for the wanted signals will always be line-of-sight paths.

With the knowledge of the pertinent factors, it is possible to determine, for a given set of conditions, the necessary minimum spacing between an earth station and terrestrial stations sharing the same frequency band. In this respect it is useful to define a coordination distance "representing" approximately the maximum range over which interference might occur, in order that Administrations concerned with the establishment of earth stations and terrestrial stations within interference range of one another may coordinate their planning of such stations. Recommendation 359 covers this aspect and Annex I to this Report gives a method of calculating this coordination distance and an illustrative example.

2.4 *Limitation of the transmitter powers of communication-satellite and radio-relay systems*

The following discussion is concerned with the limitation of the transmitter powers of communication-satellite and radio-relay systems necessary to avoid mutual interference between systems operating in the range 1 to 10 Gc/s and conforming to the relevant Recommendations.

2.4.1 *Active satellite transmitter*

The permissible power of a satellite transmitter should be high enough to give reasonable freedom to the designers of communication-satellite systems to meet the performance requirements of such systems, but must not be so high as to degrade significantly the performance of existing or future line-of-sight radio-relay systems below that of Recommendation 393. It can be shown that a practical limit can be set which meets both of these requirements.

However, a limitation expressed in terms of the satellite transmitter power would be inconvenient, due to the need to cover a range of altitudes and it is considered preferable to define the permissible power-flux (in W/m^2) produced at the surface of the earth by a satellite. This would allow the use of larger radiated powers in satellites in the higher orbits.

In addition to the permissible power-flux, it is also desirable to define the permissible power-flux spectral density in W/m^2 per 4 kc/s in the normal bandwidth of a telephone channel. The object of this requirement is to prohibit the concentration of radiated energy into a small frequency band which could cause excessive interference. A discussion of the relation between power flux and interference caused by it in a radio-relay system is given in Annex II and provisional values for the permissible power-flux are given in Recommendation 358.

2.4.2 *Radio-relay system transmitter*

In considering interference from radio-relay transmitters to reception in communication satellites in any shared bands, the situation is the converse of that described in § 2.4.1. Thus, it is necessary to allow sufficient freedom to the designers to meet the performance requirements of these systems. On the other band, the permissible powers transmitted by these systems, of which there may be very many, must not be such as to inhibit the achievable performance of communication satellites.

A discussion of this problem is given in Annex III and provisional values for permissible power and permissible effective radiated power of radio-relay link transmitters is given in Recommendation 406.

2.5 *Use of carrier-energy dispersal techniques*

A substantial reduction of interference between satellite systems and radio-relay systems sharing the same channel can be obtained by carrier dispersal techniques. In a satellite system using frequency modulation, a large proportion of the radiated power may be concentrated at or near the radio-frequency carrier under certain modulation conditions, e.g., when the loading by telephony signals is light, or when a television picture with large areas of the same brightness is being transmitted.

Such concentration of carrier energy could, for example, severely limit the permissible power to be radiated by satellites. Accordingly, the application of carrier-energy dispersal techniques to communication-satellite systems using frequency modulation is proposed in Recommendation 358.

2.6 *Use of radio-frequency channel interleaving*

The problem of selecting suitable sites for satellite system earth stations in relation to line-of-sight radio-relay system stations could be eased by the use of radio-frequency channel interleaving in the two systems, thus reducing the distance separation between such stations needed to avoid mutual interference. The feasibility of this practice should be studied in each particular case and it would be helpful if the frequency plans for communication-satellite systems could provide possibilities for such interleaving, taking account of the difficulties arising from the fact that frequency plans used by radio-relay systems are not uniform in all regions of the world. An example of the advantage of such interleaving is given in § 3.4 of Annex I.

2.7 *Use of different polarizations*

The possibilities of minimizing interference between satellite systems and radio-relay systems by the use of different polarizations appears to be limited to a maximum improvement of about 3 db, in view of the general need to use circular polarization in satellite communication systems.

BIBLIOGRAPHY

1. CURTIS, H. E. Interference between satellite communication systems and common carrier surface systems. *BSTJ*, **41**, 921 (1962).
2. MEDHURST, R. G., HICKS, E. M. and GROSSETT, W. Distortion in frequency-division-multiplex FM systems due to an interfering carrier. *Proc. I.E.E.*, **105**, B, 282 (May, 1958).
3. HAMER, R. Radio interference in multi-channel telephony FM radio systems. *Proc. I.E.E.*, **108**, B, 75 (January, 1961).
4. MEDHURST, R. G. RF spectra and interfering carrier distortion in FM trunk radio systems with low modulation ratios. *IRE Trans.*, CS-9, 107 (June, 1961).
5. MEDHURST, R. G. FM interfering carrier distortion, General formula. *Proc. I.E.E.*, **109**, B, 149 (March, 1962).
6. CHAMBERLAIN, J. K. and MEDHURST, R. G. Mutual interference between communication satellite and terrestrial line-of-sight radio-relay systems. I.E.E. International Conference on Satellite Communications (Nov. 1962). *Conference Digest*, 46-52 (published in full in *Proc. I.E.E.*).
7. MEDHURST, R. G. and ROBERTS, J. H. Expected interference levels due to interactions between line-of-sight radio-relay system and broad-band satellite systems. I.E.E. International Conference on Satellite Communications (Nov. 1962). *Conference Digest*, 39-45 (published in full in *Proc. I.E.E.*).

ANNEX I

DERIVATION OF NECESSARY SEPARATION DISTANCES BETWEEN COMMUNICATION-SATELLITE SYSTEM EARTH STATIONS AND LINE-OF-SIGHT RADIO-RELAY STATIONS SHARING THE SAME FREQUENCY BANDS

1. Introduction

The following discussion is concerned with the siting of earth stations in relation to existing and possible future radio-relay stations to avoid mutual interference.

Specific decisions as to the siting of earth stations would need to be the subject of agreement between the Administrations concerned and affected. This Annex outlines the technical procedures involved in determining:

— the coordination distance, i.e. that distance within which mutual consultation may be required;

— the necessary separation distance between a given earth station and a given radio-relay system station.

In determining the coordination and separation distances it cannot necessarily be assumed that all radio-relay systems will conform to the Recommendations of the C.C.I.R. as regards their channelling arrangements. Thus, consideration is given here to the most unfavourable co-channel interference case, and also to interleaved satellite and radio-relay system channels.

2. Coordination distance

Recommendation 359 outlines the procedure involved in determining the coordination distance within which interference might occur.

The data to be used in calculating the coordination distance would include the known antenna gain and directivity, transmitter power and receiver sensitivity of the earth station, and the maximum antenna gains, transmitter powers and receiver sensitivities likely to be used by the radio-relay stations. The limits of permissible interference power set out in Recommendation 357, and the propagation data derived from measurements over typical land and sea paths and given in Report 239, should be used.

3. Separation distance

Following the consultation procedure outlined above, it will be necessary to assess more precisely the probability of interference to specific stations and thus to determine the final location of the earth station. A similar situation arises in the provision of new radio-relay stations within the coordination distance of an existing earth station. The technical procedure for calculating the necessary separation distances between the stations concerned is discussed below.

The data to be used in this calculation include the location of the station concerned, the actual transmitter powers, antenna gains and radiation patterns, receiver sensitivities and operating frequencies, of all the radio-relay stations within the coordination distance, as supplied by the Administrations concerned. Furthermore, it would be necessary to use tropospheric wave propagation data obtained on, or predicted for, the actual paths, for example taking into account any natural screening by hills. The percentage of time during which the earth station antenna would point in a given direction, and the modulation conditions of the communication-satellite system and of the terrestrial radio-relay system, should be taken into account in making a statistical assessment of the interference likely to occur in each system.

3.1 *Permissible interference*

The permissible interference to the hypothetical reference circuit of a radio-relay system is given in Recommendation 357. It is necessary to recognize that more than one earth station, say two, may interfere within a radio-relay system of 2500 km, and that each earth station can interfere with more than one radio-relay receiver, again two being taken as an example.

The permissible interference to the hypothetical reference circuit of a communication-satellite system is given in Recommendation 356. Here again it is necessary to recognize that more than one radio-relay transmitter might interfere with the earth station receiver.

3.2 *Transfer characteristic*

In a particular case of interference, the ratio of wanted to unwanted carriers at the input of the receiver is related to the ratio of the wanted to unwanted signals at the output of the receiver by the transfer characteristic.

When both carriers are frequency modulated, the transfer characteristic depends on the width of the baseband and the frequency deviation of both the interfering and interfered-with carriers, as well as the frequency difference between them, and the baseband frequency at which the interference is observed. Although baseband widths, frequency deviations and channelling arrangements have been set down in several C.C.I.R. Recommendations for radio-relay systems, these factors have not yet been agreed upon for communication-satellite systems.

For this reason it is possible to give only preliminary figures for the transfer characteristics, based on the most unfavourable values that these factors can be reasonably expected to have *.

	Transfer characteristic (db)	
	Co-channel	*Separated by > 10 Mc/s*
Earth station interference to radio-relay system:		
with 960 channels	1	17
with 1800 channels	—5	10
Radio-relay station interference to earth station	10	26

It is now possible to calculate the required ratio of wanted to unwanted carriers at the input to the interfered-with receiver. For example, a typical calculation for a communication-satellite system earth station interfering on a co-channel basis with a 960-channel radio-relay system might be as follows: (the calculation is related to the higher value of interference noise permissible for a very small percentage of time since this proves to be the limiting case where tropospheric propagation is concerned.)

Permissible noise in hypothetical reference circuit for 0·01 % of time (50 000 pW psophometrically weighted converted to a 4 kc/s bandwidth unweighted)	—40 dbm0
Allowance for two interfering earth stations	— 3 db
Allowance for two interference entries per earth station	— 3 db
Total allowance per interference	—46 dbm0
Transfer characteristic for co-channel condition	1 db
Maximum value of unwanted signal in relation to wanted signal at the receiver input, co-channel condition	—45 db

Similarly, by using the appropriate transfer characteristic of 17 db, the maximum value of unwanted signal in relation to wanted signal for the interleaved condition is 29 db.

* Specifically the assumptions are a 1200-channel satellite system with an r.m.s. frequency deviation of 0·3 Mc/s (light loading) 2·2 Mc/s (narrow deviation) or 6·8 Mc/s wide deviation, whichever gives the lower (i.e. most unfavourable) transfer characteristic; the co-channel frequencies are actually slightly separated by an amount not greater than the highest baseband frequency of the system subject to interference, so as to give the worst interference; the communication-satellite system includes carrier-energy dispersal to the degree indicated by Recommendation 358. A more detailed account of transfer characteristics is given in [7] § 2·8 of the Report.

3.3 *Wanted and unwanted signal levels at the receiver input*

It is necessary to recognize that different modes of transmission are involved:

— the wanted signal at the earth station is relatively free from atmospheric fading, but may vary somewhat in power with moving satellites;

— the wanted signal at the radio-relay station is subject to atmospheric fading for a small fraction of the time, this fraction having strong diurnal and annual variations;

— the unwanted signal at either the earth station or the radio-relay station is likely to involve trans-horizon propagation, with continuous fading and with an average power which varies diurnally and annually.

In calculation of separation distance the known power of the wanted signal at the input to the radio-relay receiver will be used. For calculating coordination distance, however, it may be necessary to assume a reasonable minimum wanted signal power to protect radio-relay stations where exact parameters are not known.

It can be shown that receivers of radio-relay systems meeting the relevant C.C.I.R. Recommendations will have input signals of —74 and —65 dbW for systems of 960 and 1800 telephone channels respectively, assuming that the noise temperature of the radio-relay receiver is 700°K.

Thus, the maximum interfering signal at the input to the 960-channel radio-relay receiver considered above can be calculated as follows:

	Co-channel	*Interleaved channel*
Maximum ratio of unwanted to wanted signal (db)	— 45	— 29
Wanted signal power (dbW)	— 74	— 74
Maximum unwanted signal at receiver input (dbW)	—119	—103

For the wanted signal at the input to the earth station receiver, calculations using parameters consistent with the state of development expected in the next few years indicate that the signal power is not likely to be less than —120 dbW. Taking this value, the maximum unwanted signal at the input to the earth station receiver can be calculated by the same methods as those used above.

3.4 *Determination of coordination and separation distances*

The interfering signal at the input to the receiver is determined by:

— the power of the interfering transmitter

— less the feeder loss to the antenna

— plus the gain of the transmitting antenna in the direction of the receiver subject to interference

— less the basic transmission loss over the path concerned

— plus the gain of the receiving antenna in the direction of the interfering station

— less the feeder loss to the receiver.

For specific interference calculations, all the factors necessary to compute the transmission loss will be known. To determine the transmission loss associated with coordination distance, however, it will be necessary to assume certain radio-relay parameters. For an interfering radio-relay station, the first three items above can, in accordance with Recommendation 406, be assumed to total +55 dbW. For a radio-relay station subject to interference, the last two items can be assumed to be 42 db, also consistent with the same Recommendation.

At the earth station, the transmitter power might be +40 dbW, the feeder loss can be assumed to be negligible, and the antenna gain in the direction of the radio-relay station can, taking the worst case, be assumed to be +10 db, in the following example.

Continuing the 960-channel example discussed above, the necessary transmission loss relevant to the determination of coordination and separation distances, may be computed as follows. The worst, i.e., the co-channel, case has been assumed in determining coordination distance, but both co-channel and interleaved cases are treated in illustrating the calculation of separation distance.

	Coordination distance determination	Separation distance determination	
		Co-channel	Interleaved channel
Earth station transmitter power less feeder loss	40 dbW	40 dbW	40 dbW
Earth station antenna gain	10 db	0 db (1)	0 db (1)
Radio-relay station antenna gain less feeder loss	42 db	20 db (2)	20 db (2)
	92 dbW	60 dbW	60 dbW
Permissible power of interfering signal at receiver input for 0·01 % of time	—119 dbW	—119 dbW	—103 dbW
Minimum permissible basic transmission loss to be exceed for all but 0·01 % of time	211 db	179 db	163 db
Typical distance	500 km	200 km	115 km

(1) In calculating separation distance, it would generally be appropriate to allow a lower antenna gain in the direction of the radio-relay station for the earth station. For example, the earth station antenna may always operate in a direction well removed from that of the radio-relay station. In this example, it is assumed that the average gain in the direction of the radio-relay station is 0 db, the statistical variations of the actual value being ignored in relation to the larger statistical variation of transmission loss over the interfering path.

(2) In this example, it is assumed that the antennae of the particular radio-relay station are directed some 5° away from the direction of the earth station.

The coordination distance shown in the table may be determined by reference to the tropospheric propagation curves given in Report 243. These show that, for overland propagation, the basic transmission loss exceeded for all but 0·01 % of the time is 500 km which thus would be the coordination distance in the case considered for possible interference from the earth station to radio-relay stations. Where oversea propagation or propagation in non-temperate regions of the earth is concerned, Report 244 should be used where appropriate.

The separation distances shown in the table are calculated similarly, either by using the same data or, if measurements or more appropriate prediction methods are available for the particular path profile and climate involved, by these more precise methods, e.g. Report 244. In particular, account would need to be taken of any local screening near the earth station which would appreciably reduce the separation distance. In the examples here taken, which do not assume local screening and which use the propagation data of Report 243, the minimum separation distances for interference from earth station to radio-relay station become 200 km (co-channel) and 115 km (interleaved channel). If, by local screening, increased antenna discrimination, or other means, an improvement, of, say, 20 db is obtained, the separation distances become about 100 km (co-channel) and less than 50 km (interleaved channel).

The examples taken have referred largely to interference from the earth station to radio-relay stations. It will, of course, be necessary to determine coordination and separation distances also for the reverse case of interference from radio-relay stations to the earth station and these may be larger or smaller than those here derived, depending upon the station parameters involved. The technical procedure involved will be evident from the preceding discussion.

In applying any coordination procedure and in finally determining the location of a new earth station or radio-relay station, it will be appropriate to employ the greater of the coordination and separation distances for the two directions of interference.

ANNEX II

RELATIONSHIP BETWEEN PERMISSIBLE POWER FLUX AT THE SURFACE OF THE EARTH AND THE RESULTING INTERFERENCE IN A TELEPHONE CHANNEL IN THE HYPOTHETICAL REFERENCE CIRCUIT OF A RADIO-RELAY SYSTEM

1. Introduction

The following considerations are intended to explain how the permissible power flux, as specified in Recommendation 358, is related to that permissible in radio-relay systems by communication-satellite systems.

The assumptions taken as bases for the calculation are the following:

1.1 The interference is assumed to consist of a uniform spectrum noise producing—149 dbW/m^2 per 4 kc/s bandwidth power flux at the surface of the earth, as given in Recommendation 358.

1.2 The noise figure of the radio-relay receiver is 4 db, taking into account the trends in current development to lower receiver noise-figures.

1.3 The antennae of the radio-relay system have an effective area of 10 m^2. This corresponds to 43 db gain at 4 Gc/s and assumes a bigger antenna than those normally used on radio-relay systems, where the average antennae employed have an effective area of about 5 m^2 corresponding to about 40 db gain at 4 Gc/s.

2. The noise power at the receiver input produced by a given flux spectral density within the beam of the receiving antenna of a radio-relay system

2.1 The interfering power flux of —149 dbW/m^2 per 4 kc/s bandwidth is converted by an antenna of 10 m^2 effective area to a power of —139 dbW/4 kc/s. This power is reduced 3 db, because satellite systems use circular polarization whereas linear polarization is usually employed by radio-relay systems. A further reduction of 3 db is produced by the feeder loss and radio-frequency filters before the receiver mixer. Hence, the power flux of —149 dbW/m^2 per 4 kc/s bandwidth, under the assumptions made, is converted to a power of —145 dbW per 4 kc/s at the receiver input.

2.2 The noise power produced by a receiver with a 4 db noise figure in a 4 kc/s band is —164 dbW/ 4 kc/s. That is 19 db below the —145 dbW/4 kc/s generated by the power flux. With an antenna of 5 m^2 effective area the interfering power is only —148 dbW/4 kc/s and the ratio 16 db. For a receiver noise figure of 10 db, which applies to most modern radio-relay systems, the ratio reduces to 10 db.

2.3 Radio-relay systems designed in accordance with Recommendation 393, can be subject to about 40 db fading before a one-minute mean noise power of 47 500 pW is exceeded in a telephone channel. This means, without fading, the thermal noise per radio section is of the order of 5 to 10 pW in the telephone channel. The 19 db deterioration of the receiver noise figure caused by the interference brings this up to something between 400 and 800 pW noise power in a telephone channel of the rather sensitive radio-relay system considered. Appreciably less interference noise is generated in most existing radio-relay systems.

The figure of 400 to 800 pW compares favourably with the 1000 pW given as the upper permissible interference limit in Recommendation 357.

3. Probability of a satellite being within the beam of the receiving antenna of a line-of-sight radio-relay system

Studies of this problem have been made by the Administrations of the U.S.A., the U.K. and Canada (Docs. 53, 54, 116, 244 of Geneva, 1963). From these studies it follows that in a radio-relay system comprising about 50 stations and corresponding in length to the 2500 km hypothetical reference circuit the probability is less than 10% that a system of 20-co-channel satellites affects one of these stations. The 10% figure corresponds to the most unfavorable assumptions. The probability that two or more radio-relay stations are affected simultaneously seems to be considerably less than 1% under worst assumptions.

This means that the power flux as specified in Recommendation 358 gives satisfactory protection to radio-relay systems and ensures that the provisional interference limits as given in Recommendation 357 are unlikely to be reached, even if a very sensitive radio-relay system with a low noise figure is concerned.

ANNEX III

LIMITATION OF THE EFFECTIVE RADIATED POWER OF RADIO-RELAY SYSTEMS SHARING THE SAME FREQUENCY BANDS WITH COMMUNICATION-SATELLITE SYSTEMS

To make frequency sharing between communication-satellite systems and radio-relay systems feasible, it is necessary, among other measures, to impose a limitation on the effective radiated powers of line-of-sight radio-relay systems. This would make it possible to avoid undue interference occurring with the satellite system in particular into satellite receivers. Recommendation 406 sets the upper limit of power from a radio-relay transmitter and its associated antennae at 55 dbW and it has to be shown that with this limit undue interference into a satellite receiver would be avoided.

The effective radiated powers of communication-satellite earth stations are expected to be of the order of 95 dbW and no need is foressen to increase this power appreciably. The ratio of the power radiated from an earth station to that radiated from a radio-relay station is thus 40 db.

The interference noise power appearing in a telephone channel of a communication-satellite system due to interference at a satellite when it is within the beam of a radio-relay station antenna may now be derived as follows:

E.r.p. of earth station (dbW)	95
E.r.p. of radio-relay stations producing unwanted signal (dbW)	55
Allowance for cross-polarization of wanted and unwanted signals (db)	3
Resulting ratio of wanted-to-unwanted signals at the input to the satellite receiver (db)	43
Transfer characteristics for co-channel frequency modulation (see Annex I) assuming carrier-energy dispersion (db)	10
Resulting ratio of wanted-to-unwanted signals in 4 kc/s band at receiver output (db)	53
Allowance for 3·1 kc/s channel and psophometric weighting (db)	3
Resulting interference noise power in telephone channel (pW)	2500

From the studies mentioned in Annex II, it follows that full co-channel interference from any one of several hundred radio-relay stations beaming directly at any satellite would occur, in the most unfavourable case, for less than 10% of the time. The probability of interference from radio-relay systems generally is much lower than this. It may be concluded that the full "in-beam" interferences to a satellite of a communication-satellite system will probably occur for appreciably less than 20% of the time. Thus, for rather less than 20% of the time the level of noise may rise by up to some 2500 pW due to interference from a large number of radio-relay stations to a satellite receiver. The fact that very many radio-relay systems use e.r.p.'s lower than +55 dbW will provide a margin of safety.

REPORT 210 *

FREQUENCY SHARING WITHIN AND BETWEEN COMMUNICATION-SATELLITE SYSTEMS

(Question 235 (IV), Study Programme 235 C (IV))

(Geneva, 1963)

The extent to which the same frequencies may be used, without causing harmful interference, by different satellites within the same communication-satellite system, and by different systems of communication satellites, is a subject of considerable importance, bearing as it does on the efficient use of the frequency spectrum [1, 2].

At this time, it is possible only to provide some preliminary and provisional guidance in the matter and it is clear that a considerable amount of further study will be required to reach definite conclusions. Such study as has so far been made suggests:

1. The increasing probability of eclipse interference with increasing numbers of satellites will, in due course, limit the number of satellites that could use a given frequency channel.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

2. The radiation pattern of earth-station antennae will be a vital factor in determining the angular extent of eclipse interference. Relatively high-gain antennae with very well-suppressed side-lobes will be needed to prevent the interference beamwidth from being excessive.

3. Stationary satellites may share frequencies, but the usable number of co-channel satellites will be limited, the precise limit depending upon the system characteristics, e.g. the modulation method employed and the radiation patterns of the antennae used.

4. A satellite system using station-keeping satellites may be able to share frequencies with a similar satellite system using the same orbit, but this would only be possible if precise station-keeping of the two systems is employed.

5. Independent random-orbit systems may be able to share frequencies, but this would involve the exchange and use of complete orbital information by the operating agencies concerned.

6. Possibilities exist that, with appropriate safeguards, systems in different types of orbit might be able to share common frequency channels, but this subject needs further study.

BIBLIOGRAPHY

1. C.C.I.R. Doc. 55 of Geneva, 1963.
2. LUTZ, S. G. Interference problems of co-channel communication satellites. *IRE* Transaction PGRFI (Autumn, 1962.)

REPORT 211 *

ACTIVE COMMUNICATION-SATELLITE SYSTEMS

A comparative study of possible methods of modulation

(Question 235 (IV) and Study Programme 235D (IV))

(Geneva, 1963)

1. Introduction

Several factors enter into the choice of a method of modulation for active communication-satellite systems, some of them being of particular significance in regard to one direction of transmission only. The modulation techniques used may not be the same for both directions of transmission. The most important aspects to be considered in this comparison are as follows:

— the radio-frequency transmitter power (particularly in the satellite) needed to give acceptable signal-to-noise ratio performance;

— bandwidth requirements in relation to the traffic capacity to be accommodated, i.e., the comparative economy in use of the radio-frequency spectrum;

— the system flexibility, particularly in regard to the manner by which provision can be made for multi-station access to the system;

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

— susceptibility to cause interference to, or to receive interference from, systems sharing the same frequency bands;

— operational reliability;

— practicability in the light of current, and probable future technology.

The present study is concerned primarily with multi-channel telephony systems and three distinctly separate methods of modulation appear at this stage to warrant detailed consideration. These are:

— frequency-division multiplex with frequency-modulation of the carrier (FM);

— frequency-division multiplex with single-sideband amplitude-modulation of the carrier (SSB);

— pulse-code modulation (PCM) with vestigial phase-modulation of the carrier.

These are the three basic methods compared here, but it should be borne in mind that each method may have variants which are not considered here, a study of these variants is not expected to affect the conclusions reached greatly. For convenience, the three methods of modulation will be referred to as FM, SSB and PCM respectively.

2. Assumptions made and limitations involved in the comparison

Certain restrictions are necessary in a study of this nature in the interest of conciseness. Nevertheless, so long as the restrictions are suitably chosen and clearly borne in mind, useful conclusions can be drawn.

To provide a reasonably broad basis of comparison for the three modulation methods, systems have been considered for various specified numbers of telephone channels in both upward and downward directions of transmission. For high-capacity earth stations (e.g. those providing blocks of 120 channels), an antenna aperture equivalent to that of a paraboloidal dish reflector of 26 m diameter has been assumed, and an equivalent noise input temperature of 40°K. For low-capacity earth stations (e.g. those providing blocks of 24 channels), an antenna aperture of 9 m diameter and a system noise input temperature of 70°K have been assumed.

The equivalent noise temperature of the satellite receiver is taken as 3000°K in all cases.

For each of the three methods of modulation, the following numbers of channels have been taken as examples:

Direction of transmission	Number of channels
Satellite to earth (per system)	1200 240 120
Earth to satellite (per station)	1200 120 24

The assumptions made and limitations involved in this study are as follows:

2.1 Detailed calculations refer to multi-channel telephony only. 1200 telephone channels have been assumed as typical of the maximum capacity likely to be associated with one wide-band radio-frequency channel, until the demand for satellite communications exceeds present forecasts. For the various modulation systems considered it can, however, be shown that if the signal-to-noise ratio requirements are met for multi-channel telephony, they can also be met for 625-line monochrome television.

2.2 The assumed performance required, in terms of overall signal-to-noise ratio, is that given in Recommendation 353. This allows a noise power at a point of zero relative level in any telephone channel in each earth-satellite-earth section of a satellite communication system of 10 000 pW psophometrically weighted mean in any hour. For the purpose of the present study, 8000 pW is assumed to arise in the satellite-to-earth link and 75 % of this noise is assumed to be of thermal origin, i.e., that part not dueto intermodulation or interference. The corresponding signal-to-thermal noise ratio in a telephone channel, taking the satellite-to-earth link alone, is 50 db unweighted. For the earth-to-satellite link, the corresponding signal-to-thermal noise ratio is 56 db unweighted.

2.3 A radio-frequency channel bandwidth, not exceeding 50 Mc/s, has been assumed for each system considered. Given this maximum bandwidth and the performance requirements stated in § 2.2 above, it is possible to compare the probable traffic capacities of the three systems.

2.4 A transmission frequency in the 4 Gc/s band has been assumed in the calculations of path attenuation. However, since a fixed satellite antenna gain has been assumed for each of the orbits considered, the question of frequency does not enter as a primary factor in the final result. The comparison is, therefore, valid over a relatively large frequency range within the 1 Gc/s to 10 Gc/s part of the spectrum.

2.5 For the purposes of comparison, three different satellite orbital heights have been considered, viz: a low altitude satellite at 3000 km, a medium altitude satellite at 10 000 km, and a synchronous orbit satellite at 36 000 km. It is appreciated that the altitude of 3000 km is lower than any that are likely to be used for active communication-satellite systems, but calculations

TABLE I

Transmission loss, antenna gains and beamwidths at 4 Gc/s

Satellite orbital height (km)	3000	10 000	36 000
Maximum slant range (km)	6300	14 500	41 300
Attenuation at maximum slant range (db)	180·5	187·7	196·8
Satellite antenna beamwidth (deg)	91·4	51·8	23·3
Satellite antenna gain (db)	5·2	10	16·8
High-capacity systems			
Earth station antenna gain (db)	58	58	58
System transmission loss (db)	117·3	119·7	122·0
Low-capacity systems			
Earth station antenna gain (db)	50	50	50
System transmission loss (db)	125·3	127·7	130·0

for this altitude have been included here for completeness of comparison. In all cases, satellite attitude-stabilization has been assumed, thus permitting the assumption of antenna gain at the satellite, sufficient to give a radiation pattern covering the visible part of the earth.

These assumptions are thus immediately applicable to satellites in circular orbits, but allow the results also to be applied with certain changes to elliptical orbits. They are equally applicable to equatorial, oblique or polar orbits, but of course, the altitude of 36 000 km has particular significance only for the equatorial orbit.

For the assumed satellite orbital heights, there are related values of path attenuation, satellite antenna gain and system transmission loss. These values which have been used in the system performance calculations, are summarized in Table I.

It should be noted that the satellite and earth station transmitter powers given in the following sections represent the minimum powers theoretically necessary; in practice, some increase of power may be required, e.g. to allow for absorption and additional noise due to rain.

2.6 It should also be noted that the detailed calculations herein do not include numerical consideration of the use of compandors on telephone circuits. However, the possible use of compandors is mentioned at appropriate points, where compandored operation may be of special benefit, or where the use of compandors clearly seems to be undesirable.

In this connection, it may be noted that C.C.I.T.T. Recommendation G. 152 (Vol. III) recognizes the use of compandors on some national and international circuits. However the C.C.I.T.T. is studying, for use on intercontinental telephone circuits, compandors with better performance than those specified in Recommendation G. 152. When using such improved compandors, the noise allowance for the corresponding circuits may be raised to a certain extent, which has still to be determined by C.C.I.T.T., taking into consideration both the transmission of speech and telephone signalling. The use of compandors implies demodulation to audio frequencies at some point in the telephone network, where both echo suppressors and compandors might be used. For other services, e.g. telegraphy, compandors offer no benefit, and may even degrade service. When telephone circuits are used for the transmission of telegraphy, a guide to the desired noise performance is given in Doc. 161 of Geneva, 1963, § *a* 2, (4). Obviously, these relative advantages and disadvantages must be carefully weighed when considering the potential benefits which may be obtained with compandors.

3. Satellite transmitter power requirements

The power requirements of the satellite transmitter are considered for each of the three modulation methods in this section. It is also, however, convenient to summarize the broad features of each method and this has been done in an initial paragraph of the three subsections.

3.1 *Frequency-modulation*

The particular virtues of FM that can be exploited in satellite communications are that it is:

— a well-tried and available system;

— capable of providing improved signal-to-noise ratio performance by exploitation of available frequency bandwidth.

In view of th. likely limits on available satellite transmitter power, FM is here exploited on a wide-deviation basis within a total radio-frequency channel bandwidth of some 50 Mc/s.

Nevertheless, the benefits to be gained by the use of wide-deviation FM do not apply when the carrier level at the FM detector is less than a threshold some 12 db above the total noise level. To enable this threshold requirement to be more readily met, various methods such as FM with feedback have been devised; in a quantitative analysis therefore, account must be taken of the margin of operation above the threshold value.

In the high-capacity system, a 5·5 Mc/s baseband accommodating some 1200 FDM telephone channels is assumed to modulate a single satellite emission. A single, wide-deviation FM emission is more efficient than the alternative of a number of separate emissions each carrying a relatively small number of telephone channels. The calculations for this case are based on the following parameters:

— r.m.s. channel deviation (1 mW tone) 1·0 Mc/s;

— r.m.s. multi-channel signal deviation 6·2 Mc/s;

— minimum input power at the earth station receiver to meet the signal-to-noise requirements in the channel —117 dbW.

The thermal noise corresponding to the assumed equivalent noise input temperature of 40°K at the earth station receiver input is —136 dbW in a 50 Mc/s band, and the input carrier-to-noise ratio is thus 19 db. The intermediate-frequency carrier-to-noise ratio resulting in the 15 Mc/s band of a feedback receiver is therefore, 24 db.

The threshold of satisfactory operation in an FM receiver is about 12 db and the system outlined is assumed to provide a fade margin above the FM receiver threshold of 12 db at the limit of range. These fades of less than about 12 db depth would thus do no more than reduce the output channel signal-to-thermal noise ratio approximately in proportion to the depth of fade.

The required satellite transmitter powers for the various examples considered are given in Table II.

TABLE II

Satellite transmitter powers for FM systems

Number of channels	Orbital height of satellite (km)						Type of station
	3000		10 000		36 000		
	dbW	W	dbW	W	dbW	W	
1200	0·3	1·1	2·7	1·9	5·0	3·2	High capacity
240	3·7	2·4	6·1	4·1	8·4	6·9	Low capacity
120	2·0	1·6	4·4	2·8	6·7	4·7	

If compandors were to be considered for use in an FM system, they could offer lower bandwidth, reduced power or higher capacity; however, the use of FM is satisfactory for international high quality circuits without the introduction of compandors and their possible disadvantages.

3.2 *Single-sideband amplitude modulation*

The SSB method has the merits of simplicity and maximum possible economy in bandwidth. It is preferable to DSB amplitude modulation with carrier because of its more efficient use of transmitter power and its smaller bandwidth. Unlike FM, it possesses no limiting threshold effect.

The main disadvantages of SSB systems are as follows. They require greater transmitter powers than wide deviation FM; it is very much more difficult to provide the necessary linearity for multi-channel operation and the SSB systems are more susceptible to interference and will produce more interference when their signals fall within the baseband of the terrestrial systems.

In determining the transmitter power requirements for SSB, it is necessary first to decide what telephone channel capacity is to be assumed. At first sight, it would appear that a radio-frequency channel bandwidth of 50 Mc/s would allow, for SSB, many times the number of 1200 channels obtainable with FM. However, for reasons which are primarily associated with frequency sharing problems, it is possible that the number of telephone channels per transmission may need to be limited. For convenience, the figure of 1200 is assumed here in calculating power requirements, but it should be remembered that perhaps about twice this capacity could be carried with, however, a doubling of transmitter power.

The calculations for this case result in separate figures for the values of mean power and peak envelope power. While the mean power is of direct interest because of its influence on the total power supply requirements aboard the satellite, it is the peak envelope power that is of most concern in SSB systems since sufficient linearity of operation must be obtained up to this power if intermodulation products are to be kept acceptably low.

The required satellite transmitter power requirements are given in Table III, which assumes no compandors on the telephone circuits. It may be expected that if the use of compandors proves satisfactory on international circuits the power quoted here would be considerably reduced.

TABLE III

Satellite transmitter powers for single-sideband systems

Number of channels	Power	Orbital height of satellite (km)						Type of station
		3000		10 000		36 000		
		dbW	W	dbW	W	dbW	W	
1200	Mean	5·4	3·5	7·8	6·0	10·1	10·2	High capacity
	Peak envelope (1)	17·6	58	20	100	22·3	170	
240	Mean	8·8	7·6	11·2	13·1	13·5	22·5	Low capacity
	Peak envelope (1)	22·5	178	24·9	310	27·2	530	
120	Mean	7·3	5·4	9·7	9·3	12·0	16·0	
	Peak envelope (1)	21·2	130	23·6	230	25·9	390	

(1) This assumes that no limiting takes place in the telephone channels. The use of channel limiters would reduce the peak envelope power.

It should be noted that the mean powers quoted above represent the average over the whole of the busy hour. The short-term mean powers (i.e. averaged over a period of about 0·1 s)* would fluctuate about the quoted values and for 1% of the busy hour might exceed them by 1 or 2 db depending on the total number of channels in the system.

3.3 *Pulse-code modulation (PCM)*

PCM is a method of modulation with considerable inherent protection against interference, the wide frequency spectrum enabling the required overall performance to be achieved with low transmitter power. However, operational PCM systems with several hundreds of telephone channels have yet to be demonstrated.

The nature of the quantization noise inherent in PCM tends to invalidate a direct performance comparison with more conventional systems; moreover, the values of the radio-frequency bandwidth required in practice are difficult to evaluate precisely in the present state of development.

The factors influencing the bandwidth requirements for PCM systems are brought out in the following discussion, in which a 1200-channel, time-division multiplex (TDM) system is taken as an example. The sampling rate per channel *(S)* must exceed twice the highest audio frequency to be transmitted, and 7400 samples/s is considered to be adequate for a channel having a top audio frequency of 3400 c/s. For the 1200-channel TDM system **, therefore, the sampling rate, neglecting synchronizing pulses, is given by:

$$S = 2 \times 1200 \times 3700 \text{ (for a top audio frequency of 3·4 kc/s per channel)}$$
$$= 8{\cdot}88 \times 10^6 \text{ samples/s.}$$

The number of binary digits per sample has now to be chosen and this depends on the limit fixed for quantization noise, for which no recommendation has yet been made by the C.C.I.T.T. However, according to published information, the smallest quantization step amplitude should be some 62 db below the peak level ***. To achieve this figure would require an 11-digit binary code if equal quantization steps were adopted. However, with non-linear encoding, it is possible to reduce the binary digits required to seven.

The bit rate, for 7 bits per sample, thus becomes

$$7 \times 8{\cdot}88 \times 10^6 = 62{\cdot}2 \text{ megabits/s,}$$

and the bit duration
$$t = \frac{1}{62{\cdot}2 \times 10^6} \text{ s}$$

Present practical systems employ basebands the widths of which are of the order of $1/t$, but systems of the future may reduce the bandwidth to the order of $1/1{\cdot}33\,t$. Adopting this latter figure as the best present estimate, a bandwidth of (62·2/1·33) = 46·6 Mc/s is indicated.

However, the pulses must be modulated on a radio frequency carrier and, using vestigial sideband transmission, the total radio-frequency bandwidth may typically exceed this by about 10%. It would seem possible to envisage, on the basis described, a channel bandwidth of some 50 Mc/s carrying 1200 telephone channels by pulse-code modulation (PCM) with phase-shift keying and vestigial sideband transmission. Some bandwidth reduction may also be possible by using more than two "states" (voltage levels) to define each digit, at the cost of increased transmitter power.

* Based on the definition of «Mean power of a radio transmitter», No. 96 of the Radio Regulations, Geneva, 1959.

** Systems have not yet been developed with this capacity, although work along these lines is being conducted within a number of Administrations.

*** Purton, R. F. A survey of telephone speech signal statistics and their significance in the choice of a PCM companding law. *Proc. I.E.E.*, B, 43, **109**, 60-66 (January, 1962).

It is to be noted that, in view of the steep threshold characteristic of PCM systems any reduction of carrier level or enhancement of noise at the input of the receiver would result in a disproportionate reduction in signal-to-noise ratio in the telephone channel. It is considered advisable, therefore, to allow a 5 db safety margin in the calculation of transmitter powers for the PCM systems, and, taking this into account, the satellite transmitter powers required are as given in Table IV.

TABLE IV

*Mean powers * of satellite transmitter for PCM systems*

Number of channels	Orbital height of satellite (km)						Type of station
	3000		10 000		36 000		
	dbW	W	dbW	W	dbW	W	
1200	1·3	1·4	3·7	2·4	6·0	4·0	High capacity
240	4·7	3·0	7·1	5·1	9·4	8·7	Low capacity
120	1·7	1·5	4·1	2·6	6·4	4·4	

The foregoing relates to PCM systems in which the telephone channels are encoded and transmitted on a time-division basis. Since, however, it is common practice for blocks of telephone channels assembled in frequency-division multiplex (FDM) as groups (12 channels) supergroups (60 channels). mastergroups (300 channels) etc., to be transmitted as an entity over transmission links of various types in the international network, it would facilitate interconnection if these FDM groups, supergroups, mastergroups etc., could be directly encoded for transmission over the satellite PCM system without the necessity for breaking them down into individual channels. The main difference between the transmission of encoded FDM blocks of channels of this type and of individual encoded channels are:

— the PCM bandwidth necessary for transmitting an encoded FDM block will be somewhat greater than that for a time-division multiplex (TDM) arrangement of the same number of channels, since there are guard bands between the FDM channels (assumed to be assembled in accordance with C.C.I.T.T. Recommendations), and also some unused bandwidth below the lower frequency channels;

— the quantization distortion requirements are much more severe when encoding an FDM block of channels, since quantization of the composite waveform results in distortion which has the effect of producing continuous noise in all channels. Hence, the required signal-to-distortion ratios are of the same order as the signal-to-thermal-noise ratios required in FM or SSB systems.

* For a single block of PCM channels, the peak-envelope powers are up to +3 db (2 times) greater than the mean values shown in the table. However, if a number of PCM blocks, from various earth stations, are stacked in FDM at the satellite, the peak envelope power of the composite emission may exceed the mean power by more than 3 db.

Theoretical considerations indicate that to attain a signal-to-distortion ratio of 50 db; 9 digits would be required for a 12-channel group and 8 digits for a 300-channel mastergroup, assuming a linear code. The use of an encoder with a logarithmic law might reduce the number of digits to 8 and 7 respectively. The corresponding radio-frequency bandwidths required for transmission of 1200 channels would be of the order of 79 Mc/s for 12-channel FDM groups and 66 Mc/s for 300-channel FDM mastergroups.

4. Earth-station transmitter power requirements and traffic handling capacity

To provide for multi-station access, the total capacity of the satellite will need to be divided among a number of separate transmissions, each originating from a different earth station. Various arrangements are possible, but a broad comparison of the three methods of modulation can be made if it is assumed, as typical, that 10 earth stations transmit at different frequencies, spaced at 5 Mc/s intervals throughout one 50 Mc/s wide radio-frequency channel. For high capacity earth stations using antennae 26 m in diameter each emission is assumed to carry 120 telephone channels giving a total of 1200 channels within a 50 Mc/s radio-frequency channel. Low-capacity earth stations are assumed for the present purpose to carry 24 channels each.

4.1 *Frequency-modulation*

It is assumed that each high-capacity earth station transmits 120 telephone channels occupying a baseband frequency range of approximately 550 kc/s. The radio-frequency bandwidth of the emission is taken as 3 Mc/s, allowing some safety margin and a guard band between adjacent emissions. Earth stations requiring higher capacities than 120 channels could be provided for by the allocation of two or more such blocks of 120 channels, each block being transmitted on a separate frequency allocation.

For the low-capacity system, it is assumed that each of the blocks of 24 channels allocated to the various earth stations might occupy different baseband frequency ranges, to simplify the assembly of a number of such blocks into a common baseband at the satellite. In the example taken in this study, a maximum baseband frequency of 550 kc/s is assumed, which could accommodate five blocks of 24 channels. To achieve the required signal-to-noise ratio, the station transmitting the block of 24 channels at the high-frequency end of the base-

TABLE V

Earth station transmitter powers for FM systems

Number of channels	Orbital height of satellite (km)						Type of station
	3000		10 000		36 000		
	dbW	W	dbW	W	dbW	W	
1200	25·1	325	27·5	560	29·8	950	High capacity
120	22·6	180	25·0	320	27·3	540	High capacity
24	25·6	370	28·0	630	30·3	1100	Low capacity

band (say 440 kc/s to 550 kc/s) would require to use either greater power or wider deviation than the other transmitters. It is reasonable therefore, to allow a radio-frequency bandwidth of 5 Mc/s for this worst case. With these assumptions, the required earth station transmitter powers may be calculated; the results are summarized in Table V.

4.2 *Single-sideband amplitude modulation*

For SSB transmission the radio-frequency bandwidth is approximately equal to the width of the baseband. The required earth station transmitter powers are determined as in Table VI.

TABLE VI

Earth station transmitter powers for SSB systems

Number of channels	Power	Orbital height of satellite (km)						Type of station
		3000		10 000		36 000		
		dbW	W	dbW	W	dbW	W	
1200	Mean	30·1	1000	32·5	1800	34·8	3000	High capacity
	Peak envelope	42·3	17 000	44·7	30 000	47	50 000	
120	Mean	21·6	150	24	250	26·3	430	
	Peak envelope	35·5	3600	37·9	6200	40·2	11 000	
24	Mean	26·8	480	29·2	830	31·5	1400	Low capacity
	Peak envelope	41·8	15 000	44·2	28 000	46·5	45 000	

It is to be noted that the use of compandors if these prove to be satisfactory, might substantially reduce the power requirements of SSB earth station transmitter. Thus, if an improvement of 15 db were achieved for the 120 channels synchronous satellite system, the last column of Table VI would need 14 W mean power and 370 W peak envelope power. The other figures in the column would be modified accordingly.

4.3 *Pulse code modulation*

For PCM systems, the radio-frequency bandwidth is in direct proportion to the number of channels and the number of digits per sample, other parameters being fixed. Thus, for a 50 Mc/s radio-frequency bandwidth for 1200 channels coded on an individual channel basis (as derived in § 3.3), the bandwidths for 120 and 24 channels are approximately 5 Mc/s and 1 Mc/s respectively. The required earth station transmitter powers are summarized in Table VII. The figures stated include a safety margin of 5 db for the reason given in § 3.3. For a high-capacity 120-channel system this would allow no guard band between adjacent emissions, as a practical system would require; thus, either the number of channels in each emission would need to be less than 120, or fewer blocks of 120 would be included in a 50 Mc/s band. However, for simplicity of comparison the powers are calculated on the basis of 120 channels in each block.

TABLE VII

*Mean powers * of earth-station transmitter for PCM systems*

Number of channels	Orbital height of satellite (km)						Type of station
	3000		10 000		36 000		
	dbW	W	dbW	W	dbW	W	
1200	26·1	410	28·5	710	30·8	1200	High capacity
120	16·1	41	18·5	71	20·8	120	
24	17·1	51	19·5	89	21·8	150	Low capacity

It should also be noted that the powers given above relate to systems where no form of pulse regeneration in the satellite is used. For systems in which the signal is either decoded and recoded or simply regenerated in the satellite, the required earth station transmitter powers would be about 7 db less than these shown above.

4.4 *Comments on transmitter power and bandwidth requirements in relation to traffic handling capacity*

It would appear from the foregoing, that a radio-frequency channel bandwidth of some 50 Mc/s could accommodate a FM transmission carrying up to 1200 telephone channels, or a PCM transmission approaching 1200 telephone channels or an SSB transmission carrying well in excess of 1200 telephone channels, and that systems using each modulation method could meet acceptable performance requirements using satellite transmitter mean powers of a few watts.

In comparing FM with PCM it should be noted that, as the satellite transmitter power is increased (up to the limit set by interference considerations), a reduction of FM deviation, and therefore of bandwidth occupied, could be made, with resulting increased efficiency of use of the frequency spectrum. Such an improvement could not be made with binary PCM since the bandwidth occupied is solely a function of the number of channels and the number of bits per sample.

With SBB systems, the actual bandwidth occupied is considerably less than for FM and PCM systems of the same capacity. However, it may not be possible to take full advantage of this bandwidth-saving in practice, since interference problems when sharing frequencies with other radio services, e.g. radio-relay systems, may restrict the usable channel assignments.

The mean power of the satellite transmitter required for 1200-channel SSB transmissions is approximately three times that required when using PCM or wide deviation FM. Moreover, the peak power of an SSB transmission is some 12 db greater than the mean power, and highly linear operation of the transmitter is essential over the full amplitude range.

The transmitter power of the earth station is of less importance than that required in satellites. However, a 120-channel PCM system would require an earth station with a

* The peak envelope powers are up to +3 db (2 times) greater than the mean values shown in the table.

transmitter of about 70 W mean power, about a quarter of that required for FM and SSB systems of comparable capacity.

5. Multi-station operation

The three methods of modulation considered can all provide for multiple earth-station access to the satellite, but differ in the complexity necessary in the satellite itself. If, at any one time, *m* earth stations are to participate via a single satellite of a system there must be, in effect, *m* separate transmissions to be received at the satellite. In the satellite these separate transmissions can be either:

5.0.1 amplified and frequency changed for re-transmission to earth on separate carriers;

5.0.2 demodulated, if necessary, and combined for re-transmission on a single carrier.

5.1 *FM systems*

The method of § 5.0.1 would require *m* separate amplifier channels or else a common linear broadband amplifier. The method of § 5.0.2 might involve demodulation to baseband, which would require *m* separate amplifier/demodulator channels in the satellite receiver, followed by re-assembly of the FDM telephony channels and modulation on a single down-coming carrier. The arrangements to do this when using FM could follow well-known and proved techniques; however, a number of design problems would need to be solved to reduce the weight and size of the equipment to meet payload limitations.

5.2 *PCM systems*

The relative immunity of PCM from interference by signals or intermodulation products below the threshold level suggests the possibility of using the method of § 5.0.1. In this method, several PCM carriers would be amplified in a common broadband amplifier in the satellite; this could be accomplished without appreciable cross-modulation and with relatively high efficiency in the radio-frequency output amplifier. This latter would, however, need to accommodate the peak-envelope power of the composite signal without significant compression of the amplitudes of individual carriers, and suitable guard bands would be required between the transmissions. Each earth station could receive all the PCM carriers transmitted by the satellite and would extract from each carrier the particular channels required.

With PCM systems, the possibility also exists in principle of assembling blocks of channels from different earth stations on a time-division basis in the satellite. However, the differences and variations in transmission delay between the satellite and the various earth stations would appear to exclude this as a practicable system.

The method of § 5.0.2, which involves the demodulation and reassembly of blocks of PCM channels in the satellite, would appear to be impracticable using PCM, in view of the complexity of the satellite equipment involved.

5.3 *SSB systems*

SSB systems have the advantage that the *m* separate transmissions, each comprising a block of FDM telephone channels, could be combined at the satellite for re-transmission to earth as a single emission without being demodulated. The transmission from the earth stations could be received at the satellite in a common broadband amplifier and arranged in frequency more or less adjacently, or, with appropriate Doppler shift corrections, contiguously. Means for ensuring that the levels of the various transmissions at the satellite were uniform would also be required. The combined signal could then be frequency-shifted in the satellite amplified to the necessary power level and re-transmitted to earth.

This technique would permit single channels or blocks of telephone channels from both high- and low-capacity stations to be assembled together, and allows considerable flexibility as to the sizes of the channel blocks. The use of SSB modulation could thus lead to a relatively simple and flexible satellite repeater. However, it would appear that existing broadband amplifiers, in particular radio-frequency power amplifiers for satellite and earth station transmitters, fall short of the amplitude linearity required to keep intermodulation products and crosstalk below acceptable levels. Furthermore, the use of a common broadband amplifier in the satellite would increase the risk of interference between transmissions in the event of malfunctioning of any earth station.

5.4 *Composite modulation systems*

With some signal processing in the satellite it is possible to use composite modulation systems, i.e. systems using one type of modulation on the earth-to-satellite paths and another type on the satellite-to-earth path. Because different considerations apply to the two paths this composite modulation may offer an improved overall system.

Possible examples of this are:

5.4.1 using narrow-deviation FM for the earth-to-satellite path, demodulation of each transmission in the satellite and combination and wide-deviation frequency modulation of the complete baseband signals on the satellite-to-earth path;

5.4.2 using PCM for the earth-to-satellite path, the PCM signals at the satellite being assembled in a wide baseband which is then transmitted to the ground using wide-deviation FM;

5.4.3 using SSB on the earth-to-satellite path, the channels are stacked at the satellite, either at intermediate frequency or at a baseband, and re-transmitted to ground using high-index phase modulation. It should be noted that such a system would combine the advantages of SSB in respect to flexibility of multi-station access, and of spectrum economy, with those of wide deviation phase modulation in conserving satellite transmitter power.

6. Interference between satellite systems and other radio services

The merits of different modulation systems must also be considered from the point of view of avoiding mutual interference between satellite communication systems and other radio services sharing the same frequency bands. Only the main characteristics of different modulation methods from the interference point of view are given below.

6.1 *Frequency modulation*

Frequency modulation produces a spectrum with an energy distribution which is a function of the frequencies of the modulating signals and of the deviations they produce. With lightly-loaded or unmodulated FM multi-channel telephony systems, a considerable part of the total energy is concentrated in a relatively narrow frequency band, with the result that a greater interference potential exists in this condition than is the case with a normally loaded FM system. This represents a limiting case unless means are adopted to prevent the condition arising. This can readily be achieved by use of the carrier energy dispersion techniques referred to in Recommendation 358 and Report 209. The use of FM with carrier energy dispersal on the satellite system reduces the interference between satellite and line-of-sight radio-relay systems sharing the same frequency bands.

6.2 *Pulse-code modulation*

Under conditions of light loading, a PCM system produces multiple-line spectrum with components spaced at $1/nt$, where n is the number of bits per sample and t the bit duration. The effect of loading is to decrease the amplitudes of the line components and to fill in the spaces between the lines. With $n = 7$, the maximum line amplitude is about 0·3 of the unmodulated carrier power. In the absence of special precautions, the interference potential of lightly loaded PCM systems could be several decibels greater than that of FM systems (using carrier energy dispersal) of similar capacity and performance. However, the interference potential of PCM systems can readily be minimized by the use of modified coding techniques which avoid repetitive patterns, such as one pulse in seven, under light loading conditions. Alternatively, frequency modulation, at a low modulating frequency, could be applied to spread the "line" spectrum energy.

With regard to interference *to* PCM systems, it is to be noted that such systems are, in general, less suceptible to interference than FM systems, and considerably less liable to interference than SSB systems.

6.3 *Single-sideband modulation*

In single-sideband amplitude-modulation systems, the total power of the emission may be concentrated within a bandwidth of a few megacycles per second or less. It is to be noted that the power in the spectrum of SSB emission generated by a given telephone channel is not spread over the spectrum as in FM or PCM. There may thus be a risk of interference from satellites using SSB modulation to line-of-sight radio-relay systems using FM, should an SSB signal fall into the effective baseband of the radio-relay system unless the limitations of Recommendation 358 are followed.

With SSB transmissions from earth stations, it should be possible to avoid interference to line-of-sight radio-relay systems by coordination of frequency usage on an area basis. For SSB transmissions from satellites, however, area coordination is insufficient, and the need to limit the power flux density at the earth's surface to a level such that interference will not occur may preclude the use of SSB without compandors on the satellite-to-ground path, except for earth stations where large antenna gain is available.

Interference to reception in satellites or at earth stations may be more troublesome when using SSB than when using other method of modulation, e.g., FM and PCM, which offer greater inherent protection against interference.

For SSB reception at earth stations, it should also be possible to avoid interference to line-of-sight radio-relay systems by frequency co-ordination on an area basis. For SSB reception in satellites, however, allowance must be made for the possibility of line-of-sight radio-relay systems using frequencies which fall within the SSB reception bands. Since not all countries use the C.C.I.R. channelling arrangements for line-of-sight radio-relay systems, it may be difficult to avoid such interference solely by choice of the SSB reception bands in satellites, although it may be reduced by such an approach.

7. Conclusions

A theoretical comparison has been made between FM, PCM, SSB and composite methods of modulation for use by satellite communication systems; the conclusions will, however, need to be verified by experiment. The conclusions drawn are summarized below.

7.1 *Transmitter power requirements*

In comparing the transmitter power requirements for the various methods of modulation, it should be noted that low power at the satellite transmitter is of considerably more importance than lower power at the earth station. The comparison shows that PCM systems require approximately the same satellite transmitter power as FM systems of comparable capactiy and performance, the required powers being of the order of 2 or 3 W for a satellite at an altitude of 10000 km. For SSB systems, the mean power required for the satellite transmitter is some 5 db greater than for FM or PCM and the peak-envelope power is some 12 db greater than the mean power. These requirements for increased power handling with sufficient linearity, therefore, present a major problem with SSB.

For satellite transmitters handling several FM or PCM multi-channel signals in a common broadband amplifier, the peak power output must be increased by several decibels to avoid amplitude compression and cross modulation; this increase is smaller with PCM than with FM, in view of the greater protection offered by PCM against cross modulation.

The powers of earth station transmitters for FM and PCM systems considered in this Report range from about 100 W to 1 kW; these are practicable and reasonable requirements well within the scope of current technology. From the operational and economic aspects, the use of powers of about 1 kW at earth stations would not be considered a serious disadvantage relative to the use of lower powers. However, it is to be noted that in frequency bands shared with terrestrial radio services, interference problems would be eased by the use of low powers at earth stations.

For SSB systems, mean powers of some 1 to 2 kW at earth stations would be needed, and the transmitters must also be capable of handling peak envelope powers some 12 db greater than these, with sufficient linearity to meet the required overall performance standards.

The use of compandors might appreciably reduce transmitter power requirements both at earth station and at satellites. However, the use of compandors will need further study by both the C.C.I.T.T. and the C.C.I.R.

7.2 *Radio-frequency bandwidth requirements*

It would appear, on the basis of this Report, that FM systems could provide up to 1200 one-way telephone channels, within a radio-frequency channel 50 Mc/s wide.

PCM systems could provide a capacity approaching 1200 telephone channels within a 50 Mc/s bandwidth. The need to minimize the bandwidth requirements for PCM suggests the use of vestigial sideband phase-modulation of the radio-carrier, with phase-modulation of $\pm 90°$.

SSB systems would provide similar capacities to the PCM or FM systems referred to above, i.e., 1200 telephone channels, in a much smaller radio-frequency bandwidth, of the order of 5 Mc/s.

7.3 *Multiple earth-station operation*

The main problem of multiple earth-station operation with a given satellite centres on the earth-to-satellite paths, for which separate radio-frequency sub-channels are required from the individual earth stations to the satellite. Time-division multiplexing between the various stations does not appear to be practicable, due to the transmission delays which are different, and generally varying.

FM, PCM or SSB modulation could be used for the earth-to-satellite paths. With SSB modulation, the radio-frequency sub-channels could be contiguous in frequency and received in a common broadband amplifier in the satellite, provided that steps were taken to correct the Doppler frequency shifts and to adjust the relative levels. With FM and PCM the sub-channels would need to be spaced in frequency to avoid overlapping sidebands. The sub-channel signals could be received at the satellite either in separate narrow-band amplifiers, or in a common broadband amplifier. The use of multiple narrow-band amplifiers in the satellite increases satellite complexity, but provides a convenient means for level adjustment of the individual signals and for carrier Doppler frequency-shift correction; such an arrangement also minimizes the risk of interference, including that due to malfunction of earth stations. It does, however, limit the number of earth stations in the coverage area to the number of narrow-band amplifiers in the satellite.

FM, PCM or SSB could also be used for the satellite-to-earth paths: however, the modulation method chosen need not be the same as for the earth-to-satellite paths. The use of a single wide-deviation FM carrier, bearing FDM signals corresponding to several earth stations, would enable efficient low-power radio-frequency transmitters to be used in satellites. The use of PCM on a similar single-carrier basis appears to offer no marked advantage, and requires considerable complexity in the satellite. Multiple-carrier techniques using FM, PCM or SSB modulation are also possible, subject to the satellite transmitter power and linearity requirements referred to above.

7.4 *Interference aspects*

These are more serious where they concern possible interference from satellite transmitters to other radio services, e.g., line-of-sight radio-relay systems, and from other radio services to reception in satellites, in shared frequency bands. The avoidance of such interference requires world-wide, as distinct from area, coordination. With regard to possible interference from satellites, wide-deviation systems such as FM with carrier-energy dispersal have a marked advantage over SSB modulation. With regard to interference to reception at the satellite, PCM offers most resistance and FM has considerable protection, and SSB offers least protection.

7.5 *Practicability*

The practicability of FDM-FM techniques has been demonstrated, both for the earth-to-satellite and satellite-to-earth paths, by the "Telstar" and "Relay" tests. The extension of such techniques to multiple-earth station operation appears to be possible.

It has yet to be demonstrated that the high degree of amplitude linearity required for SSB operation with large numbers of telephone channels, both at earth station and satellite transmitters, can be achieved in practice, bearing in mind the necessary high performance standards required. This problem is particularly acute in satellite transmitters, where the numbers of telephone channels are large and high efficiency is essential, bearing in mind the increased power supplies and weight involved if the efficiency is low.

Although the practicability of PCM techniques for the provision of a large number of telephone channels has not so far been tested, there appears to be no reason in principle why such techniques should not be effective, at least up to a hundred or so telephone channels on each carrier. It should, however, be noted that PCM systems carrying a thousand telephone channels on a single carrier may require the transmission of pulses of some 2×10^{-8}s duration through long tropospheric paths; whether such paths are sufficiently free from multipath effects to permit such transmission with the necessary standards of performance, requires experimental confirmation.

8. Need for further study

From the above conclusions it seems clear that each of the various modulation systems discussed has both advantages and disadvantages. Since it is not yet possible to state the requirements for a preferred system, it is equally not possible to state a preferred modulation system. It appears desirable to draw the attention of the C.C.I.T.T. to the possible advantages of the use of compandors on telephone circuits routed over certain satellite systems and the C.C.I.T.T. might be requested to extend their studies of the use of compandors to this particular field. It is pointed out that, with multi-station operation, a given compressor may be associated with various expandors. Further study is required of many other factors, including composite modulation systems.

REPORT 212 *

COMMUNICATION-SATELLITE SYSTEMS FOR FREQUENCY-DIVISION MULTIPLEX TELEPHONY AND MONOCHROME TELEVISION

Use of pre-emphasis by frequency modulation systems

(Question 235 (IV))

(Geneva, 1963)

The use of pre-emphasis in communication-satellite systems for frequency-division multiplex telephony, using frequency-modulation, results in a useful improvement in the signal-to-thermal noise ratio in the higher frequency channels of the system and thus enables the space station transmitter power requirements to be reduced.

The space-station transmitter power should be kept as small as possible to minimize risk of interference to the stations of other radio services sharing the same frequency bands.

A reduction in space-station transmitter power would be advantageous from an economic point of view, since it would reduce the pay load to be put into orbit and thus the size and cost of the rocket launcher.

The use of pre-emphasis for television could modify the energy distribution in the radio-frequency emission of communication-satellite systems in such a way as to reduce, substantially in some circumstances, the possibility of interference between communication-satellite systems and line-of-sight radio-relay systems using the same or adjacent channels.

The use of pre-emphasis for television may also enable the effective frequency deviation of the communication-satellite system to be increased, thereby improving the signal-to-noise ratio; however, too large an increase in deviation could offset the reduction of interference potential.

The use by different Administrations of the facilities offered by communication-satellite systems, including the shared use of space-station repeaters, would be facilitated by the use of an agreed pre-emphasis characteristic for such systems employing frequency modulation.

Conclusion

In view of the foregoing, and of potential advantages to be gained by the use of pre-emphasis in frequency-modulation systems, it is considered that the preferred pre-emphasis characteristics for frequency-division multiplex telephony and monochrome television should be the subject of further study.

---

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

In certain experiments with communication-satellite systems using wide-deviation frequency modulation, the same standard pre-emphasis characteristics have been satisfactorily employed as those recommended for terrestrial line-of-sight radio-relay systems in Recommendation 275 for frequency-division multiplex telephony and in Recommendation 405 for monochrome television.

REPORT 213 *

FACTORS AFFECTING MULTI-STATION ACCESS IN COMMUNICATION-SATELLITE SYSTEMS

(Study Programme 235 E(IV))

(Geneva, 1963)

1. Introduction

Radiocommunication on a world-wide basis in the communication-satellite service must provide ultimately not only for independent working between individual pairs of earth stations, but also for multiple interconnection between many earth stations. It is assumed that the communication-satellite service will be capable of accommodating telephony, telegraphy, data, facsimile, television, and perhaps other categories of usage.

For the purpose of this Report, the term "access" will be used in the sense of the ability of an earth station to join in and use a communication-satellite system. Multi-station access is a property of the system itself and of how the system can be used by its earth stations. There are two quite different ways in which communication satellites may be used by earth stations to provide interconnection. In the paired-terminal method, any two earth stations may use a space station for two-way communication between themselves, much as if they were connected by a cable of equal baseband capacity. In the multi-station method, more than two earth stations may use a single space station as a point of interconnection, so that each of these earth stations may communicate with any or all of the remaining earth stations.

This Report considers only the various techniques applicable to communication-satellite systems from the point of view of multi-station access. Specifically, the Report does not consider the practicability of achieving an economical, operational system using any specific technique within a given time frame. These are receiving extensive study at the present time. It is therefore too early to draw any conclusions regarding the most appropriate system for a given set of circumstances.

2. General considerations

For multi-station access through a single space station, all earth stations must be able to use the space station at the same time. With non-stationary satellites, this requires that the earth stations be capable of simultaneous hand-over, with the result that their locations must be within the area of overlapping coverage of two satellites at the time of hand-over. With a stationary satellite, no hand-over is required.

Service can be extended to adjacent areas served by another satellite through the use of additional relays: e.g. by intermediate earth station relay, direct satellite-to-satellite relay, or terrestrial systems.

---

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

3. Single-hop aspects

Two stations which are to be interconnected must be within the "mutual coverage zone", which is determined by the separation of the earth stations and the altitude of the satellite. Such a zone also exists when additional stations must be interconnected, but, in general, it becomes smaller as the number of earth stations and their separations increase.

To secure multi-station access on a continuous basis with non-stationary satellites, a "new" satellite must have entered the mutual coverage zone as the one in use moves out of the zone. Many ingenious orbit arrangements have been proposed to assure this. Since the mutual coverage zone becomes larger as the orbit altitude increases, the number of satellites required to give continuous multi-station access decreases with the higher orbits, and, for the stationary satellite, is continuous with a single satellite.

4. Multi-hop aspects

Long routes may be between antipodal points of the earth, separated by a great-circle distance of 20 000 km. This distance is some 3000 km greater than the longest path possible with even a stationary satellite, assuming minimum angles of elevation of 5° for the earth antennae. Such long paths will require extension by means of terrestrial links, or the use of two or more satellite relays. In any case, terrestrial links must be used to permit interconnection between earth stations and the parties using the circuit.

For multi-satellite circuits, direct relaying between satellites is a future possibility. However, with non-stationary satellites, the use of an intermediate earth relay-station is probable at an earlier date. Such an earth relay-station must be within the overlap area of visibility of two suitably situated space stations. With stationary satellites, an earth relay-station would only need to be within the fixed overlap area of visibility of its two satellites. Earth relaying between stationary satellites, for telephony, seems undesirable because the time-delay over two hops would exceed the tentative maximum values recommended by the C.C.I.T.T. However, for such connections, the delay can be held within these values by using terrestrial communication facilities in connection with a single stationary satellite.

5. Multiplexing and modulation aspects

When simultaneous access to a system is desired by a number of earth stations, channels can be combined by using time-division multiplex, frequency-division multiplex, a combination of the two, or other methods now undergoing evaluation. Frequency-division multiplex may be achieved by various methods. Time-division multiplex may be achieved through digital methods such as pulse code modulation or delta modulation. Each of the several methods or combinations thereof may be found advantageous for certain applications and conditions.

In communication-satellite systems, using low or medium altitude orbits, the relative velocities of satellites are of different magnitudes and direction with respect to each earth station. The resultant Doppler effects, at the order of frequency being considered, are large and variable and need suitable correction.

For reasons of simplicity and reliability of the space station, taking into consideration limitations in radio-frequency power and the need for suitable quality of transmission, the use of frequency-modulation both to and from the space station has merit. The space station can then be a simple heterodyne converter which translates the received signal spectrum to another frequency band for retransmission.

The use of frequency modulation is attractive for many reasons, such as its relatively low transmitter power requirement, resistance to Doppler frequency-shifts and ease of preserving satisfactory quality of a multiplicity of voice channels. It is also a thoroughly understood and established technique for line-of-sight radio-relay systems.

In relation to simultaneous access or feasibility of interconnection, it is impracticable for several earth stations to use a common carrier frequency for FDM-FM transmission to the satellite. Hence, each earth station would frequency modulate its own radio-frequency carrier in a separate sub-channel, all of which would be received by the satellite. If the satellite repeater is a linear frequency translator, these sub-channels will be retransmitted to the earth station receivers for separation, individual detection and subsequent selection of the desired voice (or other) signals. An alternate method involves signal processing in the satellite, requiring selection and detection of the radio-frequency sub-channels and translation of their signal channels to a common baseband for FM retransmission with a single carrier frequency. Such signal processing provides flexibility in accommodating traffic peaks, periodic traffic redistributions and signals having greatly different baseband widths.

Doppler-shift effects are minimized in stationary systems, and single-sideband techniques may be attractive. The maximum number of individual communication channels within a given bandwidth can be obtained by single-sideband techniques. However, the overall spectrum conservation achieved by use of such a technique is a function of a number of system parameters besides the method of modulation.

Consideration is being given to a system wherein the earth-to-space station transmissions employ SSB-FDM transmission and the space-to-earth station transmissions employ FDM-PM, this modulation change being accomplished in the satellite without detection to baseband. Such systems would add little complexity in the space station. Consideration might also be given to a system employing SSB-FDM transmission in both directions at such time as increased radio-frequency power becomes available in space stations.

Time-division multiplexing may offer the possibility of working with lower power at the expense of increased bandwidth. However, interleaving of pulses from several earth stations at the satellite would require difficult synchronization techniques. Hence, such a time-division system appears less desirable than one employing frequency-division.

REPORT 214 *

COMMUNICATION-SATELLITE SYSTEMS

The effects of Doppler frequency-shifts, transmission time delays and switching discontinuities

(Question 240 (IV))

(Geneva, 1963)

1. Introduction

In a communication-satellite system, the received signal will be subject to one or more of the following effects:

— Doppler frequency-shifts due to the relative velocities between satellite and earth stations;

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

— additional transmission time-delay due to the total length of the radio path being greater than the terrestrial distance between earth stations;

— discontinuities of transmission time-delay due to the difference in the length between radio paths on switching from one satellite to another.

The probable magnitude of these effects is discussed in this section, and the remainder of the Report considers how various types of communication signals would be affected.

1.1 *Doppler frequency-shifts*

The magnitude of the total Doppler frequency-shift between the terminals of a communication-satellite system depends upon the wave lengths used and the relative velocities of the satellite with respect to the earth stations. The major component of the effect of the Doppler shift, e.g. the shift of the carrier or a reference-frequency of the transmission, can be removed in the receiver and it is the differential shift across the radio-frequency spectrum occupied by the signal that produces a frequency "stretch" or "shrinkage" of the baseband signal. Depending upon the situation of the earth stations and the orbit, the Doppler shifts between transmitting earth station and satellite and also between satellite and receiving earth station can either add or subtract. If 5000 km is taken as a probable minimum orbital height for a communication satellite, then the "stretch" or "shrinkage" of the baseband signal will not exceed 2 parts in 10^5. In most practical cases, the orbital height will be greater and the Doppler shift would be considerably less than this, and in the particular case of the stationary satellite, there would be no significant Doppler shift.

1.2 *Transmission time delay*

Transmission time-delay in a communication-satellite system depends largely on the altitude of the satellites and the number of earth-satellite-earth links, or hops, forming the connection.

With stationary satellites, the time delay is essentially fixed for a given circuit, but if the satellites are in motion relative to the earth, the delay will vary with time.

1.2.1 *Single-hop connections*

For a single-hop circuit, the minimum possible time delay ,t_{min}, occurs when the two earth stations are close together and the satellite is directly overhead. The maximum possible time delay ,t_{max}, is obtained when the satellite is at the horizon as seen by both earth stations. Thus, if h is the altitude of the satellite, r is the radius of the earth, and c the velocity of light, then let $R = r + h$, further let Θ be the angle at the centre of the earth between the directions of satellite and earth station. Then the time delay for the earth satellite path is

$$t = \frac{1}{c} \sqrt{R^2 + r^2 - 2Rr \cos \Theta}$$

From this, the maximum and minimum time delays can be expressed as

$$t_{min} = 2h/c$$

and

$$t_{max} = \frac{2h}{c} \sqrt{1 + 2r/h}$$

The minimum time-delay will, in practice, be slightly greater than t_{min} because the earth stations would naturally be some distance apart. Also, the maximum time delay would be rather less than t_{max} since the earth stations would not in practice work to angles of elevation less than perhaps 5°. However, the above expressions give the mean time-delay of a single-hop circuit and the possible range of variation about this mean for different positions of earth stations, with sufficient accuracy for the present purpose.

To allow for the additional time-delay in the terrestrial extensions from the satellite system earth stations, it is considered reasonable to add a mean value of 30 ms with possible range of variation of ±20 ms. Appropriate values for total single-hop delay (one way), for two representative communication-satellite systems, are thus derived as below:

TABLE I

	One-way time delay (ms)					
	Moving satellite (altitude 14 000 km)			Stationary satellite (altitude 36 000 km)		
	Min.	Max.	Mean	Min.	Max.	Mean
Between earth stations	92	128	110	240	280	260
Tail extensions	10	50	30	10	50	30
Totals	102	178	140	250	330	290

Fig. 1 gives the maximum one-way path time-delay and the maximum separation distance between the earth stations as a function of satellite altitude.

1.2.2 *Multiple-hop connections*

Consideration of the geometry of a communication-satellite system shows that the mean radio-path delay will increase in proportion to the number of hops. The additional delay assumed for the tail extensions (30 ± 20 ms) being the same for all cases, the following values are obtained.

TABLE II

Number of hops	One-way mean time delay (ms)	
	Moving satellite (altitude 14 000 km)	Stationary satellite (altitude 36 000 km)
1	140	290
2	250	550
3	360	

1.2.3 *Variation in delay as a function of time*

In a system using satellites in motion relative to the earth, the delay on any given circuit will be subject to a gradual change arising from the varying distance between the satellite and the earth stations. In a practical moving satellite system of the type referred to above, the range of variation would not ordinarily exceed 20 ms per hop.

One method of eliminating, or at least minimizing this change, is to insert a variable time-delay device in the signal paths at earth stations. The amount of time-delay thus inserted could be controlled automatically, to maintain the total time-delay constant at a value slightly greater than the maximum time-delay of the radio path.

1.3 *Switching discontinuities*

In a moving satellite system, the time delay, due to path length, changes when switching from one satellite to another, the changes being positive or negative. The time differences when switching from one satellite to another, would not be expected to exceed 40 ms, and in practice would be expected not to exceed about 20 ms. The use of the variable time-delay device referred to in § 1.2.3 above, could reduce these switching discontinuities to negligible proportions.

With a random satellite system, time may also be lost due to the non-availability of a satellite at switch-over. This will be a function of the number of satellites and their orbits. The problem of switching does not occur with a stationary satellite.

2. Telephony

2.1 *Doppler frequency-shifts*

When a baseband exceeding some hundreds of kc/s is used for the transmission of FDM telephony, the "stretch" or "shrinkage" referred to in § 1.1 would be quite unacceptable without further correction.

Possible methods which could be used for correction of this error are:

— a suitable variable time-delay device as mentioned in § 1.2.3;

— the carrier-frequencies used in the frequency-division multiplex equipment could be automatically controlled to compensate for the effects of Doppler shift and so reduce the overall frequency errors to acceptably small values.

The first of these methods has the advantage that it would effectively cancel the errors resulting from the movement of the satellite in a manner similar to that in which they are introduced (i.e., by change in time delay during the pass). This method would, therefore, also, eliminate all the effects of Doppler shift on the baseband signals and by suitable arrangements would avoid switching discontinuities when transferring from the earth-station antenna following the next satellite of the orbital pattern. Control of the variable delay could be performed either by using predicted orbit information or on a servo basis employing a pilot signal transmitted from the earth-station to the satellite and back to the same earth-station ("local-loop" arrangement).

Alternatively, compensation for the variable delays could be located only at the receiving end and controlled by pilot signals originating at the distant stations. The "local-loop" method is generally preferable, however, for the following reasons:

— it would ensure that only the correct frequencies were received at the satellite. This facility could be of particular importance for certain systems, for example, those using closely-spaced channels or blocks of channels with single-sideband modulation in the earth-to-satellite direction;

— Doppler frequency "stretch" might to some extent be obviated by splitting the receiving bandwidth into appropriately separated portions and providing independent compensations for the blocks of circuits arriving from each of the other earth stations.

In the second method, the Doppler frequency "stretch" or "contraction" of the baseband would need to be accommodated by adaptations of the frequency-division multiplex equipment at each earth station and the C.C.I.T.T. should, therefore, be requested to study this problem. The attention of the C.C.I.T.T. should also be drawn to the special requirements of communication-satellite systems in which each satellite would, in general, be used to relay signals from a number of earth stations. This particular factor would appear to point the need for the C.C.I.T.T. to study methods involving control of the earth-station frequency-division multiplex equipment, either on a "local-loop" basis, as is described under the first method above, or on a route-by-route basis.

2.2 *Transmission time-delay*

The transmission time-delay associated with satellite links is considerably greater than that ordinarily experienced with terrestrial links. This increase in time-delay as well as being a problem in itself also increases the subjective effect of echo and may give rise to complaints due to a contrast between different calls made by the same subscriber.

2.2.1 *Time-delay*

A maximum value of tolerable delay has been recommended by the C.C.I.T.T. for circuits used in international connections. Studies carried out by Study Group XII of the C.C.I.T.T. (summarized in Doc. 20 of Geneva, 1963) provisionally indicate that, in the absence of echo, the maximum one-way time-delay on an overall telephone connection (between subscribers) should not exceed 350 ms.

With this limit, the use of communication satellite systems for telephony is restricted respecting the number of links which can be operated in tandem. It will be apparent from the Table II that not more than one link of stationary satellite systems may be included in such connections. In a system of moving satellites, the permissible number of links in tandem will depend on the particular orbit characteristics. Sometimes, the time-delay can be held within recommended limits by a suitable combination of satellite and terrestrial links for telephone calls which otherwise would be subjected to excessive time-delay.

To make an approximate assessment of the relative proportions of telephone traffic in a world-wide system which would be appropriate to single-hop, two-hop and three-hop connections, a statistical analysis of postal data of 1958 was made and the results are given in Table III:

TABLE III

Number of hops	Moving satellite (altitude 14 000 km)		Stationary satellite (altitude 36 000 km)	
	Mean delay (ms)	% of total traffic	Mean delay (ms)	Percentage of total traffic
1	140	79	290	88
2	250	18	550	12
3	360	3	810	

2.2.2 *Echo*

Echo, which has a very long time-delay, has a much worse subjective effect on a telephone subscriber than a similar level of echo with less delay and it is common practice on terrestrial systems for echo suppressors to be included in the telephone circuits when the echo is excessive. Provided that a satisfactory echo suppressor is available the limits given in § 2.2.1 may be approached on overall connections. However, pending the availability of such echo suppressors a margin should be allowed on these maximum values.

2.2.3 *Time-delay contrast*

Due to somewhat longer absolute delay in time which will be experienced on circuits employing satellite links, a contrast between international telephone calls may be experienced. This condition could be encountered as a result of the difference in propagation time-delays on different occasions when different facilities are employed. The time-delays and the associated contrast which could result on typical international circuits are indicated below:

TABLE IV

Examples of time-delay on typical international telephone connections

Total length of connection (km)	Terrestrial facilities (km)	Great circle distance between earth stations using a satellite at medium altitude (km)	Great circle distance between earth stations using stationary satellites (km)	Typical one-way delay (ms) (1)
25 000	25 000			125
25 000	10 000	15 000 (2-links)		314
25 000	10 000		15 000 (1-link)	325
7 000	7 000			35
7 000	1 000	6 000 (1-link)		137
7 000	1 000		6 000 (1-link)	280

(1) For terrestrial facilities, it is assumed that high velocity 4-wire plant will predominate and the amount of 2-wire plant will play a minor role in the overall connection. A velocity of propagation of 200 000 km/second has, therefore, been assumed.

Contrast in time delay may occasionally also be significant both as an annoyance to the subscriber and as a factor in his ability to adapt to the very long delays. This contrast is, of course, between terrestrial circuits and satellite circuits having the same subscriber terminal points.

The effect of contrast between telephone calls and the ability of the subscriber to adjust to the long absolute delays in the presence of contrast is not known. Further study is required to determine tolerable limits. It is recommended that the C.C.I.T.T. take this matter into consideration.

2.3 *Switching discontinuities*

Time differences during transfer from one satellite to another of up to perhaps 20 ms, should not cause difficulty with telephone conversations as these would occur relatively, infrequently. Interference, however, might be caused to high-speed telephone signalling, which could result in errors but are unlikely to add significantly to signalling errors due to other causes.

3. Telegraph and data transmission

3.1 *Doppler frequency-shifts*

The effect of Doppler frequency-shifts will be insignificant in both telegraph and data systems, carried by channels of a wide-band FDM telephony system, provided that the frequency error due to the "stretch" or "shrinkage" of the baseband has been corrected.

3.2 *Transmission time-delay*

When one-way transmission only is involved, time-delay would not be important. However, the loop delay is sometimes significant, such as when automatic error correction must be applied. Although the circuits provided by communication-satellite systems are unlikely to introduce significant errors in data and telegraph transmission, the earth stations may be linked to more distant terminals by other communication systems, such as HF radio, which are susceptible to errors. It may therefore be advantageous to apply error-correction to the whole circuit, including the satellite link. The loop-delay time is then of importance, since it affects the amount of storage required.

The amount of delay which may be encountered on such composite circuits is indicated in §§ 1.2.1 and 1.2.2. The most common system of telegraph error-correction (ARQ) now in use, should, when using an 8-character repetition cycle, be able to accommodate loop delays of up to 850 ms. Extended storage would be required in a two-hop stationary system and may be required in a three-hop moving satellite system.

For data systems which use automatic repetition of incorrectly received code blocks, the storage capacity of the terminal equipment must clearly be made sufficient to accommodate the loop-time delay.

Telex or Gentex operation may be confronted with some difficulties as far as long distance automatic selection is concerned: it is believed that this is a matter which the C.C.I.T.T. should take into consideration.

The smooth variation of time-delay, arising from the variation of path length, is unlikely to present any difficulty on the transmission of either telegraphy or data.

3.3 *Switching discontinuities*

These discontinuities would affect any telegraph circuit using synchronous printing or error-correcting systems in which terminal synchronization was required. At 100 bauds transmission speed, for example, each element of a 7-unit code would occupy 10 ms and, with a 2-channel system, it would be possible to "slip" a fraction less than half an element, say 4 ms, without loss of phase. The values suggested in § 1.3 are considerably in excess of this, so loss of phase might be expected at each switch-over. Present ARQ equipment would automatically re-phase, and there would be an interruption, on an average, of about eight seconds. The loss of about eight seconds of circuit time, while re-phasing takes place, at each switch-over, will not be a serious disadvantage, unless the switch-overs are very frefrequent. The loss of phase at switching would not occur with stationary satellite systems.

Switching-delay differences of the order of 20 ms would be likely to cause one or possibly more character errors in an unprotected 50-baud start-stop telegraph circuit. Since switching from one satellite to another would occur infrequently, such errors may be considered to have only a slight effect on overall circuit performance.

Switching discontinuities of up to perhaps 20 ms would affect data transmission by causing

— errors to occur in one or more code blocks,

— loss of block phase.

Provided the switching from one satellite to another is fairly infrequent, the errors of the first type would not be serious, and would in fact be similar to the effects of occasional switching or noise disturbances to be expected on normal line circuits. The loss of block phase results directly from the time discontinuity and has no equivalent in line systems.

Block phase would thus need to be re-established on data circuits each time a switch from one satellite to another occurs, unless means are adopted to compensate for the delay discontinuity. However, if the switch-overs are not unduly frequent, and re-phasing of the data transmission system is arranged to take place automatically, the loss of circuit time due to this cause would not be a serious disadvantage.

4. Phototelegraphy

4.1 *Doppler frequency-shift*

This will be insignificant in phototelegraphy systems carried by channels of an FDM telephony system, provided that any frequency error due to the "stretch" or "shrinkage" of the baseband has been corrected.

4.2 *Time delay*

The absolute time-delay is of no importance, but the smooth variation will produce a "skew" on the received picture to an extent depending on the amount by which the delay varies during the time taken to transmit the complete picture, which is of the order of 15 min, for equipment conforming to C.C.I.T.T. standards and working at 60 r.p.m. In an operational communication-satellite system, the delay variation over a 15 min period is unlikely to exceed 10 ms, and this would result in a peripheral displacement of the final scanning line from its true position by about 1% of the picture width. This amount of skew distortion would be acceptable in practice. It should be noted, however, that skew distortion can also arise from difference in drum speed between transmitting and receiving terminal equipments. The C.C.I.T.T. recommends that the terminal equipments should be equalized to within a tolerance of 10^{-5}, which is equivalent to a change of delay of 10 milliseconds over a 15-min period. In the most unfavourable circumstances, the delay variation of the satellite system could increase the effect of this speed difference and increase the total skew to about 3% of the picture width. However, such an unfavourable combination of errors would be unlikely to occur frequently. The foregoing refers to equipment conforming to C.C.I.T.T. standards, but is equally applicable to other types of equipment which provide similar definition standards, despite differences in transmission rate.

4.3 *Switching discontinuities*

The effect of these discontinuities would be an immediate displacement (either in an advance or a retard direction), of any succeeding position of the picture relative to the pre-switched position. For equipment conforming to C.C.I.T.T. standards and using a drum speed of 60 r.p.m., a time-delay discontinuity of 20 ms would produce a displacement of about 2% of the picture width, e.g. 0·5 cm displacement in a picture 25 cm-wide. This displacement would be a serious defect in most pictures or in typescript, meteorological charts, etc. With higher scanning rates, the displacement would increase in proportion. The amount of such displacement that could be accepted as tolerable is of course a matter to be decided in consultation with the C.C.I.T.T. It seems likely, however, that switching discontinuities of the order of 20 ms would produce unacceptable distortion in the majority of cases, and would, therefore, need to be avoided, either by suitable delay-compensation techniques (see § 1.2.3) or by arranging that the picture transmissions occur outside of switching times.

5. Television transmission

5.1 *Doppler frequency-shift*

The change in field frequency introduced by Doppler frequency-shift is very small. In normal monochrome television practice, the accuracy of the field frequency at the programme source is likely to be the limiting factor as far as disturbance to domestic receivers is concerned and Doppler shift will not be of concern.

While it may ultimately be desirable to correct for the effects of Doppler shift on colour television signals, initial tests with an experimental satellite system have demonstrated that standard NTSC colour receivers, using crystal controlled sub-carrier oscillators, will operate satisfactory with the order of Doppler frequency-shift likely to be encountered in a practical communication-satellite system.

5.2 *Transmission time-delay*

The transmission time-delays summarized in § 1.2 will in no way limit the transmission of television signals, provided that the accompanying sound signals are subject to the same order of delay.

Only a small overall time-difference between sound and vision signals can normally be tolerated before the sound becomes noticeably out of synchronization with the picture. It is, therefore, desirable that in a communication-satellite system, facilities should be provided to enable the vision and accompanying sound signals to be transmitted together over the system.

5.3 *Switching discontinuities*

Switching from one moving satellite to the next is very similar to and will generally produce the same effects, as switching between "non-synchronous" programme sources, and can result in temporary disturbance to the receiver field time-base. The actual time over which the disturbance exists will vary in practice depending upon the relative phase relationship at the moment of switching, but will normally lie between 0·5 and 2·0 seconds.

The change in transmission time-delay on switching may introduce a small discontinuity in the sound signal which, although noticeable, should not be disturbing.

As switching in a satellite system will be infrequent, the effects on both vision and sound signals should not prove too serious.

6. Summary

The significance of transmission time-delay, Doppler frequency-shift and switching discontinuities in communication-satellite systems varies with the type of service or signal transmitted, and with the characteristics of the satellite orbit. In general, stationary satellites are not expected to introduce significant Doppler frequency-shifts or switching discontinuities, but will introduce substantial transmission time-delays. Moving satellite systems will introduce greater Doppler frequency-shift and switching discontinuities, but will afford lower transmission time-delays per satellite link.

The major component of the Doppler frequency-shift can be removed in the radio-frequency receiver, but there will remain a "stretch" or "shrinkage" of the baseband spectrum due to differential frequency shift. The effect on monochrome television will be insignificant and the effect on colour television will probably be tolerable. In telephony, with the general use of broad-band single sideband multiplexing techniques, the changes in baseband spectrum (differential Doppler) will require compensation in the form of time-delay equalization of the entire baseband or of automatic control of the carrier frequencies used in the multiplex equipment. It is felt that such compensation is feasible. Telegraph, data and phototelegraphy services, which are transmitted over channels adequately corrected for telephony, should not require any further consideration of Doppler effects.

Transmission time-delay need not be of concern for services utilizing uncorrelated one-way channels, e.g. television alone, phototelegraphy, and those telegraph and data systems not requiring error correction. Telegraph and data systems with automatic error-correction may require adaptation to cope with the time-delays of communication by satellites, which will ordinarily be greater than encountered on other transmission media. For television with an accompanying sound channel, which is the usual case, precautions will be required to see that their relative transmission delays are within acceptable values. Transmission of the vision signal and sound signal over the same satellite system is desirable.

Transmission time-delay takes on added significance in telephony. In the absence of echoes, C.C.I.T.T. studies indicate that an overall round-trip delay of 700 ms between subscribers (350 ms one-way), should be the maximum allowed. However, satisfactory operation of practical circuits having 700 ms loop delay is conditional upon the development of better echo suppressors than are currently available. Consequently, communication-satellite links, or combinations of links, yielding overall loop delays approaching 700 ms should be considered with caution.

Subscriber tolerance of the contrast between the relatively long time-delays of satellite circuits and the shorter delay of circuits over conventional facilities, requires some consideration.

The switching discontinuities estimated for practical moving-satellite systems will occur sufficiently infrequently and be of short enough duration to be considered tolerable (or correctable with supplementary equipment) for all the services reviewed.

The attention of the C.C.I.T.T. and the C.M.T.T. is drawn to the problems which may arise in communication-satellite systems due to Doppler frequency-shifts, transmission time-delays and switching discontinuities; the C.C.I.T.T. with regard to telephony, telegraphy, phototelegraphy and data transmission and the C.M.T.T. for television transmission, including the related sound channel.

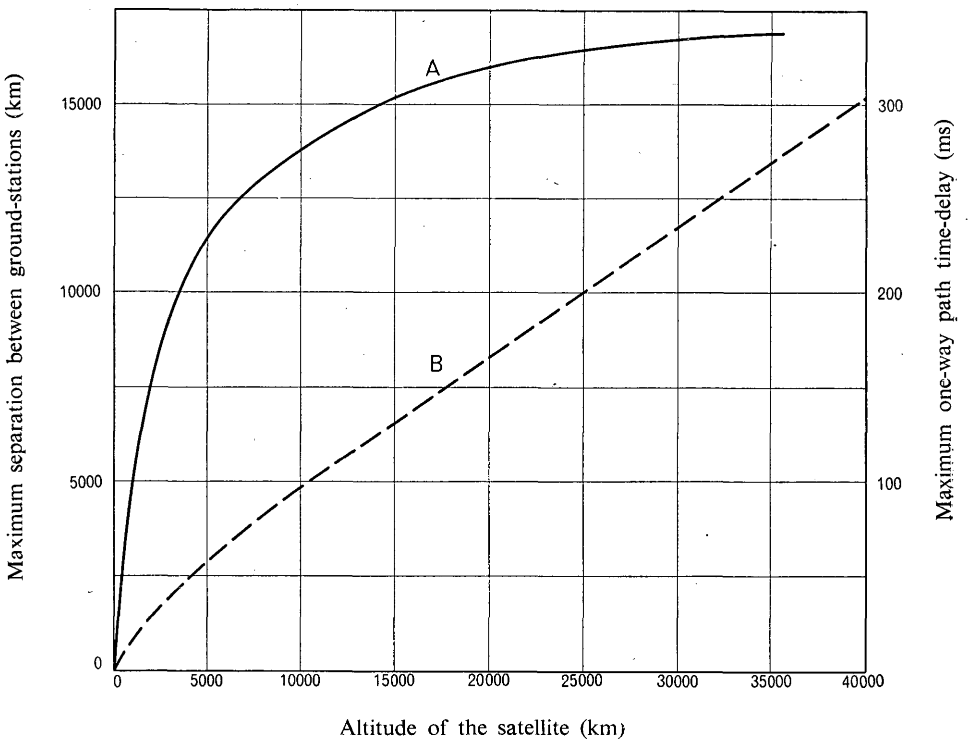


FIGURE 1

Single-hop radio link via a satellite (minimum angle of elevation: 5°)

Curve A: distance between ground stations
B: path time-delay

L. 3 - Direct broadcasting from satellites

REPORT 215 *

FEASIBILITY OF DIRECT SOUND AND TELEVISION BROADCASTING FROM SATELLITES

(Question 241(IV))

(Geneva, 1963)

1. Introduction

The large coverage area possible from a satellite-borne radio transmitter raises the possibility of establishing a direct broadcasting service to the general public, despite the major technical problems that would need to be resolved. An earth station transmitter would direct programme material to the satellite, which in turn would broadcast this over a wide area to individual home receivers, by either passive or active techniques. This Report is based on [1 to 4].

Communication-satellite systems used to relay programme material to earth stations for subsequent broadcast are not considered to be a space broadcasting system and arenot, therefore, discussed in this Report.

2. Preferred satellite orbits

Table I shows the amount of broacasting time possible for different orbits, and the approximate coverage area possible from each of these orbits.

TABLE I

Satellite altitude		Passes per day over a given point	Visibility per pass	Coverage area for maximum broadcast period (degrees of longitude at the equator)
(km)	(statute miles)		(min)	
320	200	16	9	16° for 5-min programme
1600	1000	12	24	28° for 15-min programme
8000	5000	4	126	60° for 1-h programme
36 000	22 300	stationary	continuous	160° continuous

There are a variety of possible orbits for communication-satellite systems, but the desirability of relatively simple receiving antennae for home reception and of uninterrupted broadcasting, preclude consideration of all but stationary satellites using the synchronous orbit, 36 000 km (22 300 miles) above the earth. Low orbits are considered to be unsatisfactory for satellite broadcasting because they do not permit uninterrupted broadcasting, and would require complex tracking antennae with home receivers.

More than a third of the surface of the earth (see Fig. 1) would be visible from a single stationary satellite, and this would permit the use of fixed antennae at home receiving installations, and at earth station transmitters used to transmit programmes to the broadcasting satellite.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

3. Preferred technical characteristics

3.1 *Compatibility with existing terrestrial broadcasting systems and standards*

It appears that a major consideration in direct broadcasting from satellites would be the large number of earth station receivers (home receivers) which might be used to receive such broadcasts. This would suggest that space broadcasts should be received on typical home receivers in preferably the same manner as conventional terrestrial broadcasts are, at present, received and that the technical standards for broadcasting-satellite systems should be compatible with existing standards for the terrestrial broadcasting service.

Since technical standards vary in different areas of the world, additional circuitry may be required in home receivers to achieve compatibility, when more than one set of technical standards are in use in the area in which space broadcasts can be received from a satellite. Such circuitry should enable the selection of the appropriate technical standards to be made by simple adjustment of the receiving controls.

3.2 *Frequencies for broadcasting-satellite systems*

Direct broadcasting to home receivers, with minimum modification to the latter, would require that space broadcasting take place in those bands already allocated to the broadcasting service in the Radio Regulations, Geneva, 1959.

It is considered that the effects of the ionosphere preclude uninterrupted direct broadcasting from satellites in bands 5, 6 and 7. While the broadcasting service allocations in bands 8 and 9 are, from the point of view of propagation, suitable, their use for space broadcasting would require time and/or area sharing, since channels in these bands are at present, heavily assigned on a planned basis, throughout most of the world. Use of these bands for direct satellite broadcasting raises frequency-sharing problems which require further study by the C.C.I.R. While band 10 is technically suitable for space broadcasting, nevertheless there is no terrestrial broadcasting in this band at present, and home receiving equipment is not available [4].

For greatest efficiency it appears that the earth station transmitter, sending programmes to the satellite, should operate in an appropriate communication-satellite service band between 1 and 10 Gc/s, or higher.

4. Order of power.

4.1 *Passive stationary satellite.*

Reference [1] considers a stationary satellite in the shape of a rectangular trihedron 100 m in diameter as a passive reflector of radio broadcasts. Such a satellite would provide a uniform received field of 1 mV/m throughout an area of the size of France if the transmitted power directed to the satellite from the earth is 30 MW, and the diameter of the earth transmitting antenna is 8400 λ. If one were content with a received field of 0·1 mV/m, the transmitted power required would be of the order of 300 kW.

4.2 *Active stationary satellite for FM sound-broadcasting in band 8* .

Reference [2] contains calculations for the order of satellite primary power that would be required for FM sound broadcasting in band 8 from an active stationary satellite. Examples are given for the case of maximum coverage (approximately one-third the surface of the earth) and for limited geographical coverage (approximately the size of Europe). A similar example for the coverage of North America is given in [3].

Table. II summarizes the results given in [2] and [3]. The primary power requirements shown have been computed by the method given in Reports 65 and 112, and Doc. IV/57 of Washington, 1962. The primary power requirements are those necessary for producing a level at the receiver terminals, equivalent to that obtained with a dipole in a received field of

50 μV/m as contained in Recommendation 412. They do not take into account ionospheric or atmospheric absorption, terrain effects, or power required for satellite equipment other than the broadcast transmitters.

TABLE II

Primary power requirements for FM sound broadcasting in band 8

	Maximum coverage	Europe	North America
Required pre-detection signal-to-noise ratio (db)	26	26	26
Required signal power (dbW)	—115	—115	—115
Receiving antenna gain (db)	6	6	6
Half-power beamwidth of transmitting antenna	17·5°	5·5°	10°
Diameter of parabolic transmitting antenna (m)	12·5	40	20
Gain of transmitting antenna (db)	19·3	29·4	23·6
Required transmitter power (W)	550	54	205
Primary power required based on 50% efficiency (W)	1100	108	410

4.3 *Active stationary-satellite for television broadcasting in bands 8, 9 or 10*

Reference [2] contains calculations for the order of satellite primary power that would be required for television broadcasting in bands 8, 9 or 10 from an active stationary-satellite. Table III summarizes the primary power required for maximum visible coverage (approximately one third of the surface of the earth), while Table IV summarizes the requirements for coverage of a limited geographical area (approximately the size of Europe). The power requirements shown do not take into account ionospheric or atmospheric absorption, terrain effects, or power required for satellite equipment other than the broadcast transmitters. The specific parameters assumed in estimating the power requirements are given in Appendices 1 and 2 of [2] and the required powers have been computed by the method in Reports 65* and 112 and Doc. IV/57 of Washington, 1962.

TABLE III

Primary power requirements for maximum coverage, television broadcasting in bands 8, 9 or 10

	Band		
	8	9	10
Frequency (Mc/s)	70	650	11 800
Assumed ratio of peak carrier to r.m.s. noise (db)	30	30	30
Required signal power (dbW)	—97·2	—94·1	—102·8(1)
Receiving antenna gain (db)	6	15·2	38·8
Half-power beamwidth of transmitting antenna	17·5°	17·5°	17·5°
Diameter of parabolic transmitting antenna (m)	17·9	1·9	0·11
Gain of transmitting antenna (db)	19·3	19·3	19·3
Required vision transmitter power (kW)	17·4	427	74
Required sound transmitter power (kW)	4·3	107	18·5
Primary power required based on 50% efficiency (kW)	43·4	1068	185

(1) Based on the assumption that the front end of the receiver will be designed as an integral part of the receiving antenna.

* Replaced by Report 322.

TABLE IV

Primary power requirements for limited geographical coverage (approximately the size of Europe) for television broadcasting in bands 8, 9 or 10

	Band		
	8	9	10
Frequency (Mc/s)	70	650	11 800
Assumed ratio of peak carrier to r.m.s. noise (db)	30	30	30
Required signal power (dbW)	—97·2	—94·1	—102·8([1])
Receiving antenna gain (db)	6	15·2	38·8
Half power beamwidth of transmitting antenna	7·8°	6·7°	5·0°
Diameter of parabolic transmitting antenna (m)	40	6	0·37
Gain of transmitting antenna (db)	26·3	30·2	30·2
Required vision transmitter power (kW)	2·75	69·2	6·0
Required sound transmitter power (kW)	0·69	17·3	1·5
Primary power required based on 50% efficiency (kW)	6·9	173	15·1

[1]) Based on the assumption that the front end of the receiver will be designed as an integral part of the receiving antenna.

5. Major problems

Formidable technical problems remain to be solved before high-quality broadcasting from satellites can be considered feasible. Among these are:

— the development of high-capacity power supplies capable of providing continuous service over a reasonably long period of time;

— the dissipation of heat resulting from large power losses;

— the development of precise stabilization, orientation and station-keeping systems;

— the development of system components of such size, weight and reliability, as will permit operation of a high-power broadcasting station for a reasonable period of survival;

— the accommodation, if necessary, of broadcasting-satellite space stations capable of wide-spread reception in a portion of the spectrum (bands 8 and 9) already assigned heavily throughout most of the world on a planned basis, and/or the development of home receiving equipment for space broadcast reception in band 10.

In order that broadcasting satellite programmes can be received by large numbers of viewers with low-cost home receivers designed for conventional broadcast services, a number of problems dealing with technical compatibility require solution.

6. Conclusions

This Report is intended to serve as an interim reply to Question 241 (IV), which replaces Question 215. Formidable technical problems remain to be solved before high quality broadcasting from satellites can be established. In view of the above, this Question requires continued study.

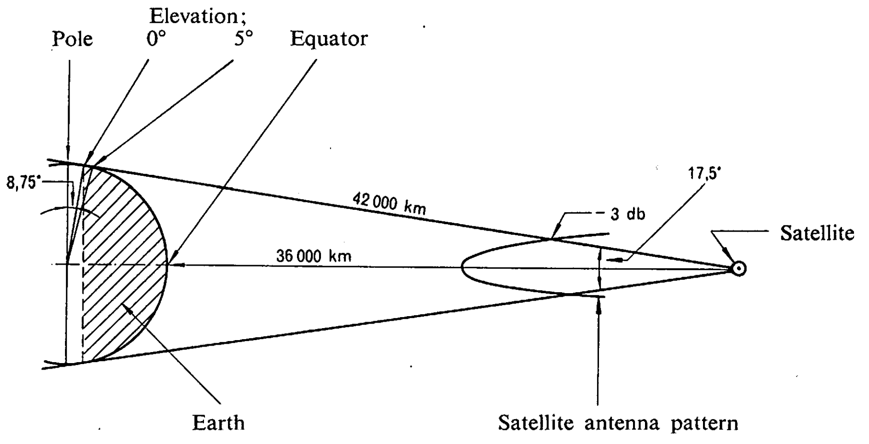


FIGURE 1

Geometry of stationary satellite system

BIBLIOGRAPHY

1. C.C.I.R. Doc. IV/21 (France) of Washington, 1962. Feasibility of direct broadcasting from earth satellites.
2. C.C.I.R. Doc. IV/73-Rev. (U.S.A.) of Washington, 1962. Technical factors affecting the feasibility of direct broadcasting from earth satellites.
3. C.C.I.R. Doc. 242 (Canada) of Geneva, 1963. Active earth satellites for broadcasting. The feasibility of direct F.M. broadcasting from earth satellites.
4. C.C.I.R. Doc. 48 (U.S.A.) of Geneva, 1963. Feasibility of direct broadcasting from earth satellites; sharing considerations.
5. CRAIN, C. M. Broadcasting from satellites. International Symposium on Space Communications, U.R.S.I., Paris (September, 1961).
6. CRAVEN, T. A. M. International broadcasting by means of space satellite relays. *Signal* (March, 1962).
7. DECKER, M. T. Airborne television coverage in the presence of co-channel interference. *NBS Technical Note No. 134.* U.S. Dept. of Commerce, Washington, D.C. (March, 1962).
8. GOULD, R. C. TV broadcasting from an earth satellite. *Report NA*-55-586. National Aeronautics and Space Administration, Washington, D.C. (August, 1961).
9. IVES, G. M. Television broadcasting from satellites. Paper 61-185-1879. Convention of the American Rocket Society, New York (1961).
10. JACOBS, G. and MARTIN, E. T. Direct broadcasting from earth satellites. *Telecommunication Journal* **1**, 11-18 (1963).

L. 4 - Radionavigation by satellites

REPORT 216 *

USE OF SATELLITES FOR TERRESTRIAL RADIONAVIGATION

(Question 242(IV))

(Geneva, 1963)

1. Introduction

This Report is a partial reply to Question 242 (IV), § 1.3, concerning satellite systems for radionavigation.

Study Group IV concludes that a preferred type of system, which will meet the needs of all potential users, cannot be specified at this time. The investigations and theoretical work effected to date indicates that several techniques show promise for the realization of usable systems. However, further experimental work must be undertaken to determine the best types and design criteria for global, all-weather systems.

It is further concluded that additional studies and experimental investigations should be undertaken.

Information is given on five possible types of systems as presented in Doc. 71, 84 and 85 of Geneva, 1963.

2. Doc. 71, Geneva, 1963

This document discusses the specific contributions that might be expected from appropriately instrumented satellites to provide radionavigational information to ships, aircraft and possible land vehicles on a global basis with increased and uniform accuracy under all weather conditions. Such satellites might also provide world-wide time signals **. The desirable characteristics of a radionavigation satellite are also specified in detail.

Of approximately twenty techniques that have been investigated, four types, which appear to be the most promising, are discussed, giving the advantages and disadvantages of each. These techniques are the angle of elevation, the horizontal angle (azimuth), range and range-rate. Each system has differing advantages and disadvantages, but those associated with the angle of elevation and horizontal angle are similar. The range system appears to be less desirable because of possible system of saturation, multiple response problems, poor spectrum economy and the need for an accurate time standard.

The document further discusses various orbital heights for radionavigation satellites in terms of coverage area at one time and the potential dynamic coverage. As the height of the orbit affects the frequency with which orbital data must be revised, the optimum height for the various techniques is indicated as varying between once or twice a year to once or twice a day. The problems associated with predicting the positions of satellites in low orbit and the means whereby these problems can be minimized are outlined. In addition, the advantages and disadvantages of radionavigation satellites in a stationary orbit and the various considerations relative to selection of an optimum orbit for the four techniques are presented.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

** The use of satellites for the transmission of time signals is the subject of Study Programme 249A(VII).

Also discussed in Doc. 71 is the choice of optimum frequency for the four techniques. For the angle of elevation and horizontal angle, any frequency band between approximately 8 and 20 Gc/s should be suitable. For the range and range-rate, frequencies in the VHF and UHF range up to about 1000 Mc/s are considered suitable.

The document concludes that telemetering of conditions inside the satellite is desirable and that the telecommand requirements for the four techniques described are nominal and could be accommodated in band 8.

3. Doc. 84 and 85 of Geneva, 1963

These documents consider the requirements of radionavigation-satellite systems in regard to beacon, telemetering and telecommand transmissions. Doc. 84, "Active earth-satellite systems for radionavigation—Preferred frequency bands and radio-frequency channelling arrangements", gives estimates of the numbers of channels for telemetering and telecommand required in the typical radionavigation systems that are discussed in greater detail in Doc. 85, "Applications of earth satellites for the terrestrial radionavigation service".

Doc. 85 states that radionavigation satellite systems can be expected to provide more easily greater coverage than can be provided by existing terrestrial systems. Such satellite systems might provide the accuracy of astronavigation and the reliability of existing terrestrial radio aids.

Conventional radionavigation systems are, in general, adequate in high traffic-density areas or where ships or aircraft make landfalls. Satellite systems should mainly aim to provide an adequate service at great distances from such areas. A radionavigation service should be available to an unlimited number of independent observers simultaneously, the latter using only receivers. For ships, an accuracy of ± 10 km at intervals of the order of several hours can suffice. The document reviews basic principles of possible satellite navigation systems and rejects those depending directly on distance measurement. It concludes that there are three preferred methods:

— a single-satellite Doppler system,

— a radio sextant system employing several satellites,

— a path-difference system employing several satellites.

3.1 The first system is of the CW type and is most satisfactory when using satellites with altitudes between 500 and 2000 km. The beacon transmitter should have a frequency stability within 1 in 10^8 over the observational period.

Two parameters of interest are the maximum rate of frequency change and the time at which the Doppler shift is zero. By measurement of these a user's position can be computed. It is not considered that two-frequency systems are justified for normal navigational purposes. The low altitude which is desirable for maximum Doppler frequency changes results in long periods of non-availability which render the system unsuitable for use by aircraft.

Each satellite would be periodically supplied with orbit data over a telecommand channel from an earth station and would store and retransmit this data continuously. Maintenance telemetering as well as orbital data can be incorporated in the beacon transmission if a suitable form of modulation is chosen.

The discussion leads to the conclusion that the preferred frequency range would be between 100 and 1000 Mc/s. For a typical simple system using four satellites, four beacon/telemetering channels and one telecommand channel would be used.

3.2 The second system considers satellites as celestial bodies and uses traditional angle measurement to determine the user's position. This technique is difficult except with stationary or near-stationary satellites; the report mentions that while such orbits have not yet been achieved, their ultimate possibility can be assumed. With such stationary satellites, tracking is simplified, though a stabilized mount with an accurate vertical reference would be required. High directivity is a requirement and this implies frequencies in the range 3 to 300 Gc/s (e.g. the window at 35 Gc/s), to reduce the size of the user's antenna. These frequencies would avoid trouble due to ionospheric refraction but may be subject to effects of cloud and rain. The use of infra-red (e.g. 3000 to 43 000 Gc/s) is also considered a future possibility.

Three to eight satellites would give world-wide cover (except for polar regions), continuous in time. With eight satellites, four telemetering channels and one shared telecommand channel would be needed.

3.3 The third system is a path-difference system, based on conventional radionavigation principles, and permits much simpler receiving equipment. It should be arranged that at least three satellites can be seen from any given point within the coverage area of the earth's surface. The satellite emissions, on different frequencies would have modulations mutually phase-locked. Hyperbolic surfaces of constant phase difference for each pair of transmissions are thus provided. From intersections of these surfaces with the earth, two possible positions of a user can be determined and the ambiguity can be resolved by dead-reckoning. Frequencies in the range 100 to 2000 Mc/s would be suitable; this system can use frequencies comparable to those of the Doppler system and the bandwidths, tens of kc/s, are similar. A system with twelve satellites would need six beacon channels, one shared telecommand channel and two channels for phase synchronization (the latter could be earth-to-satellite or satellite-to-satellite links).

Doc. 84 emphasizes the similarity of radio-frequency band - and channel-widths for the Doppler and path-difference systems and also for the associated telemetry which, in turn, is similar to that for other operational systems.

Further study is needed on frequency sharing possibilities with other systems.

The radio links described could, in addition, carry satellite identification signals, if needed.

4. Conclusions

Of the various techniques described in the aforementioned documents, it appears that there is not a preferred choice for a radionavigation-satellite system that will meet the needs of all potential users. In initial development work it appears that radionavigation-satellite systems will be primarily applicable to maritime radionavigation on the high seas and possibly surveying applications in areas remote from conventional navigational aids. For the lower orbit systems (800 to 2000 km), frequencies in the VHF and UHF bands up to approximately 1000 Mc/s appear most suitable, with frequencies in the 8 to 35 Gc/s range being most suitable for higher orbit systems (8000 to 9500 km) and stationary systems. Telecommand and telemetering are considered necessary with any radionavigation-satellite system. Where combination is feasible, telemetering signals should be accommodated on frequency channels provided for the radionavigation satellite. Telecommand requirements may be accommodated between 100 Mc/s and 10 Gc/s.

L. 5 - Meteorological satellites

REPORT 217 *

RADIOCOMMUNICATIONS FOR METEOROLOGICAL SATELLITE SYSTEMS

(Question 243(IV), Study Programme 243 A(IV))

(Geneva, 1963)

This Report is a partial reply to Question 243(IV) and Study Programme 243 A(IV).

Study Group IV concludes that a preferred type of telecommunications system for meteorological satellites should not be specified at this time. The experimental work conducted to date is of great value. The value to the meteorological service of the use of meteorological satellites has been demonstrated. There is, however, a great need for more experimental data to resolve certain design considerations.

The following Report describes the current U.S.A. programme for a meteorological satellite system as presented in Doc. 70 and 24 of Geneva, 1963. It is to be realized, however, that this development is offered as an example only.

Further studies as well as investigations of experimental systems are necessary.

Doc. 70 (U.S.A.) of Geneva, 1963, discusses "Nimbus", a meteorological satellite, in detail and draws attention to the potential uses of meteorological satellites to complement conventional meteorological data by providing data which is not, at present, available.

The system discussed is based upon placing a stabilized and attitude controlled satellite in a circular, retrograde orbit inclined at 80° and at an altitude of 800 to 1200 km.

The U.S.A. plans to use a frequency in band 8 for the tracking and maintenance telemetering system of this experimental meteorological satellite system. The 3-camera television system together with its data storage and transmission link is described. This television camera system provides a three-array picture, covering 2600 by 800 km when the spacecraft is at an approximate altitude of 1100 km. Successive frames overlap by roughly 10%. Complete daylight orbital coverage is obtained by 32 picture frames. Tape recorders are provided in the satellite which can store up to 64 frames (or two orbits) which, upon telecommand, can be played back to an earth station in 10 minutes.

The television camera system will show the complete meteorological cloud cover over the illuminated side of the globe at local noon. Over the unlit half of the globe, a high resolution infra-red radiometer system is used. The output of the infra-red detector system is also stored on a tape recorder in the satellite capable of play-back to an earth station upon telecommand.

In addition to these data systems, the Nimbus meteorological satellite will employ a telemetering system for providing maintenance information on both the operation of the satellite and of the data systems.

Doc. 24 (U.S.A.) of Geneva, 1963, predicts some future developments in meteorological satellites based upon extrapolation of experience gained from the initial meteorological satellite.

The possibilities of increasing the resolution of the television camera system thus allowing discrimination between ice and clouds is discussed. Cloud types and other significant meteorological features are also recognizable when resolution is increased. These types of operations will increase the bandwidth requirements of meteorological satellites.

---

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

The benefits of using cloud and precipitation detection radars on board meteorological satellites is also discussed together with an indication of the approximate spectrum area where good radar returns from clouds or precipitation will occur. These radars would operate in the same manner as the television camera system. The radar data for each orbit would be stored on tape and played back upon telecommand to an earth station.

The future possibilities of including systems for the collection of sferics data and microwave spectroscopy data are also discussed.

The philosophy of placing the operational meteorological satellite in frequency bands adjacent to bands used in the development of these systems is discussed in this paper, together with the possibilities of frequency sharing with conventional meteorological aids.

These technical studies of meteorological satellite systems indicate, that present and future developments of meteorological satellites can use frequencies in bands 8, 9 and 10 for telecommand, telemetering, low data-rate meteorological information, high data-rate meteorological information, and precipitation radars. Cloud detection radar could operate in band 11.

L. 6- Maintenance telemetering, tracking and telecommand

No Reports in this sub-section

L.7 - Space research

REPORT 218 *

TECHNICAL CHARACTERISTICS OF TELECOMMUNICATION LINKS BETWEEN EARTH STATIONS AND SPACECRAFT FOR RESEARCH PURPOSES

(Question 237(IV))

(Geneva, 1963)

1. Introduction

This Report presents a summary of the technical characteristics and system parameters of the telecommunication systems used for the purposes of space research. The discussions and conclusions provide a foundation for establishing the radio-frequency spectrum requirements for space research purposes, and for ensuring that the maximum practical use is made of this spectrum space.

2. General system considerations

There are three basic telecommunication systems which are required by nearly all spacecraft. These are:

— a telemetering system for transmitting to the earth station, data obtained from the sensor systems in the spacecraft, or from its human occupants;

— a tracking system to provide information regarding the position and velocity of the spacecraft necessary for computing its orbit;

— a telecommand system to enable the ground experimenter to guide or control the spacecraft.

In addition, some spacecraft will carry television equipment and voice communication equipment.

The detailed technical characteristics of these telecommunication links differ widely from one system to another, making standardization impracticable at this time, particularly for research spacecraft. However, sufficient experience has been gained to make possible a compilation of typical characteristics for several types of spacecraft systems. A list of these characteristics is given in Table I.

Because of severe limitations on size and weight, many spacecraft use combined tracking-telemetering-telecommand-video-voice systems similar to those illustrated in Fig. 1. Such systems have the advantage of allowing one receiver and one transmitter to perform several functions simultaneously, thus providing for efficient spectrum usage.

More detailed information regarding the technical characteristics of telecommunication links between earth stations and spacecraft, pertinent to the determination of suitable operating frequencies and bandwidth is given in the following sections of this Report. Additional technical information, pertinent to telecommunication links between earth stations and spacecraft, is presented in [1 to 9].

3. Telemetering systems

3.1 *Modulation techniques*

In a general way, the modulation forms employed for telemetering can be classified in two major categories:

— time-division multiplex systems;

— frequency-division multiplex systems.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, *1963*.

TABLE I

Illustrative experimental communication links between earth stations and spacecraft

Parameter		Typical near-earth satellites	Lunar orbiter with television	Lunar lander with television	Mars orbiter with facsimile	Probe to edge of solar system with cosmic-ray counter
Range (km)		10^3 to 10^4	4×10^5	4×10^5	4×10^8	4×10^{10}
Earth station antenna	gain (db)	25	50	60	60	60
	diameter (m). (ft).	12 40	26 85	76 250	76 250	76 250
Spacecraft antenna	area (m^2)	0·18	3·5	3·3	25	25
	beamwidth	Omni-directional	3°	4·7°	1·2°	1·2°
Temperature of earth system (°K)		300 to 400	125	225	25	25
Radiated power of spacecraft (W)		0·1 to 10	20	10	150	150
Frequency (Gc/s)		0·2	2·3	2·3	2·3	2·3
Video bandwith for a signal-to-noise ratio of 30 db (c/s)		1×10^3 to 2×10^6	10^6	10^6	$2{\cdot}5 \times 10^3$	
Video bandwidth for a signal-to-noise ratio of 20 db (coded transmission) (c/s)		Not used	10^7	10^7	$2{\cdot}5 \times 10^4$	2·5
Time for spacecraft to reach destination			3 days	3 days	200 days	6 years (electric propulsion)

The performances of various specific modulation systems are described in considerable detail [10 to 22] and [26 to 28] and especially in [20]. In general, time-division multiplex systems make more efficient use of the transmitted energy for highly accurate measurements (1% to 3% accuracy, or better). For less accurate measurements, frequency-division multiplex systems are simpler and will, therefore, remain desirable for certain applications.

The radiated power per bit of information in the presence of noise may be reduced by increasing the occupancy of the radio-frequency spectrum. Conversely, bandwidth occupancy may be contracted by expending more energy per bit of information. Limitations in the power capabilities of spacecraft will thus tend to make modulation system design lean toward a smaller amount of energy per bit of information at the expense of bandwidth. Frequency or phase modulation systems are attractive, because they can exchange bandwidth for transmitter power fairly easily. Pulse-code modulation systems also accomplish this exchange by proper selection of the code structure. Extensive use can safely be predicted in the immediate future for suitable orthogonal coding techniques in space telemetering.

3.2 *Storage and processing of data aboard the spacecraft*

The use of on-board data storage and processing techniques provides a possibility for significant reduction in the required bandwidths for the information to be transmitted and of transmitter power.

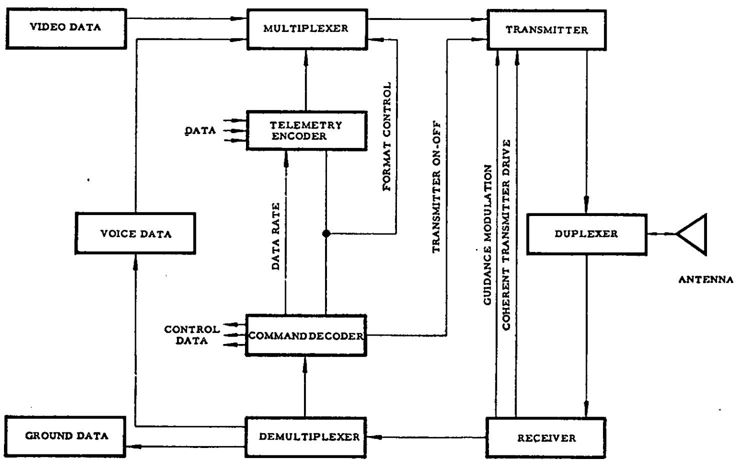


FIGURE 1

Typical block diagram of a spacecraft for a system of integrated tracking, telemetering and telecommand

Data storage can provide a step-down conversion between real-time and actual transmission rates to reduce transmission bandwidth. This technique is particularly effective when the source produces information at a high rate, but for short periods of time. Also, the use of on-board data storage permits several spacecraft to share common earth station facilities, since the information stored by the spacecraft may be transmitted only when commanded by a ground station.

On-board data processing has not as yet been extensively employed because the weight, power, and complexity of the equipment required have been incompatible with the requirements of the spacecraft. Greater use of this technique in the future depends greatly on component reliability and miniaturization.

3.3 *Required bandwidths for spacecraft to earth station telemetering links*

The estimates of radio-frequency bandwidth in Table II refer to a single link of each type contemplated; in consequence, it will be necessary to estimate the total number of spacecraft in operation at any one time, the number of links per spacecraft and the extent to which frequencies can be shared to obtain final estimates for the total bandwidth required.

The estimates in Table II allow for the width of the radiated radio-frequency spectrum, typical guard bands, Doppler shifts and transmitter frequency-drifts.

TABLE II

Bandwidths for data transmission for typical spacecraft

Frequency range (Mc/s)	Type of signal	Radio-frequency bandwidth per link
Less than 1000	Telemetering	10 to 100 kc/s
	Wideband data	50 to 500 kc/s
1000 to 5000	Telemetering	500 to 800 kc/s
	Wideband data and television	500 kc/s to 4 Mc/s
5000 to 10 000	Telemetering	500 kc/s to 4 Mc/s
	Wideband data and television	4 to 20 Mc/s

4. Tracking systems

4.1 *Introduction*

Reliable radio tracking of spacecraft is one of the basic requirements of any experimental space programme. In addition to providing information necessary to determine the location in space of the spacecraft at any instant (past, present, and future), tracking is also necessary for evaluation of launch performance, for vernier corrections to trajectories, for determining precise timing for critical manœuvres such as retro-rocket firing, and for pointing highly directional ground receiving antennae.

4.2 *Characteristics of interferometer tracking systems*

A simple type of spacecraft tracking system may use an unmodulated low-power transmitter on board the spacecraft and an interferometric receiving system on the earth, to provide a measure of the angular position of the spacecraft with respect to the antenna of the earth station. (In more common combined systems, however, the transmitter in the spacecraft is modulated by telemetering data.)

The power transmitted from the spacecraft will range from a fraction of a watt to a few watts; the fixed-array, receiving antenna at the earth station produces a fan-shaped beam of approximately 10° × 75°. A typical operating temperature for an earth station is 300°K to 3000°K, determined largely by the manner in which the system temperature depends on cosmic noise.

The optimum frequency range for the interferometer system is determined from consideration of the necessity for a good omnidirectional antenna on the spacecraft, transmitter efficiency in the spacecraft, and a sufficiently wide beamwidth for the earth antenna. Consideration of such factors usually favours a frequency below 1 Gc/s. More elaborate, moving antenna interferometers have been built for frequencies greater than 5 Gc/s, but atmospheric attenuation and noise usually limit their performance at frequencies greater than about 6 Gc/s.

4.3 *Characteristics of two-way coherent Doppler and ranging systems*

An interferometric system such as that described above, only provides angular-bearing information and several observations must be made over an appreciable period of time before the orbit of a satellite can be computed. When more precise data are required in a shorter time (e.g., manned space experiments), more elaborate tracking systems, which provide a measurement of range and range-rate as well as angular bearing, are required. One system of this type, uses a coherent turn-around transponder. In this type, a signal is transmitted from the earth to the spacecraft, where it is multiplied coherently by a rational fraction of the received frequency and retransmitted to the earth station.

A measurement of range is also obtained from turn-around systems by appropriate modulation of the carrier-frequencies of the earth station and the spacecraft. The main factor which dictates the maximum bandwidth needed per one-way channel is the range resolution required. Range resolutions of 15 to 50 m can be obtained by using appropriate modulations with bandwidths of about 1 to 3 Mc/s. The ranging systems are "duplex" systems and require equal transmitting and receiving bandwidths. Consideration of the design of antenna diplexers and the frequency multiplying circuitry in the spacecraft dictate that the "up frequency", transmitted from the earth, be spaced between 6% and 10% from the "down frequency" transmitted from the spacecraft.

The principal limitations imposed by tropospheric attenuation and ionospheric refraction [23] define a useful frequency range of 1 to 8 Gc/s for these precision tracking systems, which must operate during all weather conditions, and in which the error in incremental position is limited to between 10^{-5} and 10^{-4}.

4.4 *Radar systems*

Tracking information for short periods of time can also be obtained by the use of conventional pulse and CW radars. Such systems have proved particularly useful in the real-time tracking of manned space flights of short duration. Current plans indicate, that frequencies for conventional radar tracking systems will generally be available in the bands already assigned to the radio-location service.

5. Telecommand systems

A telecommand system is necessary to control functions within the spacecraft (manned or unmanned), from the earth station. It may use its own radio-frequency link or be combined in an integrated system, in which the radio-frequency link is shared with voice, ground data and tracking signals. Commands, transmitted to the spacecraft when it is in radio visibility of the earth station, can either be executed immediately as real-time commands, or stored in a memory to be extracted later and executed as stored-programme commands.

The telecommand signals are coded to provide a capacity for a number of discrete commands and to protect the spacecraft from spurious signals. Commands may be transmitted either by the use of various combinations of sub-carriers modulating the main carrier, or in the form of a serially pulse-coded transmission.

Typically the operating noise temperature of the telecommand receiver in the spacecraft is from 600°K to 3000°K and a design margin of 6 to 10 db is allowed for fading, nulls in the antenna pattern and degradation in equipment performance. Typical information rates range from as low as 1 to 10 bits per second for a deep-space probe to more than 1000 bits per second for some of the more complex near-earth satellites. The rates for manned spacecraft have attained as many as 32 000 bits per second.

The problem of interference for the telecommand receivers in spacecraft is difficult, in that the "wanted signal" is not always present—the interfering signal must not trigger the telecommand receiver even in the complete absence of the "wanted signal". However, this factor is partly offset by the rejection by the spacecraft of signals which are not properly coded.

6. Spacecraft voice links

The requirements for the transmission of voice, to and from a manned spacecraft, differ from more conventional mobile voice links in the high degree of reliability required during critical periods and the necessity for communications with a given spacecraft from points widely separated on the surface of the earth.

For normal speech transmission, an information bandwidth of 3 kc/s and a speech-to-noise ratio (for peak speech-power as read on a VU meter and r.m.s. noise power for flat spectrum noise) of 20 db is recommended.

6.1 *Speech compression techniques*

There is some promise that future requirements for power and bandwidth for voice transmission from spacecraft might be reduced by the use of the techniques of speech bandwidth compression. The results obtained to date, with experimental voice compression systems, suggest that word intelligibility of the order of 80% and 85% can be achieved with analogue bands of 200–800 c/s or with digital transmission rates of 1200 to 2000 bits per second. Assuming equal speech-to-noise ratios for uncompressed and compressed speech, analogue transmission of compressed bands can be expected to result in a transmission improvement of 6 to 12 db. Digital transmission at a rate of 1500 bits per second would be possible with a received power 4 db above the noise in a 6 kc/s band. Speech transmitted over such channels would not be comparable in quality to that transmitted by uncompressed analogue methods, but the potential exists for communicating by voice beyond the range of conventional voice transmission.

In considering the use of speech compression devices, the reduction in transmitter power they afford must be weighed against the penalties incurred by the additional weight and complexity of the equipment and by power requirements. At their present state of development, most of these equipments are rather bulky. The non-digital devices require considerable numbers of audio-frequency filters. Digital equipment requires in addition hundreds of transistors. It remains to be established that careful design and further development effort can produce speech compression equipment with physical characteristics and reliability suitable for use in manned spacecraft. A more quantitative evaluation of such equipment will be essential, but is beyond the scope of this Report.

6.2 *Power and spectrum conservation by peak clipping techniques*

Peaks some 15 db above the average speech power can be expected for about 0·1% of the time; smaller peaks occur more frequently. The peak factor (ratio of peak to average power) can be reduced by clipping the peaks above a specified level, thereby permitting higher average modulation and a higher average received signal. Clipping of peaks above 7 or 8 db permits a 5 to 1 reduction in transmitter power compared with that required for essentially unclipped speech, at a moderate sacrifice of speech quality and appears to be a reasonable compromise between quality and power.

6.3 *Modulation characteristics*

In spacecraft-to-earth voice links, emphasis is placed on minimizing the transmitter power requirements of the spacecraft. This is an important consideration both from the standpoint of primary power and of peak-power rating of the radio transmitting equipment. There is not a great difference in the size, complexity and weight of the output stages of radio transmitting equipment per watt of peak radiated-power for the various methods of modulation. Thus, a comparison of different modulations on the basis of peak-power requirements seems reasonable, but other equipment comparison must also be made. For example, both double-sideband (DSB) and single-sideband (SSB) equipments, transmitting and receiving, will involve additional complexity relative to AM and FM equipments. Furthermore, from the viewpoint of primary power in the spacecraft, average transmitter power may be of more importance than peak power, and average power will be substantially lower than peak power for DSB and SSB transmitters.

Pulse code modulation does not appear to offer transmission advantages in a single-link voice transmission system; however, it may be attractive for time-sharing a digital transmission channel with voice and telemetry.

6.4 *Carrier frequency*

In most circumstances it appears that the optimum frequency ranges for other earth station-to-spacecraft emissions, will also be the best for voice links. However, there are special situations where frequencies outside the normally recommended 100 Mc/s to 10 Gc/s will be required. Voice frequencies in the HF range are needed to extend the range of the voice link beyond the normal line-of-sight. Frequencies higher than 10 Gc/s appear to be useful for voice communications with the pilot of a spacecraft, in conditions of blackout during atmospheric re-entry.

7. Television systems

7.1 *Bandwidth*

The video bandwidth of a television system can be expressed as [24]:

$$\text{Bandwidth} = 0{\cdot}35 mL^2FR\ (1 - V)\,/\,(1 - H)\quad \text{(c/s)}$$

where

L = number of lines per frame,

F = number of frames per second,

R = width-to-height ratio of picture,

V = fraction of total vertical sweep-time, during which the trace is blank,

H = fraction of total horizontal sweep-time, during which the trace is blank,

m = ratio of horizontal-to-vertical resolution.

The values of R, V, and H of the above equation will remain approximately the same for all applications. The important parameters are, therefore, L and F. The choice of the value of L is a matter of the degree of resolution required for the mission.

Present day television systems for spacecraft, planned or in use, have from 200 to 800 lines per picture. With new pick-up devices under development, and the higher powers which will be available in future spacecraft, it is expected that the number of lines will be increased substantially.

In some applications, the time needed to read-out each frame for transmission to the earth may differ by orders of magnitude from the time used initially to view each frame. For example, in a recent series of meteorological-satellites, each picture is taken with an exposure time of 1·5 ms, while the time taken to transmit the picture is 2 s. For applications where a given number of pictures are taken, to be played back later, when the satellite is in view of a suitable earth station, the time needed to read out each frame is chosen to permit that number of pictures to be scanned during the time in view.

7.2 *Modulation*

In television broadcasting, vestigial side-band transmission is used to conserve spectrum. For space applications, the modulation method must be chosen primarily on the basis of minimizing weight and complexity. Given the video-bandwidth and the wanted signal-to-noise ratio, the designer may use a minimum radio-frequency bandwidth system, such as vestigial-sideband transmission and a corresponding transmitter power output, or a wider band system such as FM, FM with feedback, or pulse-code modulation, and a lesser power output.

Commercial quality television using pulse-code modulation would require a radio-frequency bandwidth of approximately 70 Mc/s. In general, it does not appear that pulse-code modulation offers any advantages in a single link video transmission system; however, slow speed television pulse-code modulation may be attractive for time-sharing a digital channel with telemetering.

7.3 *Carrier frequency*

For normal conditions, it appears that frequencies between 0·1 Gc/s and 10 Gc/s will be suitable for television between earth stations and spacecraft, with the centre of the range usually being most suitable.

7.4 *Interference*

The problem of interference on the space-to-earth circuit is somewhat different for television than for other types of signals. The wider bandwidth of the former makes it correspondingly more susceptible to outside interference. On the other hand, the damaging effects due to the loss of some television signals on a mission, are usually much less than a comparable loss of tracking, telemetering or telecommand signals. The error rates can therefore be somewhat higher.

8. **Transmitters in spacecraft**

The development of solid-state transmitters is advancing very rapidly. Moderate power may be generated by amplification techniques up to about 100 Mc/s, and at frequencies above this, efficient methods of parametric frequency-multiplication may be employed. The powers and the efficiency of conversion from d.c. to radio-frequencies achievable with solid-state devices (some experimental) (January, 1963), are given in Table III:

TABLE III

Frequency (Mc/s)	Power output (W)	Efficiency (%)
100	20	50
400	11	27
1000	6	15
2000	3	11
5000	1	4
10 000	0·25	1

Substantial increases may be expected during the period 1965-1970, in the powers and efficiencies achievable with solid-state transmitters, due to the rapid rate of progress.

Solid-state transmitters are inherently well suited to relatively wide-band applications. Due to the small size of solid-state devices, the low voltages involved (which renders pressurization unnecessary) and the simplicity of the problem of heat transfer, the weight of this type of transmitter can be much less than its tube counterpart.

Powers in excess of those tabulated can be obtained with various types of vacuum tubes, such as high trans-conductance triodes, tetrodes, beam power-tubes, klystron oscillators, klystron amplifiers, backward-wave oscillators, voltage-tuned magnetrons and travelling-wave tubes.

Triodes, tetrodes and beam power-tubes are most efficiently used in medium bandwidth systems in the UHF region and below. Powers in excess of 150 W are possible in push-pull configurations with conversion efficiencies from d.c. to radio-frequencies, of approximately 15%.

High level output above the UHF region is best obtained with voltage tuned magnetrons, klystron oscillators, klystron amplifiers and travelling-wave tubes.

9. Antenne for spacecraft

For many applications, essentially isotropic antennae are required for spacecraft. Such antennae can usually be designed much more readily at frequencies toward the low end of the spectrum, below 1 Gc/s, than above. However, some antennae for spacecraft have been designed which produce omnidirectional radiation pattern characteristics at frequencies as high as 10 Gc/s, with a loss of efficiency not exceeding a few db.

Considerations of pointing accuracy and surface precision for a directional antenna on a spacecraft are essentially the same as those for a directional antenna at an earth station. However, some of the problems encountered with high-gain antennae on the earth will be absent in space. For example, the mechanical design of an antenna might be simpler since it will not involve loadings due to gravity, wind and ice; on the other hand, problems of erecting antennae with suitable surface accuracy and protection against micrometeorites will be important. Isotropic or small broad-beam antennae are usually desirable for spacecraft, to minimize the requirements for stabilization and attitude control, but for communication at very great distances high-gain spacecraft antennae are essential. Precision in attitude control and the other factors mentioned above will limit the antenna beamwidth on the spacecraft. For a gain degradation of 1 db due to pointing errors of $\pm 0{\cdot}2°$, $\pm 1°$ and $\pm 3°$, the minimum beamwidths at the 3 db points are approximately 0·8°, 4°, and 12° respectively. Assuming typical antenna diameters of 1 foot (30 cm), 3 feet (98 cm), 10 feet (3 m) and 30 feet (9·8m), the corresponding frequency limits are given in Table IV.

TABLE IV

Beamwidth (degrees)	Frequency (Gc/s) for antenna size (m)			
	0·3	0·9	3	9
0·8	87·5 (1)	29·2 (1)	8·75	2·92
4	17·0 (1)	5·7	1·70	0·57
12	5·7	2·0	0·57	0·2

(1) The upper frequency limits are determined by atmospheric absorption rather than by minimum usable beamwidths.

10. Receivers for spacecraft

On the spacecraft, a low-noise receiver would be desirable, but this might not be worth a large weight penalty, since a more powerful transmitter at the earth station could compensate for less receiver sensivity. If a narrow-beam antenna is used on a spacecraft, it would "see" the earth station transmitter against a background at 300°K (temperature of the surface of the earth), so there would be no advantage in a receiver temperature much lower than 300°K. The noise-temperature of typical spacecraft receivers range from 600°K to 3000°K.

A deep-space probe, however, would see a far lower temperature, particularly at frequencies above a few hundred megacycles per second, since the earth will not fill the antenna beam. Therefore, a low-noise receiver could advantageously be used, space and weight considerations permitting. The sensitive receivers, however, are more susceptible to man-made interference and thus demand better spectrum control.

11. Earth station antennae.

The type of antenna at an earth station used for space research, tracking and data acquisition, depends to a large degree, on the particular mission requirements and spacecraft performance including orbital characteristics. It can, therefore, be expected that earth station antennae will have a number of configurations for experimental telecommunication links between earth stations and spacecraft.

11.1 *Fixed-beam, low-to-medium gain antenna at earth stations for automatic tracking*

Many scientific near-earth satellites will operate at frequencies below 1 Gc/s and at altitudes where angular rates are high. For these applications, a number of fixed fan-beam antennae or low-to-medium gain, automatic-tracking, parabolic reflectors or arrays will be used.

11.2 *High-gain antennae at earth stations for automatic-tracking*

For deep-space missions and for high-information rate near-earth satellites, earth station antennae with gains and effective aperture areas as large as practicable will be required. The antenna gain and effective area of earth station antenna are limited by the mobility oj massive structures for tracking spacecraft, attainable manufacturing tolerances, and meteorological conditions.

11.2.1 *Tracking*

The tracking errors of antennae, which use automatic tracking circuitry to control the pointing of the main beam, must be less than one-half the beamwidth at maximum gain. This limitation is closely related to the tracking rates involved;

for near-earth orbital vehicles, angular rates can be as high as several degrees per second, but may be as low as sidereal rates (0·004 deg/s), or even essentially zero with stationary satellites.

11.2.2 *Surface tolerance*

The accuracy of the surface contour which can be fabricated and maintained with loads due to gravity, heat, wind and ice decreases as the size of the antenna increases. Current manufacturing practices result in an r.m.s. deviation from a true parabola ranging from approximately $1{\cdot}0 \times 10^{-4}$ to $2{\cdot}5 \times 10^{-4}$ times the antenna diameter. Fig. 2, based on a method developed by Ruze [25], shows the frequency at which maximum gain occurs as a function of antenna diameter for an r.m.s. deviation from a true parabola of $10^{-4} \times$ diameter. Fig. 3 shows antenna gain as a function of frequency for several parabolic antennae of different diameters with an r.m.s. surface deviation equal to $10^{-4} \times$ diameter.

11.2.3 *Meteorological conditions*

Insufficient information is at present available regarding the phase instability of the earth's atmosphere during periods of adverse meteorological conditions, to predict accurately the degradation in gain which can be expected with large paraboloidal antennae. Present estimates indicate that the combination of limitations on structural tolerance and the inhomogeneities of the earth's atmosphere will probably limit the gain of large aperture antennae to between 60 and 70 db.

12. Receivers at earth stations

The smallest signal that a radio receiver can detect is limited by the ambient noise generated in the receiver and that contributed by external sources. At the earth station receiver, the noise is kept as low as possible, to minimize the power requirements of the spacecraft transmitter. The effective input noise temperature of earth station receivers, due to the receiving equipment alone, should be capable, by 1965, of being reduced to the range 5°K to 10°K over the part of the spectrum concerned. Except for possible man-made interference, the major contribution to the total system-noise will be the antenna background-noise which is a function of the operating frequency, angle of elevation of the antenna, existing meteorological conditions, and ground thermal radiation into the antenna side- and back-lobes. Sky background noise, due to the galaxy and sun bursts, decreases with frequency (approximately as $f^{-2{\cdot}5}$) while noise due to the earth's atmosphere increases above 1 Gc/s. For frequencies above approximately 4 Gc/s, heavy rainfall can increase the noise contribution due to the atmosphere to more than 100°K. Using narrow-beam antennae at the earth station down to angles of elevation of 5°, under adverse weather conditions, the minimum overall operating noise temperature which can be expected is 30° to 40°K at approximately 2·5 Gc/s. This temperature is almost lower by a factor of 100 than that of conventional terrestrial service systems.

13. Transmitters at earth stations

The transmitter powers and stabilities required in the foreseeable future at earth-stations, for telecommunication links between earth-stations and spacecraft, should not present any serious technical problems. It may sometimes be necessary to programme the Doppler frequency-shift into the earth-station transmitter to reduce the bandwidth or complexity of spaceborne receivers and antennae. By 1965, the powers of earth-station transmitters greater

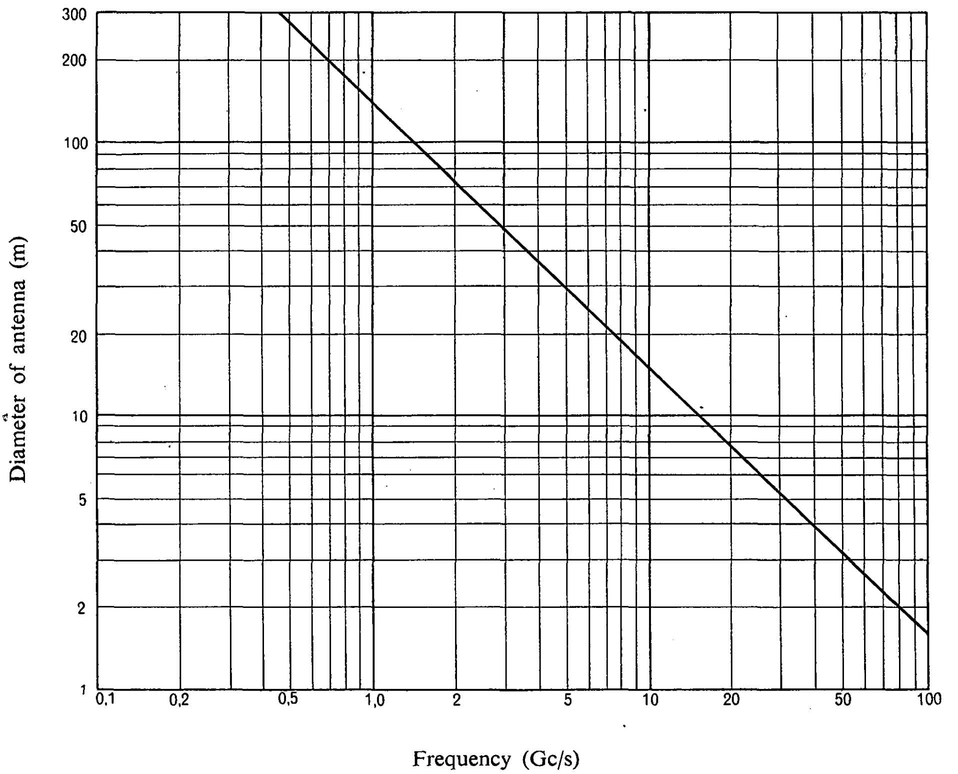


FIGURE 2

Frequency at which maximum gain occurs as a function of antenna diameter ($\sigma/D = 10^{-4}$)

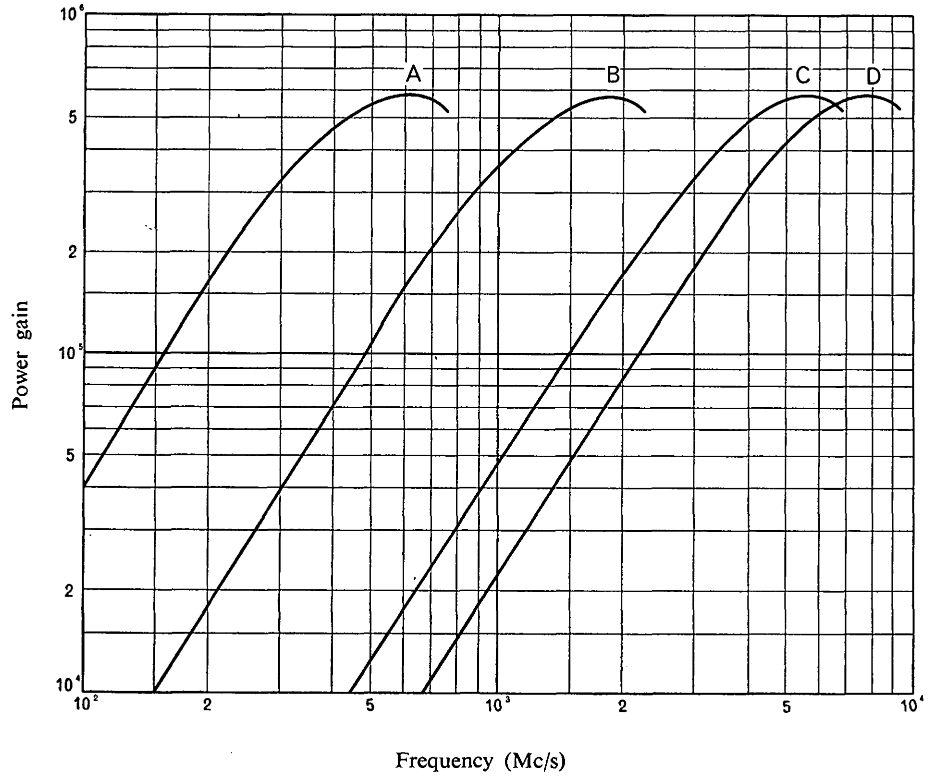


FIGURE 3

Gain/frequency characteristic for antennae of various diameters (based on $\sigma/D = 10^{-4}$)

A : Antenna diameter: 750 ft (230 m)
B : Antenna diameter: 250 ft (76 m)
C : Antenna diameter: 85 ft (26 m)
D : Antenna diameter: 60 ft (18 m)

than 100 kW will be needed in the frequency range under consideration, and should be realizable.* Occasionally, the geographical location, antenna characteristics, and distance from earth stations of other users sharing the same frequency, may limit the amount of radiated power of specific earth-based transmitters.

14. Radio-frequency spectrum

14.1 *Introduction*

The subject of the choice of frequency bands suitable for telecommunication links between earth stations and spacecraft is covered in considerable detail in Report 205. On the basis of the information contained therein, and in the preceding sections of this Report, it is possible to specify those frequency ranges in the radio-frequency spectrum for which allocations are required for various links between earth stations and spacecraft for research.

14.2 *Below 1 Gc/s*

Frequencies below 1 Gc/s, particularly in the range from 100 Mc/s to 500 Mc/s, are suited primarily for transmission from near-earth spacecraft. Frequencies in the region from 100 Mc/s to 300 Mc/s are desirable for use by existing tracking networks and the extensive VHF networks which have been established for reception of telemetering data.

The use of frequencies in the region from 100 Mc/s to 500 Mc/s is especially attractive for spacecraft and earth stations which have very broad or isotropic antenna patterns. Such patterns are normally required for spin-stabilized or unstabilized spacecraft and simple earth stations without facilities for antenna tracking.

14.3 *Between 1 and 6 Gc/s*

The radio-frequency spectrum from 1 to 6 Gc/s is expected to be the region which will be most heavily used for links between earth stations and spacecraft for research. In this range, the galactic noise density is low, atmospheric absorption is low, low noise parametric and maser preamplifiers are feasible, directional spacecraft antennae whose gains are compatible with the capabilities for attitude stabilization and beam-steering of the spacecraft are practical, and both surface tolerance and pointing accuracy requirements for large earth station antennae can be met.

14.4 *Between 6 Gc/s and 10 Gc/s*

Frequencies in the range from 6 to 10 Gc/s will be required to accommodate very wideband (10 to 100 Mc/s) precision tracking and communication systems. Some re-entry links may also use frequencies in this range. Low-noise parametric and maser pre-amplifiers are feasible in this region and galactic noise is even lower than that in the 1 to 6 Gc/s region; however, atmospheric absorption is somewhat higher and atmospheric noise can be considerably higher.

14.5 *Above 10 Gc/s*

At present the solution of the problem of re-entry "black-out" can only be solved by the use of frequencies above 10 Gc/s. It is unlikely that operation will be attempted above the partial atmospheric window at about 34 Gc/s, because of the heavy atmospheric absorp-

---

* It should be noted that these high powers will be used with high-gain antennae with beamwidths less than 1° and angles of elevation greater than 5°.

tion, although, with very high speed re-entry, operation at even higher frequencies may possibly be required. Practical considerations will, in general, force the frequency of operation as close as possible to the lower end of this range.

15. Conclusions

15.1 Tracking, telemetering and telecommand systems will be required on essentially all experimental spacecraft; in addition, many spacecraft will also carry voice and video telecommunication systems. These systems will normally be combined to reduce the number of transmitters required aboard the spacecraft and to conserve radio-frequency spectrum.

15.2 Because of differing research mission requirements, the same links between earth stations and spacecraft in current or planned use do not all depend on the same parameters. It is, therefore, premature at this time to attempt establishment of system or performance standards.

15.3 The choice of frequencies most suitable for telecommunication links between earth stations and spacecraft are determined by consideration of several factors including: propagation, noise, and interference; gains and patterns of spacecraft and earth station antennae; availability of electrical power, transmitter efficiency, complexity and reliability of the system in the spacecraft; weight and volume of the spacecraft; and the nature and required bandwidth of the data to be transmitted. Most useful frequencies are those between 100 Mc/s and 10 Gc/s, although some frequencies below 100 Mc/s, particularly in the HF range, will be required for voice communication from manned spacecraft, and some frequencies above 10 Gc/s will be required for communications with spacecraft re-entering the earth's atmosphere.

15.4 Frequencies from 100 Mc/s to 1 Gc/s will be used primarily for telecommunications with near-earth spacecraft, especially where the use of wide-beam or non-directional antennae are required on the spacecraft or on the earth.

15.5 The range from 1 Gc/s to 10 Gc/s will be used for applications involving directional antennae and wide bandwidth links, such as precision tracking systems and video transmission links.

15.6 The bandwidths required for the transmission of telemetering data range from a few kilocycles per second in the region below 1 Gc/s to many megacycles per second in the regions above 1 Gc/s.

15.7 The bandwidths required for tracking range from a few kilocycles per second for simple interferometer systems operating below 1 Gc/s to several megacycles per second for precision, coherent turn-around systems operating at higher frequencies.

15.8 The widths of the basebands required for typical telecommand systems are of the order of a few kilocycles per second, but Doppler frequency-shift, being much larger, usually determines the required radio-frequency bandwidths.

15.9 Voice transmission between earth stations and spacecraft does not differ greatly from other mobile voice links, except in the high degree of reliability required and the necessity for communications with a given spacecraft from points widely separated on the surface of the earth. There is some promise, that future requirements for voice bandwidth might be reduced by the use of the techniques of speech bandwidth compression.

15.10 For normal conditions, it appears that frequencies between 0·1 and 10 Gc/s will be suitable for television between earth stations and spacecraft, the centre of this band usually being most suitable.

BIBLIOGRAPHY

1. RECHTIN, E. Deep-space communications. *Astronautics*, Part I (April, 1961); Part II (May, 1961).
2. RECHTIN, E. Space communications. Jet Propulsion Laboratory. *Technical Release* No. *34*, 68 (May, 1960).
3. PIERCE, J. R. and CUTLER, C. C. Interplanetary communications. Advances in space science. Vol. I, Academic Press (1959).
4. MCCOY, C. T. Space communications. *Philco Corporation Report* No. *279*.
5. MUELLER, G. E. A pragmatic approach to space communication. *Proc. IRE*, 557-566 (April, 1960).
6. VOGELMAN, J. H. Propagation and communications problems in space. *Proc. IRE*, 567-574 (April, 1960).
7. SMITH, A. G. Extraterrestrial noise as a factor in space communications. *Proc. IRE*, 593-599 (April, 1960).
8. SWERLING, P. Space communications. *Rand Corporation Report* P. 1443.
9. SHANNON, C. E. Communication in the presence of noise. *Proc. IRE*, 10-21 (January, 1949).
10. INTER-RANGE INSTRUMENTATION GROUP, I.R.I.G. Telemetry standards. Document No. 106-60 (November, 1960).
11. OLIVER, B. M. and PIERCE, J. R. The philosophy of PCM. *Proc. IRE*, 1324-1331 (November, 1948).
12. BALAKRISHNAN, A. B. and ABRAMS, I. J. Detection levels and error rates in PCM telemetry systems. *IRE Convention Records* (March, 1960).
13. CAHN, C. R. Performance of digital phase-modulation communication systems. *IRE Transactions on Communication Systems* (May, 1959).
14. CAHN, C. R. Performance of digital phase-modulation communication systems. *Ramo Wooldridge Report M110-9U5* (April, 1959).
15. DEVELET, J. A., Jr. A note on demodulation of PCM/PM signals with switching-type phase detectors. *S.T.L. Report No. 8616-0001-NU-000* (June, 1961).
16. VITERBI, A. J. On coded phase-coherent communications. *J.P.L. Report No. 32-25* (August, 1960).
17. DEVELET, J. A., Jr. A note on product demodulation of binary PCM/PM signals. *S.T.L. Report No. 8949-0002-NU-000* (February, 1961).
18. LAWTON, J. G. Theoretical comparison of binary data transmission systems. Cornell Aeronautical Laboratory (May, 1958).
19. STUMPERS, F. L. H. M. Theory of frequency-modulation noise. *Proc. IRE* 1081-1092 (September, 1948).
20. NICHOLS, M. H. and RAUCH, L. L. Radio telemetry. John Wiley and Sons, Inc. (June, 1957).
21. BAGHDADY, E. J. Lectures on communication system theory. McGraw-Hill (1961).
22. SANDERS, R. W. Communication efficiency comparison of several systems. *Proc. IRE*, 575-588 (April, 1960).
23. BARTON, D. K. and SHERMAN, S. M. Pulse radar for trajectory instrumentation. *Proceedings of Sixth National Flight Test Instrumentation Symposium, Instrument Society of America* San Diego, California (3 May, 1960).
24. FINK, D. G. Television engineering. McGraw-Hill, New York, 31-32 (1952).
25. RUZE, J. Physical limitations on antennae. *Technical Report* No. 248, Research Lab. for Electronics, *M.I.T.* (October, 1952).
26. BATTAIL, G. Etude générale comparée des systèmes de modulation. *Colloque International de l'U.R.S.I. sur les recherches en télécommunications spatiales* (Paris, September 1961). Elsevier(1962).
27. BATTAIL, G. Détermination approximative de la position extrême du seuil de réception en modulation de fréquence. International Symposium on Information Theory, Brussels (September, 1962) *IRE Transactions on Information Theory*, **8,** 5.
28. BATTAIL, G. Un démodulateur pour modulation de fréquence, utilisant une estimation préalable de la fréquence instantanée. International Conference on satellite communication (London, November, 1962), published in *Proc. I.E.E.*

REPORT 219 *

INTERFERENCE CONSIDERATIONS FOR NEAR-EARTH RESEARCH SATELLITE TELECOMMUNICATION LINKS

(Questions 236(IV), 237(IV) and Study Programme 205(VI))

(Geneva, 1963)

1. Purpose of the Report

This Report presents technical information applicable to the establishment of criteria for prevention of harmful interference to experimental near-earth research satellite telecommunication links from other telecommunication services. Examples of system designs and functions are given, followed by a discussion of appropriate interference protection criteria.

2. Illustrative designs

Techniques for communicating with near-earth satellites are covered in considerable detail in Reports 205 and 218. Selection of optimum frequencies, types of modulation, and the characteristics of antennae, transmitters, and receivers are discussed in these Reports.

Earth terminals are located to provide optimum coverage of earth-satellite orbits. Because of the relatively short periods that a near-earth satellite may be within view of any one instrumentation site, acquisition time is of the utmost importance, and while effective operation is difficult below 5° elevation, acquisition is attempted at lower angles of elevation.

The tasks assigned to near-earth satellites, and the time available for read-out of large amounts of data result in larger radio-frequency bandwidth requirements than those associated with similar functions on deep-space missions.

3. Radio-frequency interference protection criteria

The degree of protection from radio-frequency interference, generated by external sources, which is required by any receiving system depends upon the sensitivity of the system to interference and the consequences of the degraded reception upon the overall operation.

3.1 *Protection for the earth-station*

Radio frequencies from about 100 Mc/s to 10 Gc/s have been shown to be suitable for near-earth satellite communications (see Reports 205 and 218). The variety of functions and the conditions under which they must be performed further divides this region into the following desired bands: 100 to 300 Mc/s, 300 Mc/s to 1 Gc/s, and 1 to 10 Gc/s. Within these frequency

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

bands the following operating noise temperatures for typical receiving systems can be achieved within the scope of the present techniques:

Frequency	Operating noise temperature of system (°K)
100 Mc/s	3000
500 Mc/s	300
1 to 10 Gc/s	30

As an example, maser receivers operating at microwave frequencies are available, which have an internal thermal noise figure of about 10°K. This internal thermal noise, plus the addition of 6° to 8° from radiation of the earth into the antenna back and side-lobes, and 3° to 13° (depending upon the angle of elevation), from atmospheric and galactic background would constitute a system operating at —214 dbW per c/s (30°K). In addition, there is a contribution from atmospheric water vapour which is a function of frequency, angle of elevation and weather conditions.

Interference, which is considerably less than the background noise discussed above, is of no consequence. The permissible ratio of interference to background noise is determined by the design margins customarily used in the particular communications links. Typical design margins for near-earth satellite links from space to earth of 3 to 6 db are characterized primarily by the lack of available electrical power on board the spacecraft, because of severe penalties in weight and cost. These small design margins are practical only because noise and propagation conditions are optimized and utmost care is exercised in equipment design tolerances. Significant penalty results in the communication system design whenever man-made interference increases the total noise level by more than 1 db. Complete communications and tracking disruption could occur if the interference level were two or three times that of background noise.

Background noise, with its relatively constant spectral density, produces a particular kind of performance degradation which the communications link is designed to accept. The same amount of interference concentrated in narrow-frequency bands would be much more harmful to functions such as Doppler, narrow-band telemetering, synchronization and certain types of range modulation, all of whose bandwidths may typically be of the order of 1 to 100 c/s depending upon the mode of operation. Because signals are moved across a band of frequencies by Doppler shift, an interfering carrier would successively harm each sub-carrier or sideband (disrupting the corresponding telemetry channel or range tone), as the Doppler shift changes.

A significant increase in background noise level for prolonged periods of time is not likely to occur. However, sporadic interference from man-made sources can be expected, due to the dependence of trans-horizon propagation on fluctuating weather conditions, the changing gain in the link between the interfering station and the receiving station due to relative motions of the antennae, etc. Therefore, any established interference criterion must be stringent enough to minimize the possibility of this type of interference. Critical periods are only during the times the satellite is within viewing range of a tracking site. Thus, for any one site the duty cycle per satellite over a 24-hour period may be quite low, because of the requirement to obtain a large amount of data in a relatively short period of time.

The following criterion is therefore the most directly appropriate for protection of a near-earth satellite ground instrumentation site:

for frequencies greater than 1 Gc/s, the total time during which the power density of the interference, in any single and all sets of bands 1 c/s wide, is greater than —220 dbW per c/s, shall not exceed 0·1% of the time; for frequencies below 1 Gc/s the permissible interference power density may be increased at the rate of 20 db per decade of decreasing frequency.

Such a criterion acts strongly against narrow-band interference, carriers, and discrete sub-carriers, but is relatively permissive to interference distributed uniformly across the earth-satellite radio-frequency bandwidth.

Specifying the power density at the receiver input terminals, rather thant the spatial power density (W/m^2), has two particular advantages for the present discussion. It is independent of frequency within a broad frequency region and it permits advantage to be taken of the exact siting of the earth-station antenna and its pattern characteristics. These characteristics are generally in the direction of reducing the interference level at the receiver inputs.

As mentioned in § 2, the directional antenna of the earth-station will seldom be used below angles of elevation of 5° for normal full performance communications. Therefore, many of the earth antennae have an effective capture area in the horizontal direction where the gain is equivalent to an isotropic antenna. A more refined estimate, based on specific antenna pattern characteristics, might be expected to lead to a ± 10 db modification to the isotropic assumption. Typical 85 ft (28 m) diameter dish-type earth-antenna beamwidths will be between 0·2° and 6° between half-power points, over the frequency range of 100 Mc/s to 4 Gc/s with the near side-lobes (5 to 20 beamwidths) averaging 10 db above isotropic, with side and back lobes averaging zero to 12 db below isotropic. Beamwidths of the less elaborate antennae at the lower frequencies may be as great as 20°. Using the assumption of isotropic gain as a first approximation, the interference power density in dbW per c/s can be converted to an equivalent interference spatial power density by multiplying by the effective area of a unity gain antenna. For example, at 1·7 Gc/s, the effective area of the isotropic antenna is $2{\cdot}5 \times 10^{-3}$ m^2 and the interference spatial power density is —194 dbW per c/s/m^2 (corresponding to —220 dbW per c/s).

3.2 *Protection for the spacecraft*

The derivation of a criterion for protection of the spacecraft is similar to that of the earth station.

3.2.1 Some factors which make spacecraft more vulnerable than earth stations are:

— the spacecraft is in the line-of-sight of great areas of the earth;

— the antennae on the spacecraft are, of necessity, pointed continuously and directly at the earth and potential interfering sources;

— limitations on weight generally prevent the design of elaborate receivers to reject interfering signals.

3.2.2 Some of the factors which reduce the vulnerability of the spacecraft are:

— the receiver operating noise temperature in the spacecraft is normally limited (600°K or —171 dbW per kc/s), by the necessity of viewing the warm earth;

— the design margins are higher on the earth-to-space link, permitting the interference spectral density to exceed that of the noise background;

— the detection bandwidth of the spacecraft is greater, due to the need for rapid, automatic acquisition of the earth signal;

— the angular motion of the spacecraft in the heavens keeps it from remaining very long within the (fixed) main beam of an interfering station;

— the telecommand signals are normally coded, providing the spacecraft with some protection against spurious signals;

— in some instances, vulnerability of the spacecraft command-receiver can be further reduced by raising its sensitivity threshold.

In view of these factors, a spacecraft receiver can operate satisfactorily under interference levels 10 db greater than the receiver noise temperature. The appropriate criterion for spacecraft protection is therefore:

the total time during which the density of the interference, in any single and all sets of bands 1 kc/s wide is greater than —161 dbW/kc/s, shall not exceed 0·1% of the total time.

4. Examples of mutual interference

The following examples are intended to show the approximate magnitude of the mutual interference problem in various situations for simple line-of-sight transmissions.

4.1 *Other stations within line-of-sight of the earth-terminal*

The allowable power densities (—220 dbW per c/s and —210 dbW per c/s) are produced by the sources described below radiating into the side-lobes of isotropic gain of satellite earth receiving antenna operating at 500 Mc/s and 1·5 Gc/s.

TABLE II

Source	Distance (km)	Bandwidth (1) (kc/s)	E.r.p. to produce −210 dbW per c/s at 500 Mc/s	E.r.p. to produce −220 dbW per c/s at 1·5 Gc/s
Fixed, mobile or aircraft	10	5	0·25 μW	0·2 μW
		5000	0·25 mW	0·2 mW
Aircraft	100	5	25 μW	20 μW
		50	0·25 mW	0·2 mW
Aircraft	1000	5	2·5 mW	2 mW
		50	25 mW	20 mW

(1) Uniform spectral density assumed. If the spectral density is not uniform, lower values of e.r.p. result.

The above examples show that all of the typical line-of-sight sources listed will produce harmful interference to an earth receiving station of a satellite-earth link, because every source type normally radiates more e.r.p. than would be permitted by the interference criteria and often in narrow-band form.

4.2 *Other stations within line-of-sight of the satellite*

A power density of —161 dbW per kc/s is produced by the sources described below radiating into an omnidirectional antenna on a satellite receiving at 500 Mc/s and 1·5 Gc/s.

TABLE III

Source	Distance (km)	Bandwidth (1) (kc/s)	E.r.p. to produce −161 dbW per kc/s at 500 Mc/s	E.r.p. to produce −161 dbW per kc/s at 1·5 Gc/s
Fixed, mobile or aircraft	500	1	10 mW	100 mW
		50	500 mW	5 W
		1000	10 W	100 W
	1000	1	40 mW	400 mW
		50	2 W	20 W
		1000	40 W	400 W
	3000	1	400 mW	4 W
		50	20 W	200 W
		1000	400 W	4 kW

(1) Uniform spectral density assumed. If the spectral density is not unform, lower values of e.r.p. result.

The above examples show that some line-of-sight sources can operate within the criterion, providing the satellite remains at a high altitude (above 1000 km) and does not remain in the main beam of the interfering station for too long since the e.r.p. via the side-lobes of such sources is typically less than that in the Table, particularly for frequencies in the region above 1 Gc/s. There are some exclusions: terrestrial radars, whether aimed at the satellite or not, can be harmful and, in turn will probably be harmed if receiving on the satellite transmitting frequency. In general, harmful interference from a satellite into other terrestrial circuits is unlikely. The satellites will be in the main beam of the other circuit only occasionally and for short periods of time, because of the angular motion of the satellite in the sky.

4.3 *Other stations over the horizon from an earth station*

The permissible distance between an interfering source and the affected trans-horizon receiving system is theoretically calculable, providing the interference criterion and sufficient knowledge of the propagation conditions are known. Minimum permissible distance between typical earth-stations and terrestrial stations with the parameters listed below have been computed, using the methods outlined in Doc. IV/45 of Washington, 1962 and propagation data from Doc. V/102 of Geneva, 1962.

TABLE IV

	Terrestrial station	Earth-station
Transmitter power	10 W	1 kW
Bandwidth of the emission	10 Mc/s	4 kc/s
Coupling loss (db)	4	4
Sum of antenna gains in pertinent direction (db)	0	0
Effective temperature at receiver input (°K)	900	25
Unit receiver bandwidth	4 kc/s (1)	1 c/s
Noise power in unit of bandwidth	—163 dbW/4 kc/s	—215 dbW/1 c/s
Maximum tolerable interfering power per unit of bandwidth	—163 dbW/4 kc/s	—221 dbW/1 c/s
Available transmitter power per unit of bandwidth	— 64 dbW/1 c/s	26 dbW/4 kc/s

(1) 4 kc/s was chosen as the reference bandwidth of the terrestrial station following the method outlined in Doc. IV/45 of Washington, 1962.

These calculations, which indicate that interference from the earth-station transmitter to the terrestrial station receiver is the limiting factor, show that the minimum separation required ranges from more than 500 km at 100 Mc/s to approximately 300 km at 1 Gc/s, 250 km at 2 Gc/s, and 200 km at 4 Gc/s.

Caution should be exercised in applying these illustrative computations to specific situations; for example, if naturally shielded sites are available it may be possible to obtain 10 to 50 db of additional attenuation between the sites. On the other hand, an aircraft in mutual view of the two stations (interfering and interfered), can produce harmful interference by reflection of the signals from one station to the other station, particularly if the aircraft is in the beam of one of the stations.

Terrestrial radars over the horizon from the earth stations can produce harmful interference if they illuminate aircraft, space objects, or the moon which are above the horizon of the earth station. Depending upon the circumstances, the illuminated target may or may not have to be in the main beam of the earth station. For this reason, it is highly desirable that the space research service should not share frequencies with terrestrial radars, almost regardless of point-to-point distance separation along the earth. The interference can be shown to be mutual if the radar is receiving on the earth station-to-satellite transmitting frequency and both stations are viewing the same target.

4.4 *Other stations over the horizon from a satellite*

From the previous discussion, stations over the horizon from the satellite are unlikely to create mutual interference problems.

4.5 *Sharing within the space-research service*

The sharing of frequencies among near-earth satellite telecommunication links will be feasible because of the use of directional ground receiving antennae, on-board data storage, on-board data processing, and the increasing use of ground commands for the initiation and cessation of transmission. However, to avoid mutual interference problems, considerable prior planning and close coordination will be required.

Sharing of frequencies among near-earth satellites and deep-spacecraft is not desirable, since satellites will seriously interfere with reception from deep-space by an earth-station whenever the satellites are within line-of-sight of the earth-station.

5. Conclusions

It is concluded that near-earth satellite research telecommunication links can share frequencies with certain fixed and mobile terrestrial services. For some sharing situations, as shown in this Report, separation of several hundreds of kilometres can be required. If near-earth satellite research is to be undertaken in areas where required separations are difficult to obtain, co-equal sharing with other services does not appear practical.

REPORT 220 *

INTERFERENCE CONSIDERATIONS FOR TELECOMMUNICATION LINKS USED FOR DEEP-SPACE RESEARCH

(Questions 236(IV), 237(IV) and Study Programme 205(VI))

(Geneva, 1963)

1. Purpose of Report

This Report is intended to present technical information applicable to considerations of mutual interference between deep-space communications for research and tracking and various other services. Designs for deep-space telecommunication links and operations are given for illustration, followed by a discussion of the appropriate interference criteria. The Report concludes with the results of application of the criteria to various types of mutual interference.

2. Illustrative designs

There have been many studies made of conventional and unconventional techniques for communicating to and from the earth and spacecraft journeying to the moon and beyond. The most practical approach is now generally agreed to be communications using directional antennae operating at decimetric wavelengths (see Report 218). Typical antennae for spacecraft have diameters between 1 m and 10 m. The radiated powers from spacecraft are on the order of tens to hundreds of watts. Practical earth antennae have diameters between 20 m and 80 m. Effective radiated powers (e.r.p.) from the earth are on the order of 10 kW, during the early portion of flight, to more than 1000 MW for flight near the planets. The operational noise temperatures of the receivers are typically 25°K, at frequencies greater than 1 Gc/s (except for lunar landings, when the noise temperature of the moon increases the system temperature by about 100°K), and 600°K to 3000°K for the spacecraft. At frequencies lower than 1 Gc/s, the system temperatures are increased by cosmic noise (see Report 205, Fig. 6). For example, for reception at 100 Mc/s, one may expect a system temperature greater than 500°K for the earth station and greater than 1000°K for the spacecraft.

Earth stations for deep-space links are usually located in terrain providing a natural horizon of several degrees above the horizontal. Full performance communication and tracking is seldom planned for angles of elevation less than about 10°, with initial acquisition of the signals beginning at about 5°. Operations are characterized by critical periods immediately after earth launching, during mid-course (vernier) manœuvres, and during the terminal phases at the moon or planets. The critical periods last from a few minutes to several hours, depending upon the technique. For lunar operations, the critical periods occur approximately once a day.

3. Interference criteria

The degree of protection from interference required by any receiving system depends upon the sensitivity of the system to interference and the consequences of degraded reception upon the over-all operations.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

3.1 *Protection for the earth-station*

Frequencies from about 400 Mc/s to 10 Gc/s have been shown to be suitable for earth-space communications (see Report 218). The need for highly efficient communications combined with precise tracking, particularly characteristic of deep-space operations, tends further to restrict the preferred frequencies to the region between 1 and 4 Gc/s.

Within this frequency range, operating noise temperatures of 25°K can be expected for operational deep-space earth stations. This temperature, equivalent to —215 dbW per c/s referred to the receiver input, is composed of about 10° from the maser receiver and input circuit, 6° to 8° from radiation of the earth into the back-and side-lobes of the antenna and 3° from atmospheric and galactic background noise at zenith which may increase to 13° at an angle of elevation of 10°. In addition, there is a contribution from atmospheric water vapour which is a function of the frequency, the angle of elevation and weather conditions. Experimental data on the contribution from water vapour to the temperature are at present limited. At frequencies near 6 Gc/s, the water vapour contribution, during and preceding heavy rainfall, can occasionally increase to between 50°K and 100°K.* Deep-space earth stations are therefore located, at present, in comparatively dry, desert country and are so spaced around the earth that reception at low angles of elevation is required as seldom as possible. The preferred frequency ranges for reception at earth stations are clearly those characterized by relatively small effects due to water vapour (less than 4 Gc/s).

Interference which is considerably less than the background noise level is of no consequence. The permissible ratio of interference to background noise is determined by the design margins customarily used in the particular communications link. Typical design margins for deep-space links from space to earth are limited to approximately 6 db by severe penalties in the weight and cost of the spacecraft. Such small margins are practical, only because noise and propagation conditions are favourable, and because equipment tolerances can be controlled carefully. The operating margins can, in practice, be expected to average 3 db. Design of a communication link becomes much more difficult when man-made interference increases the total noise level by more than 1 db. Complete disruption of communications and tracking could occur if the interference level were two or three times that of the background noise.

Background noise, with its nearly constant spectral density, produces a particular kind of degradation in performance, which the communication link is designed to accept. The same amount of interference concentrated in a narrow frequency band would be much more harmful to deep-space Doppler narrow-band telemetry, telecommand, television synchronization, and certain types of range modulation, the bandwidths of which are typically of the order of 1 to 100 c/s. Because signals sweep over a considerable frequency range by Doppler shift and carrier instabilities, an interfering carrier would successively harm each sub-carrier or sideband (disrupting the corresponding telemetry channel or range tone), as the Doppler shift changes.

The background noise level encountered in the decimetric frequency region is also reasonably constant in time. Burst noise and prolonged interruptions are not expected. Man-made interference, however, can be expected to be sporadic, due to the dependence of trans-horizon propagation on fluctuating weather conditions, the changing gain in the link between the interfering station and the receiving station, due to relative motions of the antennae, etc. It is therefore necessary to specify the permissible durations of interruptions, due to interference, compatible with anticipated deep-space flight operations. As mentioned in § 2 of this Report, critical periods last from several minutes to several hours and occur approximately once a day. Loss of more than five minutes of communication during these periods would seriously

---

* Hogg, D.C. and Semplak, R. A. The effect of rain on the noise level of a microwave receiving system. *Proc. IRE*, 48, 2024-2025 December 1960).

affect the success of the mission. Loss for more than fifteen minutes could easily result in failure of the mission.

The following criterion is, therefore, the most directly appropriate for protection of a deep-space earth station:

For frequencies greater than 1 Gc/s, the total time during which the power density of the interference, in any single and all sets of bands 1 c/s wide, is greater than —221 dbW per c/s at the receiver input terminals of a deep-space earth station shall not exceed five minutes per day.

For frequencies less than 1 Gc/s, the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade.

Such a criterion acts strongly against narrow-band interference, carriers, and discrete sub-carriers, but is relatively permissive to interference uniformly distributed across the deep-space communication bandwidth.

Specifying the power density at the receiver input terminals, rather than the spatial power density (W/m^2) has two particular advantages for the present discussion. It is independent of frequency within a broad range of frequencies. It also permits advantage to be taken of the exact siting and pattern characteristics of the antenna at the deep-space earth station. These characteristics are generally in the direction of reducing the interference level at the receiver inputs.

As remarked before, the directive antenna of the deep-space earth station will seldom be used below an angle of elevation of 10° for normal full performance communications. Therefore, the deep-space earth antennae have an approximate capture area in the direction of the horizon corresponding to isotropic gain. A more refined estimate, based on specific characteristics of the antenna pattern, might be expected to lead to a modification of ± 10 db to the isotropic assumption. Typical beamwidths for earth antennae will be between 0·03° and 3° between the half-power points, with the near side-lobes (5 to 20 beamwidths) averaging 10 db above isotropic, and far and back-lobes averaging zero to 12 db below isotropic. Using the assumption of isotropic gain as a first approximation, the interference power density in dbW per c/s can be converted to an equivalent interference spatial power density by multiplying by the effective area of an antenna of unity gain. For example, at 2·3 Gc/s, the effective area of the isotropic antenna is $1{\cdot}36 \times 10^{-3}$ m^2 and the interfering spatial power density is —192 dbW per c/s-m^2 (corresponding to —221 dbW per c/s) at the receiver terminal.

3.2 *Protection for the spacecraft*

The derivation of a criterion for protection of the spacecraft is similar to that of the earth station, but some modification is, however, necessary.

3.2.1 The factors which make spacecraft more vulnerable than earth stations are:

- — the spacecraft is in line-of-sight of great areas of the earth;
- — the antennae on the spacecraft are necessarily pointed directly at the earth and potential interfering sources;
- — in the vicinity of the earth, the antenna gain of the spacecraft is usually adjusted with altitude such that the beamwidth just includes the earth (0 db at low altitudes, 20 db at 30 000 km, 30 db at 100 000 km, etc.);
- — the critical periods may occur when the spacecraft is over any point on the earth.

3.2.2. The factors which reduce the vulnerability of the spacecraft are:

- — the vulnerability period of the spacecraft is normally limited to the near-earth portion of flight by a variety of operational considerations;

— the operating noise temperature of the receiver in the spacecraft is limited (600°K or —201 dbW per c/s) by the necessity of viewing the warm earth;
— the design margins are higher on the earth-to-space link, permitting the interference spectral density to equal that of the noise background;
— the detection bandwidth on the spacecraft is greater (1 kc/s), due to the need for rapid, automatic acquisition of signals from the earth;
— the angular motion of the spacecraft in the heavens keeps the spacecraft from staying very long within the (fixed) main beam of an interfering station (angular motions are 0·25°/min. or faster. Typical beams are 1° wide);
— the high velocity of the spacecraft keeps it from staying longer than 5 min within 1000 km of any one station;
— the telecommand signals are coded, providing the spacecraft with some protection against spurious signals.

The appropriate criterion for protection of the spacecraft is therefore:

For frequencies greater than 300 Mc/s the total time during which the power density of the interference, in any single and all sets of bands 1 kc/s wide, is greater than —171 dbW per kc/s at the input terminals of the receiver in the spacecraft, shall not exceed five minutes per day.

For frequencies less than 300 Mc/s, the permissible interference power density may be increased at the rate of 20 db per decreasing frequency decade.

4. Examples of mutual interference

The following examples are intended to show the order of magnitude of the mutual interference in various situations for single line-of-sight transmissions.

4.1 *Other stations within line-of-sight of a deep-space earth station*

A power density of —221 dbW per c/s is produced by the sources described below, radiating into the 0 db side-lobes of a deep-space earth station operating at 2·3 Gc/s.

TABLE I

Source	Distance (km)	Bandwidth (1) (kc/s)	E.r.p. needed to equal −221 dbW per c/s
Fixed, mobile aircraft . .	10	5 5000	0·5 μW 0·5 mW
Aircraft	100	5 50	50 μW 0·5 mW
Aircraft, satellites	1000	5 5000	5 mW 0·5 W

(1) A uniform spectral density is assumed. If the spectral density is not uniform, lower values of the e.r.p. result.

The above examples show that typical line-of-sight sources will produce harmful interference to a deep-space earth station, because each type of source in Table I normally radiates a considerably higher e.r.p. (and often in narrow-band form) than would be permitted by the interference criterion. This interference can be expected to be mutual because a typical deep-space earth station often transmits 100 kW through its 0 db side-lobes.

4.2 *Other stations within line-of-sight of the spacecraft*

A power density of —171 dbW per kc/s is produced by the sources described below, radiating into an omnidirectional antenna on the spacecraft receiving at 2·1 Gc/s. As discussed in previous texts, distances less than 1000 km need not be considered.

TABLE II

Source	Distance (km)	Bandwidth (1) (kc/s)	E.r.p. needed to produce −171 dbW per kc/s
Fixed, mobile, aircraft and satellites	1000	1	0·1 W
		50	5 W
		1000	100 W
	3000	1	1 W
		50	50 W
		1000	1 kW
	greater than 3000 (2)	1	1 W
		50	50 W
		1000	1 kW

(1) A uniform spectral density is assumed. If the spectral density is not uniform, lower values of the e.r.p. result.

(2) Assumes that the antenna gain of the spacecraft is adjusted for altitude.

The above examples show that a variety of line-of-sight sources can exist within the criterion, providing the spacecraft does not remain too long in the main beam of the interfering station, because the e.r.p. via the side-lobes of such sources is typically less than that in Table II. There are some possible exclusions. Terrestrial radars, whether aimed at the spacecraft or not, will be harmful and, in turn, will probably be harmed if receiving at the transmitter frequency of the spacecraft. Care should be taken to determine the possible presence of sources of narrow-band radiation below the spacecraft during the near-earth phase of flight. On the other hand, without illustrating the calculations here, it can be stated that harmful interference from the spacecraft into other terrestrial circuits is unlikely. The spacecraft, because of its angular motion in the sky, will seldom be in the main beam of the other circuit. Also, the distance from the spacecraft to the other service will be at least ten times as great as the length of the service circuit.

4.3 *Other stations over the horizon from a deep-space earth station*

The permissible distance between an interfering source and the affected trans-horizon receiving system is theoretically calculable, providing the interference criterion and sufficient knowledge of the propagation conditions are known. Minimum permissible distances between typical deep-space earth stations and terrestrial stations with the parameters listed below have been computed using the methods outlined in Doc. IV/45 of Washington, 1962. (In the absence of applicable propagation data for the 5-minute-per-day limitation propagation data for interruptions lasting 0·1% of the time, as given in Doc. V/103 of Geneva, 1962, were used.)

TABLE III

	Terrestrial station	Deep-space earth station
Transmitter power	10 W	100 kW
Bandwidth of emission	10 Mc/s	1 kc/s
Coupling loss (db)	4	4
Sum of antenna gains in pertinent direction (db)	0	0
Operating noise temperature (°K)	900	25
Unit receiver bandwidth	4 kc/s	1 c/s
Noise power in unit bandwidth	—163 dbW/4 kc/s	—215 dbW/1 c/s
Maximum tolerable interfering power per unit bandwith	—163 dbW/4 kc/s	—221 dbW/1 c/s
Available transmitter power per unit bandwidth	— 64 dbW/1 c/s	46 dbW/4 kc/s

From these calculations, which indicate that interference from the deep-space earth station transmitter to the terrestrial station receiver is the limiting factor, it can be shown that the minimum separation required ranges from 380 km at 4 Gc/s to more than 500 km at 1 Gc/s and is approximately 440 km at 2 Gc/s.

Caution should be exercised in applying these illustrative computations to specific situations: for example, if naturally shielded sites are available it may be possible to obtain 10 to 50 db of additional attenuation between the sites. On the other hand, an aircraft in mutual view of the two stations (interfering and interfered) can produce harmful interference by reflection of the signals from one station to the other, particularly if the aircraft is in the beam of one of the stations.

Terrestrial radars over the horizon from the deep-space earth station can produce harmful interference if they illuminate aircraft, space objects, or the moon which are above the horizon of the deep-space earth station. Depending upon the circumstances, the illuminated target may or may not have to be in the main beam of the deep-space earth station. For this reason, it is highly desirable that the deep-space service does not share frequencies with terrestrial radars, regardless of point-to-point distance separation along the earth. The interference potential can be shown to be mutual if the radar is receiving at the deep-space earth transmitting frequency and both stations are viewing the same target.

4.4 *Other stations over the horizon from a spacecraft*

From the previous discussion, stations over-the-horizon from the spacecraft are unlikely to create mutual interference problems.

4.5 *Sharing within the space service*

Different spacecraft at the same target will interfere with each other's transmission to the earth and consequently must use different frequencies.

Spacecraft at different planets, however, must be followed by different narrow-beam earth antennae and consequently mutual interference is unlikely.

Satellites will seriously interfere with reception at a deep-space earth station, whenever the satellites are within line-of-sight of the earth station.

5. Conclusions

Telecommunication links for deep-space research can share frequencies with fixed terrestrial services only in relatively remote areas, where terrain shielding or large geographical separations (several hundreds of kilometres) are possible. If deep-space research is to be undertaken in less remote areas, frequency sharing with other services does not appear practical.

REPORT 221 *

TELECOMMUNICATION LINKS FOR MANNED RESEARCH-SPACECRAFT

Frequencies, bandwidths and interference criteria

(Questions 236 (IV) and 237 (IV))

(Geneva, 1963)

1. Introduction

This Report summarizes those unique requirements of research, manned, space-flight which are not necessarily common to unmanned space-flight, and which necessitate special frequencies, bandwidths, and interference protection criteria. Technical characteristics and factors affecting telecommunication links between earth stations and spacecraft are covered in Reports 205 and 218 and those links not unique to research, manned space-flight will not be considered here.

The most over-riding requirement of manned space-flight is that of the safety of the astronaut. Since satisfactory communications have a direct bearing on safety, it is essential that only the most reliable communication techniques be used.

To this end, critical manned space-flight communications must use those portions of the spectrum where techniques of proven reliability exist and where the most beneficial propagation characteristics may be realized. Furthermore, it is essential that sufficient interference protection be afforded, so that the safety of the astronaut should not be compromised inadvertently.

2. Telecommand

Remote control of the spacecraft is essential to insure the safety of the spacecraft crew in the event of incapacity of the astronaut as well as to take advantage of the greater diagnostic capabilities which exist on earth. Such a command capability is not intended to replace control of the spacecraft by the astronaut, but rather, to supplement it. Additional inter-spacecraft telecommand may also be required between spacecraft for some missions to effect rendezvous and/or rescue.

Near-earth telecommand communications will use tone codes and frequency modulation to obtain the highest degree of protection from interfering signals. Earth transmitters with power outputs of 500 to 10 000 W, and directive antennae will be used. Due to equipment

---

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva *1963*.

and reliability considerations, the preferred frequency range for such functions will be between 20 and 600 Mc/s. The additional telecommand capability between spacecraft will also use this frequency range. In either case, bandwidths of approximately 50 kc/s per link will be required.

3. Telemetering

In addition to voice communications, telemetering will be relied upon to monitor the safety of the astronauts and to insure their well-being. Functions of the telemetering sub-system are to monitor the astronauts, to monitor critical environment, to monitor critical spacecraft sub-systems, and to aid in checking the operation of the spacecraft during flight. The latter item is unique to manned space-flight. Since safety of the astronaut is of the utmost importance, extensive earth based and onboard check-out of critical spacecraft sub-systems must be accomplished before human lives are committed to the mission, e.g. check-out of landing module in lunar parking orbit before descent to the moon.

Spacecraft transmitters will normally use frequency or phase-modulation of the carrier to conserve power and to provide the high signal-to-noise ratios required for data transmission. Typical power outputs are 1 to 10 W, and directionnal antennae will be used to provide extended range. Equipment and reliability considerations imply that typical telemetering bandwidths will range from 100 to 200 kc/s with a preferred frequency range between 20 and 600 Mc/s.

4. Voice communications

In manned space-flight research, voice communication, with its inherent flexibility of information transmission, is an essential factor in guaranteeing successful missions with maximum safety for the astronaut.

The technical considerations involved in the choice of carrier frequencies for this function lead to requirements in both the HF range below 20 Mc/s and in the 20 to 600 Mc/s range.

For communications between the spacecraft and control centres on the earth, reliable, line-of-sight, two-way links are needed. Spacecraft equipment and antenna problems lead to a preference for the 20 Mc/s to 600 Mc/s range for this purpose, with the 100 to 600 Mc/s range being generally more suitable when multipath transmission effects are considered. Low-powered (approximately 10 W) selectable frequency, voice-modulated transceiver equipment is most suitable for this application. This same equipment may be used at the time of initiating the descent to the surface of the earth. The sequence of events that occur at this time will govern the place on the earth at which the spacecraft will land. To deploy rescue and recovery forces, it is mandatory that the sequence of events be reported by the spacecraft personnel to the earth stations in a highly reliable manner. It is necessary, therefore, that no interfering signals be present on the channels in use. Accordingly, minimum interference voice frequencies should be provided in the 20 to 600 Mc/s range.

While in low earth orbit and as the spacecraft approaches the surface of the earth, communication ranges at VHF gradually diminish due to contracting line-of-sight conditions. It is therefore necessary to provide HF communications between the spacecraft and the earth stations and recovery forces. Primary power as well as space and weight limitations aboard the spacecraft dictate the use of a low powered (approximately 5 W) HF transceiver.

The actual radiated power from this equipment will be decreased by the type of antenna that can be provided on the spacecraft. It therefore becomes necessary to provide interference free voice frequencies in the HF range below 20 Mc/s for use by manned space-flight research missions. Additionally, the frequencies provided should be spaced within the HF range, so that reliable communications can be achieved under various propagation conditions.

REPORT 222 *

FACTORS AFFECTING THE SELECTION OF FREQUENCIES FOR TELECOMMUNICATIONS WITH SPACECRAFT RE-ENTERING THE EARTH'S ATMOSPHERE

(Question 239 (IV))

(Geneva, 1963)

The communications problem encountered by spacecraft re-entering the earth's atmosphere is due to the conversion of kinetic energy into thermal energy during the deceleration process, causing a layer of ionized air around the vehicle, which temporarily prevents the passage of some frequencies. This layer is commonly called the "plasma sheath", and its effect is called "re-entry radio blackout".

The vehicular plasma sheath, which is analogous in many respects to the ionosphere of the earth, contains free electrons in high concentration. These electrons are created by thermal ionization processes in the vehicle flow field. The resulting plasma interferes with the propagation of electromagnetic energy. The degree of interference depends upon the frequency of the electromagnetic energy, the number density or concentration of electrons, and the frequency of collision between electrons and air molecules.

In the same way that a layer of the ionosphere has a critical frequency which must be exceeded for signal penetration, the plasma sheath surrounding a re-entering vehicle also has a critical frequency. However, since the plasma sheath electron density will often be extremely high, the critical frequency will be correspondingly high.

The theory of electromagnetic propagation in an ionized layer is applicable to propagation through a plasma sheath [1, 2, 3]. In computing expected signal loss, the simplest approach is to consider plane-wave propagation through a relatively uniform plasma model. More exact computations, especially those which allow for appreciable variations in plasma properties within a wave length of the incident radiation, require involved mathematical techniques [4, 5, 7].

In addition, the possible effect of the plasma sheath on the impedance, and thus the efficiency of an antenna, must be considered. This effect will normally be appreciable even at frequencies higher than the critical frequency of the sheath.

For a re-entering spacecraft, estimates can be made of the effect of the plasma sheath on signal transmission using the theory of electromagnetic propagation, in conjunction with the aerodynamic and thermodynamic characteristics of the flow field of the spacecraft. These predictions must take into consideration such factors as the configuration of the spacecraft, the velocity, altitude, operating frequency, etc., as well as the effect of detuning of the antenna.

The propagation computations result, quite generally, in a transmission curve giving high loss at frequencies lower than the critical frequency. The extent of the transition region depends on the collision frequency and, for thin layers, on the thickness of the layer as well. Provisional estimates and a few experimental results indicate that the critical frequency is often as high as 1 to 10 Gc/s, and may sometimes be even higher.

---

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

It is concluded that frequencies of 10 Gc/s or higher are technically required for some re-entry communications, especially for re-entry from lunar or planetary missions [6].

At these frequencies, absorption in the earth's atmosphere can be very important. Report 205 gives data on this point. Although only operating frequencies higher than the critical frequency are considered in this Report, it is possible, on theoretical grounds, that frequencies in band 7 (3 to 30 Mc/s) or lower may be used. However, this has not yet been established experimentally. This and other possible techniques for re-entry communications remain to be explored.

The attention of U.R.S.I. is drawn to this Report.

BIBLIOGRAPHY

1. BACHYNSKI, M. P., JOHNSON, T. W. and SHKAROFSKY, I. P. Electromagnetic properties of high temperature air. *Proc. IRE*, **48**, 347 (March, 1960).
2. HOLLIS, R. Reciprocal relations in an N-slab dielectric. *Proc. IRE*, **49**, 1579 (October, 1961).
3. DIRSA, E. F. The telemetry and communication problem of re-entrant space vehicles. *Proc. IRE*, **48**, 703 (April, 1960).
4. RAWER, K. Elektromagnetische Wellen in einem geschichteten medium. (Electromagnetic waves in a stratified medium). *Annalen der Physik* (1939).
5. BUDDEN, K. G. Radio Wave Propagation in the Ionosphere. Cambridge (1961).
6. C.C.I.R. Doc. IV/14 (U.S.A.) of Washington, 1962.
7. KLEIN, M. M., GREYBER, H. D., KING, J. I. F. and BRUECKNER, K. A. Interaction of a non-uniform plasma with microwave radiation. Electromagnetic effects of re-entry. Selected papers from the Symposium on Plasma Sheath, its effect on communication and detection, Boston, Mass. (1959), Pergamon Press, 105 (1961).

L. 8- Radioastronomy

REPORT 223 *

LINE FREQUENCIES OR BANDS, OF INTEREST TO RADIOASTRONOMY AND RELATED SCIENCES, IN THE 30 TO 300 Gc/s RANGE ARISING FROM NATURAL PHENOMENA

(Question 244 (IV))

(Geneva, 1963)

The scientific interest in bands above 30 Gc/s has reached the stage where experimental components are being assembled at several laboratories, in preparation for observing programmes. The capabilities of these components are such, that the overall system performance will be adequate for observations at these frequencies. As a consequence of this scientific work, advances in component design and improvements in system performance may be anticipated, that will soon permit observations and possible use at frequencies higher than those discussed in Recommendation 314.

Our present knowledge of the atmospheric absorption characteristics in the 30–300 Gc/s range is summarized in Fig. 1. The centre frequencies of the absorption bands are shown by arrows. Pressure broadening is indicated by the difference between the curves for sea level and for an elevation of 4 km. Fig. 2 gives the total absorption by a one-way transmission through the atmosphere, for several zenith angles. Table I provides additional technical information, that is pertinent to future action at frequencies above 30 Gc/s (i.e. the 1 to 10 mm band).

TABLE I

Nature of phenomena	Frequency (Gc/s)	Band suggested for scientific programme (Gc/s)
Window in earth's atmosphere	30–35	31·3–31·5
OH	36·983–36·994	36–38
O_3	36·023 and 37·832	
Window in earth's atmosphere	80–90	88–90
N_2O	100·492	98–102
CO	115·271	110–120
O_3	118·364	
O_2	118·746	
Window in earth's atmosphere	130–150	(1)
NO	150·176–150·644	148–152
Window in earth's atmosphere	200–300	(1)

(1) Band recommendation must await further study.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

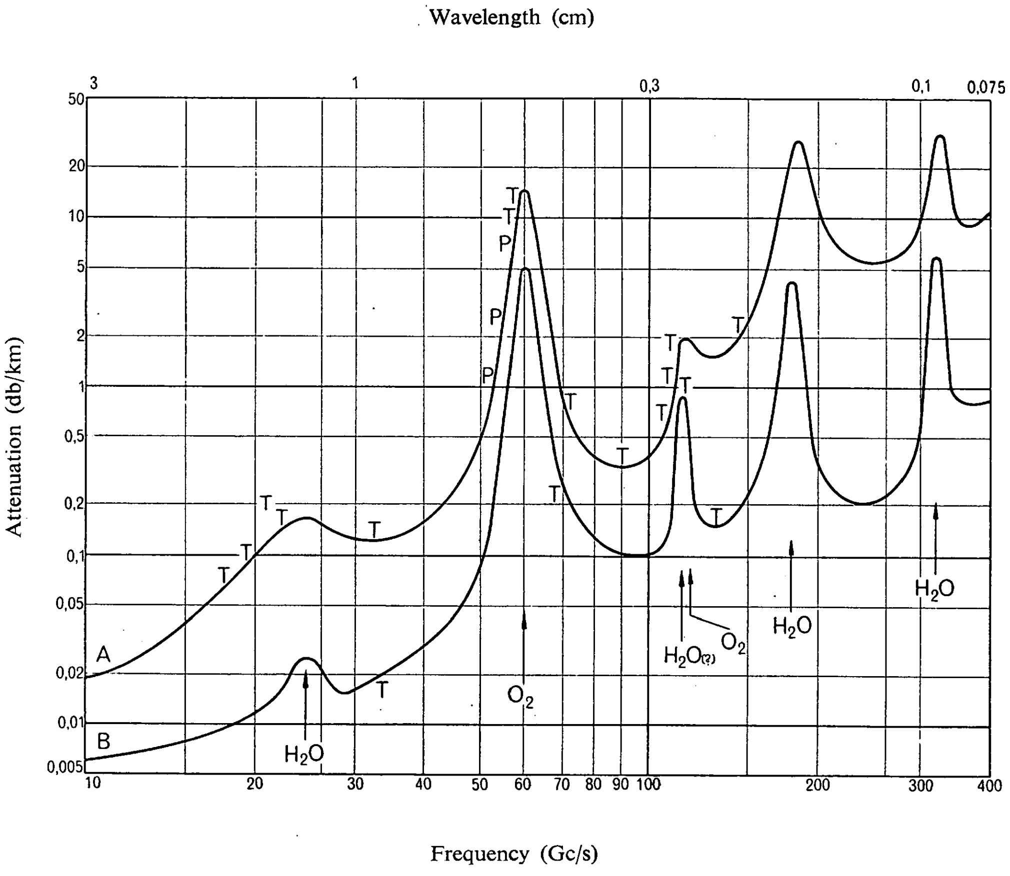


FIGURE 1

Attenuation per kilometre for horizontal propagation

A : sea-level; P = 760 mm Hg; T = 20°C; ρ (H_2O) = 7·5 gm/m³

B : 4 km above sea-level; T = 0°C; ρ (H_2O) = 1·0 gm/m³

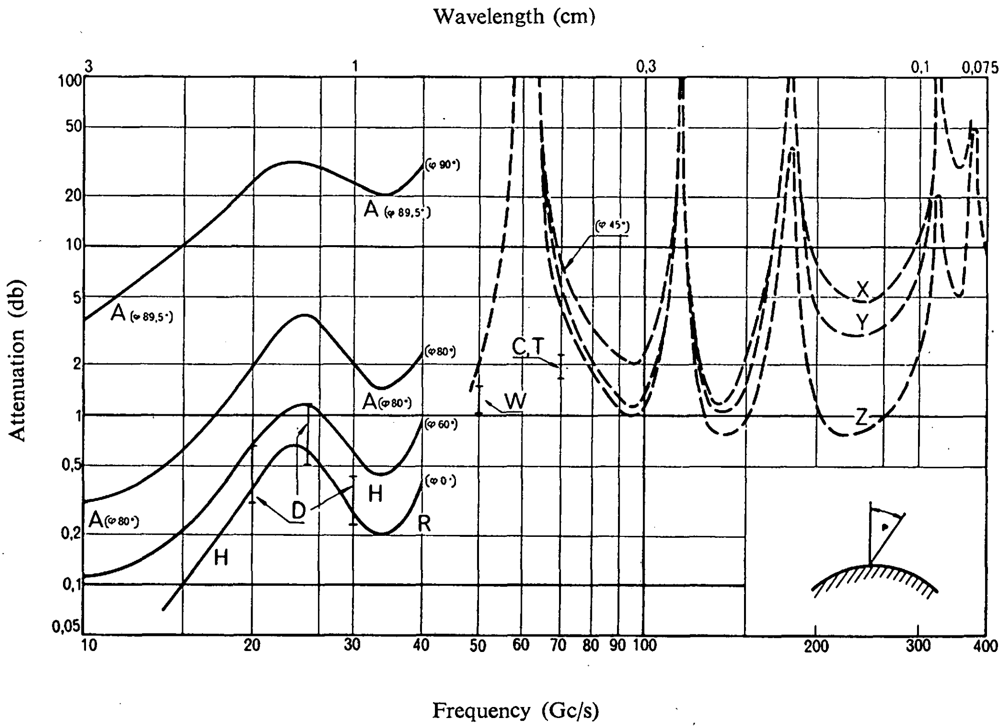


FIGURE 2

Total attenuation for a one-way transmission through the atmosphere

A: AARONS 1958
D: DICKE et al 1946
W: WHITEHURST 1957
T: TEXAS 1960
C: COATES 1958

H: Handbook Geoph. 1960
R: RING (HOGG 1960)
——— HOGG 1959, 1960
— — — THEISSING and KAPLAN 1958

X: humid
Y: mean
Z: dry

BIBLIOGRAPHY

1. DICKE, R. H. The measurement of thermal radiation at microwave frequencies. *Rev. Sci. Instru.*, **17**, 268 (1946).
2. VAN VLECK, J. H. The absorption of microwaves by oxygen. *Phys. Rev.* **71**, 413 (1947).
3. VAN VLECK, J. H. The absorption of microwaves by uncondensed water vapour. *Phys. Rev.*, **71**, 425 (1947).
4. GORDY, W. and HILL, R. M. Zeeman effect and line breadth studies of the microwave lines of oxygen. *Phys. Rev.*, **93**, 1019 (1954).
5. HOGG, D. C. and CRAWFORD, A. B. Measurement of atmospheric attenuation at millimetre wavelengths. *B.S.T.J.*, **35**, 907 (1956).
6. HOGG, D. C. Effective antenna temperatures due to oxygen and water vapour in the atmosphere. *J. Appl. Phys.*, **30**, 1417 (1959).
7. WHITEHURST, R. N., COPELAND, J. and MITCHELL, F. H. Solar radiation and atmospheric attenuation at 6-mm wavelength,. *J. Appl. Phys.*, **28**, 295 (1957).
8. AARONS, J., BARRON, W. R. and CASTELLI, J. P. Radioastronomy measurements at VHF and microwaves. *Proc. IRE*, **46**, 325 (1958).
9. BARRETT, A. H. Line spectra in radioastronomy. *Proc. IRE*, **46**, 250 (1958).
10. COATES, R. J. Measurements of solar radiation and atmospheric attenuation at 4·3 millimetres wavelength. *Proc. IRE*, **46**, 122 (1958).
11. KAPLAN, L. D. Inference of atmospheric structure from remote radiation measurements. *J. Opt Soc. Am.* **49**, 1004 (1959).
    Handbook of Geophysics (Revised). Macmillan Co., New York (1960).
12. MEEKS, M. L. Atmospheric emission and opacity at millimetre wavelengths due to oxygen. *J., Geop. Res.* **66**, 3749 (1961).
13. ROSENBLUM, E. S. Atmospheric absorption of 10-400 Gc/s radiation. *Microwave J.* **91** (1961).

REPORT 224 *

RADIOASTRONOMY

(Question 244 (IV))

(Geneva, 1963)

1. Introduction.

Radioastronomy has been a subject of scientific study for just over thirty years. Since the discovery of radio noise from cosmic sources in 1932 by Karl Jansky, this science has made great progress. In addition to the new knowledge of our universe which has been obtained, the pursuit of radioastronomy has played a part in the development of practical devices, including antenna systems and special receivers, which have been applied to other services. However, the rapid growth of radiocommunications may subject the radioastronomy service to interference to such a degree as to jeopardize its future.

To ensure the continued progress of this science at a comparable rate in the future, there is a need for the I.T.U. to give all practicable protection to the radioastronomy service.

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

2. Definition of radioastronomy.

Radioastronomy and the radioastronomy service are defined in Article I, Nos. 74 and 75 of the Radio Regulations, Geneva, 1959, as being astronomy based on the reception of radio waves of cosmic origin.

"Radar" astronomy, which involves the transmission of a signal at a high power level and the detection of that signal after reflection, from celestial bodies, man-made satellites or meteor trails, is a quite different service and is defined in Question 245 (IV).

3. Two classes of observations in the radioastronomy service.

3.1 Radioastronomy observations can be broadly divided into two classes.

3.1.1 *Class A observations* are those in which the sensitivity of the equipment is not a primary factor. They are used in the study of variations of cosmic radiations, generally well defined and often of relatively large intensity. Many of the solar, Jupiter, riometer and scintillation observations fall into this class. Continuity is a primary factor for these observations; they are commonly carried out on a routine basis and involve the setting-up of permanent services similar to other services covered by I.T.U. Regulations.

3.1.2 *Class B observations* are of such nature that they can be made only with advanced low noise receivers using the best techniques. The significance of these observations is directly related to the sensitivity of the equipment used in making them.

3.2 This division into two classes may sometimes simplify the administrative and technical measures needed to provide the appropriate level of protection. Class A observations can often be carried out with a protection of the order of 20 db less than is needed for class B programmes, which involve radio signals from celestial bodies at the limit of detectability.

The interference levels at radioastronomy observatories are discussed in Docs. IV/24, IV/49 and IV/64 of Washington, 1962. This last document provides a reference that will be helpful to those who are seeking observatory sites with favourable interference protection, which is relevant to the last paragraph, of Recommendation No. 32 of the Administrative Radio Conference, Geneva, 1959.

Tolerable interference levels are described for class B observations in Annex I. Because these tolerable interference levels are so very low, it is impracticable to measure them with conventional mobile survey equipment; it is difficult to measure them with a very sensitive radioastronomical receiver unless it is used with a high-gain antenna. Accordingly, it appears that the probability of interference must be computed for each case of a possible source of interference and a specific observatory site.

4. Details of radioastronomy observatories.

Recommendation 32, § 4, calls on Administrations for information concerning the locations of observatories and the frequencies in use. Doc. IV/25 of Washington, 1962, provides the information that was available before the Interim Meeting of Study Group IV. Having in mind the division of observatories into class A and class B, it is desirable to expand the information. Annex II is a tabulation of details of class B observatories in draft form.

It is desired that this tabulation be sent to Administrations to obtain their confirmation, with a request that they provide any additional information on the observatories or additional observations. This information will then be published as provided for in Recommendation No. 32 of the Administrative Radio Conference, Geneva, 1959, with the indication of the class of station (A or B).

5. Protection of frequencies for radioastronomy.

Recommendation 314 states basic frequency requirements for the radioastronomy service. These requirements are discussed in Docs. IV/24 and IV/48 of Washington, 1962; reference is also made to the Table of Frequency Allocations (Article 5, Section IV of the Radio Regulations, Geneva, 1959) and to Doc. IV/58 (Rev.) of Washington, 1962. It continues to be desirable that Administrations should individually seek to provide the maximum feasible protection for research in radioastronomy and related sciences. It is also necessary that new observatory sites be located as remotely as possible from man-made sources of interference. But it must be expected that the increase in power of ground-based transmitters and the advent of many orbiting devices will necessitate that more positive protection be given to the radioastronomy service. It may be that in some cases sufficient protection cannot be given, save by exclusive allocations on a world-wide or regional basis. This is a matter which requires further study.

In order that the radioastronomy service may be continued on a satisfactory and efficient basis, it is important that the status of protection of the bands of frequencies allocated to that service be improved to the greatest extent practicable.

ANNEX I

TOLERABLE LEVELS OF INTERFERENCE FOR RADIOASTRONOMY OBSERVATIONS IN CLASS B

1. Level of accuracy of class-B observations.

The extra-terrestrial signal detected in any radioastronomy observation is a broadband noise that is superimposed upon other noise signals, which are unavoidably produced in the receiver system itself or collected by the antenna from the sky, the ground, and from the earth's atmosphere. These different sources of noise are incoherent and thus add to give a total power level P which fluctuates with time. The root mean square fluctuation of P about its mean value is given by:

$$\Delta P = \frac{P}{\sqrt{2\,Bt}} \qquad (1)$$

where B is the bandwidth of the receiver and t is the total time of observation of the signal. Note that t is not the usual receiver time constant.

It is the usual pratice to express the power in terms of an operating noise temperature T_e, according to the quotation:

$$P = \mathrm{k} T_e B \qquad (2)$$

where k is the Boltzmann constant ($1{\cdot}38 \times 10^{-23}$ J/°K), T_e is in degrees absolute (°K) and B is in c/s. The root mean square fluctuation of T_e about its mean value is given by

$$\Delta T_e = \frac{T_e}{\sqrt{2\,Bt}} \qquad (3)$$

where t is the same as in (1).

From (1) and (3), it follows that ΔP or ΔT_e may be taken as a measure of the accuracy of the power or temperature determination made in class-B observations.

The operating noise temperature T_e is made up of a number of components, which correspond to the several sources of noise that contribute to P. These components will be considered separately.

One may write

$$T_e = T_{eff} + h\,T_a$$

where T_{eff} represents the component due to the receiving system and hT_a is the component due to the noise collected by the antenna. Although the numerical value of h may be greater, it has been taken as identically equal to unity in the discussion that follows, which pertains to a very good quality receiver.

The T_{eff} for many current receiving systems for class-B observations is about 200°K, or lower. The most advanced apparatus in use at a few observatories has a T_{eff} of the order of 20°K. It is expected that such low values of T_{eff} will be achieved in many observatories by 1967.

The antenna temperature, T_a, is a consequence of the following noise inputs to the antenna:

1.1 *Cosmic noise*

The flux density of radio-frequency radiation from the celestial sphere is a function strongly dependent on frequency and direction or position in the sky.

In Table I at the end of this Annex, we list, for several frequencies representative values of the minimum observed sky temperatures, T_a. We note that $T_a > T_{eff}$ for frequencies lower than 160 Mc/s; $T_a \simeq T_{eff}$ in the frequency range 160 Mc/s to 320 Mc/s; and $T_a < T_{eff}$ for frequencies higher than about 400 Mc/s.

1.2 *Radiation from the terrestrial environment*

For any class-B observation, particularly at higher frequencies, the observing programme is devised to minimize the effects of thermal noise from the terrestrial environment compared with T_{eff}.

From (1) and (3) it is seen, that the accuracy of a measurement is increased by using large B and large t. In current practice, B ranges from approximately 5 kc/s for discrete emissions (the precise bandwidth being fixed by the nature of the phenomenon being investigated), to several Mc/s for continuous radiation (where the limitation is the available frequency-band clear of disastrous interference). The total observing time, t, ranges from a few seconds to several hours or even days or weeks.

In (3) we shall take $T_{eff} = 200$°K; $B = 10$ Mc/s; $t = 2 \times 10^3$ sec. For these values, we find:

$$\Delta T_e = \frac{T_a + 200}{\sqrt{2 \times 2 \times 10^3 \times 10^7}}$$

$$= (5 \times 10^{-6})\,T_a + 0{\cdot}001$$

With the values of T_a given in Column 2 of Table I, we compute the values of ΔT_e given in Column 3 of Table I. These values of ΔT_e are representative of the potential (interference free) accuracy of the best observations currently being made (Doc. IV/24 of Washington, 1962).

2. Harmful and tolerable levels of interference.

A harmful level of interference will be reached when the unwanted signal-flux impinging upon the antenna is so great that the operating noise temperature is increased by an amount comparable to ΔT_e. If radioastronomers are to secure the advantages of low-noise receivers, the level of interference should not introduce an error of more than 10% in the measurement of a flux density corresponding to ΔT_e. For example, the flux density of a continuou; unwanted signal should be no greater than that corresponding to $0{\cdot}1\Delta T_e$; alternatively, the flux density of an unwanted signal corresponding to ΔT_e should not exist for more than 10% of the time.

To calculate the precise level of interference for any unwanted signal, we require knowledge of the antenna pattern and of the direction of the antenna in relation to the incoming unwanted signal.

2.1 *Unwanted signals in the side lobes*

We shall assume here that the interference arises from the unwanted signal coming in through the side lobes. To estimate typical values of the harmful interference level, we may approximate our real antenna by an isotropic antenna, except in the direction of the main lobe and the near side lobes. Under this simplifying assumption, we compute the flux density of unwanted signals that can be tolerated without serious degradation of the quality of the observation.

We adopt as a tolerable interfering flux density, a value corresponding to $0{\cdot}1\Delta T_e$. We let S_{tol} represent the tolerable flux density and derive:

$$S_{tol}\frac{\lambda^2}{4\pi} = 0{\cdot}1\, k\, \Delta T_e$$

$$S_{tol} = 1{\cdot}73\times10^{-23}\,\frac{\Delta T_e}{\lambda^2} \quad (\mathrm{W/m^2/c/s})$$

Values of S_{tol}, computed with the ΔT_e values quoted in Table I are listed in Column 7 of Table I.

2.2 *Unwanted signals in the main beam or near-in-side-lobes*

It is not possible to calculate the flux density of a tolerable interfering source located in or very bear the main lobe of an antenna without specific knowledge of the particular antenna pattern. We remark, however, that the tolerable flux density of an unwanted signal located in the main lobe may be expected to be 10^{-3} to 10^{-4} times the flux densities listed in Table I.

3. Sources of interference.

We conclude by listing some of the most probable causes of interference, even at an observing site chosen to be especially free of interference: reflections of ground-band transmissions from high altitude objects such as aircraft, satellites, belts of dipoles and ionospheric electrons. We might also mention emissions from active satellites.

Aircraft and satellites will reflect signals of flux density much larger than S_{tol} even for a distant ground transmitter of lower power (Doc. IV/24 of Washington, 1962). However, these signals may be expected to be effective only during a relatively short time and the whole level of interference will depend upon the density of the space traffic.

Incoherent scattering by ionospheric electrons will have a more permanent character than the reflectors mentioned above. The level of interference from the ionosphere would depend on the density of high power transmitters likely to radiate towards the part of the ionosphere through which the radioastronomy observations are being made.

TABLE I

Sky temperatures, T_a, sensitivity, ΔT_e, and tolerable flux densities, S_{tol}, as a function of frequency

Frequency f (Mc/s)	Minimum sky temperature T_a (°K)	Sensitivity ΔT_e (°K)	Typical bandwidth, B (Mc/s)	Power input (1) $0{\cdot}1\, k\, B\, \Delta T_e$ (W)	Tolerable level of unwanted signal Incident upon isotropic antenna (2)		
					$S_{tol}\, B$ (W/m²)	S_{tol} (W/m²/c/s)	Field strength E_{tol} (3) (V/m)
20	32 000	1·6	0·1	22×10^{-20}	$1{\cdot}2 \times 10^{-20}$	12×10^{-26}	$2{\cdot}1 \times 10^{-9}$
40	6 200	0·32	0·1	$4{\cdot}4 \times 10^{-20}$	$1{\cdot}0 \times 10^{-20}$	10×10^{-26}	$1{\cdot}9 \times 10^{-9}$
80	1 000	0·02	1	$2{\cdot}6 \times 10^{-20}$	$2{\cdot}3 \times 10^{-20}$	$2{\cdot}3 \times 10^{-26}$	$3{\cdot}0 \times 10^{-9}$
160	200	0·004	2	$1{\cdot}1 \times 10^{-20}$	$3{\cdot}9 \times 10^{-20}$	$1{\cdot}9 \times 10^{-26}$	$3{\cdot}8 \times 10^{-9}$
320	30	0·003	2	$0{\cdot}83 \times 10^{-20}$	$11{\cdot}8 \times 10^{-20}$	$5{\cdot}9 \times 10^{-26}$	$6{\cdot}7 \times 10^{-9}$
640		0·001	10	$1{\cdot}4 \times 10^{-20}$	79×10^{-20}	$7{\cdot}9 \times 10^{-26}$	17×10^{-9}
1280		0·001	10	$1{\cdot}4 \times 10^{-20}$	320×10^{-20}	32×10^{-26}	35×10^{-9}

(1) $K = 1{\cdot}38 \times 10^{-23}$ (J/°K).

(2) The isotropic antenna has an effective area of $c^2 / 4\pi f^2$. For an antenna of gain G (db), multiply S_{tol} by $10^{-G/10}$ and E_{tol} by $10^{-G/20}$.

(3) Computed on the basis, $E_{tol} = \sqrt{Z_o\, S_{tol}\, B}$, where $Z_o = 377\, \Omega$.

ANNEX II

LOCATION AND CHARACTERISTICS OF RADIOASTRONOMICAL OBSERVATORIES

The annexed Tables give detailed information (as known at the present time) of the radio-astronomy observatories working in the class-B category referred to above. It is requested that additional information be supplied concerning these and any other observatories not mentioned below. Most of the information requested pertaining to the different columns in the Table are self explanatory; a few require special comments:

Column (6) *Antennae.* Only antennae actually making class-B observations (as defined in this document) should be recorded.

Column (11) ΔT_e *(1962).* The ΔT_e recorded should refer to the minimum operating noise temperature differences actually detected in 1962.

Column (12) *Remarks.* They refer to state of advancement of the installation. Any other relevant information could be added, in particular the periods of observations if they are not planned to be permanent.

Column (13) *Alternate frequencies.* Frequencies should refer to radioastronomy bands listed by footnote or otherwise in the Radio Regulations, Geneva, 1959.

Column (14) ΔT_e *(1967).* Minimum value of ΔT_e expected to be measured with improved equipment in 1967.

Site of Radio-telescope	Observatory	Sponsor	Position	Altitude (m)	Antennae: type, size, steering	Beam scan	Type of observation	Operating frequencies (Mc/s)	Type of receivers	ΔT_e (1962) (°K)	Remarks	Alternative frequency band to be used if necessary protection is given (Mc/s)	ΔT_e expected in 1967 (°K)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
GREEN BANK W. Virginia (continued)					Paraboloid 42·7 m, equatorial mount under construction	HA ±6 h Dec. −50° to +90°	Planetary, galactic and extragalactic sources				Not yet operating	10·68–10·70 Gc/s 4990–5000 1400–1427	0·001
					Paraboloid 92 m, meridian transit	±60° zenith distance	Planetary, galactic and extragalactic sources	Up to 1427	Crystal mixer and parametric	Probably 0·1 at 1427 Mc/s	Not yet operating	1400-1427 A band, if protected, near 600–700	0·005
					Paraboloid 12·2 m, meridian transit	±90° zenith distance	Selected radio sources	750 and 1400	Crystal mixer	0·1	Flux comparison experiment	None	0·1
					Paraboloid 9·2 m, alt-azimuth	All sky	Interference monitor	Up to 3 Gc/s	Crystal mixer	0·5		None	0·5
					Standard-gain horn, 36·5 m long, collecting area 10 sq. m	Fixed CAS A transit only	Cassiopea−A flux	600–1450	Crystal mixer	0·1		None	0·05
					Paraboloid 3·7 m	Fixed	Atmospheric radiation	8 Gc/s	TWT	0·02		None	0·001
					Paraboloid 6·1 m	Fixed	Atmospheric radiation	5 Gc/s	TWT	0·02		None	0·001
					Paraboloid 1·5 m, under construction	HA ±6 h Dec. −52° to +90°	Planetary, galactic, extragalactic and atmospheric radiation	250 Gc/s	Ge bolometer	0·02	Not yet operating	None	0·002
HAT CREEK California		University of California	40° 49′ 03″ N 121° 28′ 24″ W		Paraboloid 10 m, Paraboloid 26 m, equatorial mount	All positions	Galactic and extragalactic sources	Up to 20 Gc/s	Various, including parametric	0·02 at 8 Gc/s, 0·1 at 1420 Mc/s		1400–1427 plus bands up to 20 Gc/s	0·001
HARVARD Mass.		Harvard University	42° 30′ 13″ N 71° 33′ 30″ W		Paraboloid 7·3 m, Paraboloid 18·3 m, equatorial mount	All positions	Galactic and extragalactic sources	Up to 3 Gc/s	Maser and others				
WESTFORD Mass.	Haystack Hill	Lincoln Laboratory	42° 37′ 23″ N 71° 29′ 18″ W	145	Paraboloid 36·6 m, alt-azimuth	All positions	Planetary and deep-space	Up to 10 Gc/s	Maser		Operating late 1963		
	Millstone Hill	Lincoln Laboratory	42° 37′ 09″ N 71° 29′ 33″ W	156	Paraboloid 25·6 m, alt-azimuth	All positions	Planetary and deep-space	Up to 1295	Parametric	≈1	Operating 1 January, 1963		
WASHINGTON D.C.	Naval Research Laboratory	U.S. Navy	38° 49′ 16″·6 N 77° 01′ 36″ W	30	Paraboloid 15·5 m	All positions except 8° of zenith, alt-azimuth	Planetary, galactic and extragalactic	Up to 100 Gc/s	Maser, parametric and others	As low as 0·01		All assigned bands are probable plus others	0·001
					Paraboloid 3·5 m	All positions, polar mount							

Site of Radio-telescope	Observatory	Sponsor	Position	Altitude (m)	Antennae: type, size, steering	Beam scan	Type of observation	Operating frequencies (Mc/s)	Type of receivers	ΔT_e (1962) (°K)	Remarks	Alternative frequency band to be used if necessary protection is given (Mc/s)	ΔT_e expected in 1967 (°K)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Green Bank W. Virginia (continued)					Paraboloid 42·7 m, equatorial mount under construction	HA ±6 h Dec. −50° to +90°	Planetary, galactic and extragalactic sources				Not yet operating	10·68–10·70 Gc/s 4990–5000 1400–1427	0·001
					Paraboloid 92 m, meridian transit	±60° zenith distance	Planetary, galactic and extragalactic sources	Up to 1427	Crystal mixer and parametric	Probably 0·1 at 1427 Mc/s	Not yet operating	1400-1427 A band, if protected, near 600–700	0·005
					Paraboloid 12·2 m, meridian transit	±90° zenith distance	Selected radio sources	750 and 1400	Crystal mixer	0·1	Flux comparison experiment	None	0·1
					Paraboloid 9·2 m, alt-azimuth	All sky	Interference monitor	Up to 3 Gc/s	Crystal mixer	0·5		None	0·5
					Standard-gain horn, 36·5 m long, collecting area 10 sq. m	Fixed CAS A transit only	Cassiopea—A flux	600–1450	Crystal mixer	0·1		None	0·05
					Paraboloid 3·7 m	Fixed	Atmospheric radiation	8 Gc/s	TWT	0·02		None	0·001
					Paraboloid 6·1 m	Fixed	Atmospheric radiation	5 Gc/s	TWT	0·02		None	0·001
					Paraboloid 1·5 m, under construction	HA ±6 h Dec. −52° to +90°	Planetary, galactic, extragalactic and atmospheric radiation	250 Gc/s	Ge bolometer	0·02	Not yet operating	None	0·002
Hat Creek California		University of California	40° 49′ 03″ N 121° 28′ 24″ W		Paraboloid 10 m, Paraboloid 26 m, equatorial mount	All positions	Galactic and extragalactic sources	Up to 20 Gc/s	Various, including parametric	0·02 at 8 Gc/s, 0·1 at 1420 Mc/s		1400–1427 plus bands up to 20 Gc/s	0·001
Harvard Mass.		Harvard University	42° 30′ 13″ N 71° 33′ 30″ W		Paraboloid 7·3 m, Paraboloid 18·3 m, equatorial mount	All positions	Galactic and extragalactic sources	Up to 3 Gc/s	Maser and others				
Westford Mass.	Haystack Hill	Lincoln Laboratory	42° 37′ 23″ N 71° 29′ 18″ W	145	Paraboloid 36·6 m, alt-azimuth	All positions	Planetary and deep-space	Up to 10 Gc/s	Maser		Operating late 1963		
	Millstone Hill	Lincoln Laboratory	42° 37′ 09″ N 71° 29′ 33″ W	156	Paraboloid 25·6 m, alt-azimuth	All positions	Planetary and deep-space	Up to 1295	Parametric	≈1	Operating 1 January, 1963		
Washington D.C.	Naval Research Laboratory	U.S. Navy	38° 49′ 16″·6 N 77° 01′ 36″ W	30	Paraboloid 15·5 m	All positions except 8° of zenith, alt-azimuth	Planetary, galactic and extragalactic	Up to 100 Gc/s	Maser, parametric and others	As low as 0·01		All assigned bands are probable plus others	0·001
					Paraboloid 3·5 m	All positions, polar mount							

Site of Radio-telescope	Observatory	Sponsor	Position	Altitude (m)	Antennae: type, size, steering	Beam scan	Type of observation	Operating frequencies (Mc/s)	Type of receivers	ΔT_e (1962) (°K)	Remarks	Alternative frequency band to be used if necessary protection is given (Mc/s)	ΔT_e expected in 1967 (°K)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
MARYLAND POINT Maryland	U.S.N.R.L. Maryland Point Observatory	U.S. Navy	38° 22′ 26″ N 77° 14′ W	10	Paraboloid, 23·5 m	All positions	Planetary, galactic and extragalactic	Up to 4 Gc/s	Maser, parametric and others	As low as 0·002		All assigned bands between 500 and 4 Gc/s	0·001
SUGAR GROVE West Virginia	Naval Radio Research Station	U.S. Navy	38° 30′ 53″ N 79° 16′ 49″ W	670	Paraboloid, 18·3 m	All positions except small cone around zenith	Galactic, extragalactic and solar system	Up to 10 Gc/s	Various	0·2		All assigned bands up to 10 Gc/s	0·001
BETHANY Connecticut	Yale University Observatory	Yale University (NSF)	41° 25′ 40″ N 72° 59′ 05″ W	200	Two, 24-element helix arrays, each 2 m × 40 m, transit, steerable in declination	Dec. −20° to +90°	Galactic and extragalactic sources	200–300	Low noise vacuum tube; parametric	0·002	Used as interferometer	300–350 600–650	0·001
OWENS VALLEY California		California Institute of Technology	37° 13′ 54″ N 118° 17′ 36″ W		Two paraboloids, 27·4 m, alt-azimuth	All positions	Galactic and extragalactic sources	Up to 3 Gc/s			May be used as interferometer		
STANFORD California	Radioastronomy Institute	Stanford University	37° 23′ 50″ N 122° 11′ 20″ W	95	Thirty-four, 3 m, equatorial paraboloids, in extended cross array	> 12 h of HA, between declinations −50° and +90°	Solar system, galactic and extragalactic	3292 ± 5 (also wide-band)	Various	2 in 1 s (0·1 wide-band)	Fan beams as small as 0·6′ × 2·3°, Pencil beams as small as 3·1′ × 3·1′	Possibly 2695	
					Four, 9·1 m, equatorial paraboloids, movable	> 12 h of HA, between declinations −50° and +90°	Solar system, galactic and extragalactic	3250 ± 250	Various	0·02 in 1 s	0·8° pencil beams, used as elements of variable-spacing interferometer		
CEDAR RAPIDS Iowa	Collins Radio Company	U.S. Navy	42° 04′ 59″ N 91° 44′ 48″ W	275	2·4 m and 1·2 m paraboloids, azimuth and altitude-steerable	All positions	Solar, lunar and atmospheric	15, 16 and 35 Gc/s	15 Gc/s TWT (under construction) and crystal mixers	$0{\cdot}03/\sqrt{t}$ at 15 Gc/s (estimated) $1{\cdot}0/\sqrt{t}$ at 16 Gc/s, $2{\cdot}01/\sqrt{t}$ at 35 Gc/s	Automatic solar and lunar tracking available	All assigned bands from 10–40 Gc/s	
DELAWARE Ohio	Radio Observatory	Ohio State University	40° 01′ N 83° 02′ W		Standing paraboloid, 21·3 × 111 m, reflecting plane, meridian transit	±7·5° HA, ±50° zenith distance	Galatic and extragalactic sources	Up to 2 Gc/s					
BELMAR New Jersey	U.S. Army Electronics Research and Development Laboratory	U.S. Army	40° 11′ 30″ N 74° 03′ 25″ W	20	Paraboloid, 18·3 m, paraboloid, 26 m, alt-azimuth	All positions	Ionospheric studies, radar astronomy	Up to 3 Gc/s Up to 1420	Various				
HAMILTON Mass.	Sagamore Hill Radio Observatory	USAF	42° 37′ 51″ N 70° 48′ 55″ W		Paraboloid, 84′, equatorial steerable	All positions	Ionospheric studies, lunar, planetary, solar, galactic and extra-galactic	Up to 10 Gc/s	Various	1 at 3 Gc/s	Multi-frequency feed permits operation at 63, 113, 225, 400, 1200 and 3000 Mc/s simultaneously	Will redesign feed to fit into protected bands	
					Paraboloid, 150′, alt-azimuth	All positions	Ionospheric studies, radar astronomy, lunar, planetary, solar, galactic and extra-galactic	1500	Various	Not operating	Various feeds up to 1500 Mc/s	Will redesign feed to fit into protected bands	

Site of Radio-telescope	Observatory	Sponsor	Position	Altitude (m)	Antennae: type, size, steering	Beam scan	Type of observation	Operating frequencies (Mc/s)	Type of receivers	ΔT_e (1962) (°K)	Remarks	Alternative frequency band to be used if necessary protection is given (Mc/sf	ΔT_e expected in 1967 (°K)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
FAIRBANKS Alaska	Gilmore Creek Data Acquisition Facility	NASA	64° 58′ 38″ N 147° 30′ 54″ W	294·42	Steerable paraboloid, 25·9 m diameter, X-Y mount	All sky, approx. 10° bove horizon	Planetary and deep-space probes	136 400 1700	Parametric and low noise vacuum tube			2300	
BOULDER Colorado	Boulder Laboratories	National Bureau of Standards	40° 08′ 54″ N 105° 13′ 54″ W	1700	Two paraboloids, E-W separation 66 m; 18·3 m diameter, elevation-azimuth	All positions	Planetary	900–1100 Mc/s	Crystal detectors	0·3			0·2
DEXTER Michigan	The Observatory University of Michigan	University of of Michigan	42° 23′ 54″ N 83° 56′ 12″ W	321	Paraboloid 26 m, equatorial mount, paraboloid 9·2 m, equatorial mount	All positions	Planetary, galactic & cosmic	200–580 sweep frequency 2–4 Gc/s sweep frequency 750–850 7500–8500 9250–9350	Maser and other	0·05		750–1100 7500–11 000 15 000–16 500	(1)
STANFORD California	Stanford Center for Radar Astronomy	Stanford University and Stanford Research Institute	37° 24′ 32″ N 122° 10′ 43″ W	152·4	Paraboloid, 45·8 m, alt-azimuth	All positions	Lunar, planetary, solar and ionospheric radar; bistatic radar with receivers in space probes	Up to 2 Gc/s	Various				
					335 m, N-S linear phased array (two rows) of 48 log-periodic antennae	HA ±2 h. Dec. −30° to +50°	Lunar and solar radar	20–60	Various				
					610 m, E-W linear array (two rows) of 96 Yagi antennae	HA ±5 min Dec. −30° to +50°	Meteor radar	23	Various				
					2 paraboloids 18·3 m, alt-azimuth	All positions	Lunar, meteor, ionospheric radar	Up to 3 Gc/s	Various				
GOLDSTONE California Pioneer site	Jet Propulsion Laboratory	California Institute of Technology	35° 25′ 22″ N 116° 50′ 54″ W	1037·54	25·9 m diameter, steerable equatorial	HA ±90° Dec. +90° to −55°	Lunar and planetary deep-space probes. Lunar and planetary radar	Transmit 890·046 ± 2 Receive, 960·05 ± 2 Transmit and receive 2388 In addition, after 1963; Transmit 2115 ± 5 Receive 2295 ± 5	Maser and parametric amplifiers, total power and switched radiometers, phase lock with information BW of 1600 and 5000 cp/s at 960 and 3·3 at 2295	0·1 at 2388 for 1 s integrating time	Maser and Cassegrain feed	8450 ± 50	0·01 at 2388 for 1 s integrating time
Echo site			35° 18′ N 116° 48′ 17″ W	989·49	25·9 m diameter, steerable equatorial	HA ±90° Dec. +90° to −55°	"	"	"	"	Parametric and focal point feed	8450 ± 50	"

(1) ΔT expected in 1967; Unknown, limitation at centimetre wavelengths will be set by geophysical factors not well known at present.

Site of Radio-telescope	Observatory	Sponsor	Position	Altitude (m)	Antennae: type, size, steering	Beam scan	Type of observation	Operating frequencies (Mc/s)	Type of receivers	ΔT_e in (1962) (°K)	Remarks	Alternative frequency band to be used if necessary protection is given (Mc/s)	ΔT_e expected in 1967 (°K)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
GOLDSTONE California (contd.) Venus site			35° 14′ 52″ N 116° 47′ 28″ W	1201·32	25·9 m diameter, steerable, alt-azimuth	Az: 0° to 360° El: 0° to 90°	"	"	"	"	Primarily used for research and development	8450 ± 50 Mc/s	"
			35° 14′ 52″ N 116° 47′ 38″ W	1213·59	9·14 m diameter, steerable, alt-azimuth	Az: 0° to 360° El: 0° to 90°	"	"	"	"	"	"	"
FRANCE NANÇAY	Observatoire de Paris-Meudon	Ministère de l'Education Nationale	47° 22′ 48″ N 00° 08′ 47″ E	140	Krauss type antenna, collecting area; 35 m × 200 m = 7000 m²	Meridian ±1 h, Zenith distance 0–90°	H-line and Continuum	1420 ± 20 2300 ± 20	Parametric and standard Standard		In operation In operation	1420–1427 2690–2700	
					Interfer, E-W and N-S 40 parabol. of total collecting area; 1280 m²	Meridian ±1 h, Zenith distance 0–90°	Continuum Continuum	4490–5000 169 ± 1·25	Standard Standard		Under study In operation	4490–5000 150–153	
SAINT-MICHEL	Observatoire de Haute-Provence	Centre National de la Recherche Scientifique	43° 55′ 47″ N 00° 22′ 52″ E		Interfer.; 2 parab. cyl. Collecting area; 3600 m²	Meridian Zenith distance 0–30°	Continuum	300 ± 1	Standard		In operation	327 ± 1	
ITALY BOLOGNA	University of Bologna Astronomical Observatory	Ministry of Public Education	44° 33′ 26″ N 10° 46′ 39″ E		Cross 1050 × 1050 m, parab. cylinders 30 × 105 m	Meridian	Continuum	330			Under construction	406–410	
NETHERLANDS DWINGELOO	Netherlands Foundation Radioastronomical Observatory	Netherlands Organization for Pure Research	52° 48′ 47″ N 06° 23′ 49″ E		Paraboloid, D = 25 m	All positions	H-line Continuum	300–3000	Parametric		In operation		
FED. REP. of GERMANY STOCKERT	Bonn University Observatory		50° 34′ 14″ N 06° 43′ 24″ E		Paraboloid, 25 m, steerable, alt-azimuth	Hemisphere	H-line	1420	Parametric		In operation	1420–1427	
GERMAN DEMOCRATIC REPUBLIC ◆ BERLIN-ADLERSHOF	Heinrich Hertz Institute	Deutsche Akademie der Wissenschaften	52° 25′ 45″ N 13° 32′ 24″ E		Paraboloid, 36 m	Meridian Zenith distance 0–90°	Continuum	600	Standard		In operation	606–614	
UNITED KINGDOM MACCLESFIELD	Jodrell Bank Experimental Station	University of Manchester	53° 14′ 11″ N 02° 18′ 24″ W		Paraboloid, D = 76·2 m	Hemisphere	Continuum, space research	15 to 1500	Parametric		In operation		
					Paraboloid, D = 66·5 m	Transit ±15°, from zenith	Continuum	16 to 26 92, 158	Standard		In operation		
							H-line	1420	Standard		In operation	1420	

◆ Information from sources outside the Union. The publication of this information implies no recognition by the I.T.U. of the status of the sender in relation to I.T.U. (Resolution 88 (amended) of the Administrative Council).

Site of Radio-telescope	Observatory	Sponsor	Position	Altitude (m)	Antennae: type, size, steering	Beam scan	Type of observation	Operating frequencies (Mc/s)	Type of receivers	ΔT_e (1962) (°K)	Remarks	Alternative frequency band to be used if necessary protection is given (Mc/s)	ΔT_e expected in 1967 (°K)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
CAMBRIDGE	Mullard Radio Observatory	Cambridge University	52° 09′ 45″ N 00° 02′ 24″ E		Interferometer, 4 parabolics cylinders, 97·5 × 12·2 m	Meridian, Zenith distance ±90°	Continuum Planets	400 160 80	Standard		In operation		
					Aperture synthesis, 442 × 19·8 m, 63 × 22 m movable	Meridian, Zenith distance 0–90°	Continuum	178	Standard				
					Aperture synthesis, 1030 × 12·2 m, 33 × 13·5 m movable	Meridian, Zenith distance 7°–90°	Continuum	38	Standard		In operation		
MALVERN	Royal Radar Establishment	Ministry of Aviation	52° 05′ 40″ N 02° 08′ 48″ W		2 paraboloids on track, D = 25 m, alt-azimuth	Hemisphere	Planets	3000 and lower			In operation		
SWEDEN RÅÖ ONSALA	Onsala Radio Wave Propagation Observatory	Chalners University of Technology	57° 23′ 30″ N 11° 55′ 00″ E		Paraboloid, D = 26 m						Under design		
U.S.S.R. SARAVAND	Burakam Astrophysical Observatory	Academy of Sciences of U.S.S.R.			Cylindrical parabola		Continuum				In operation		
NAUCHNYI	Crimean Astrophysical Observatory	Academy of Sciences of U.S.S.R.			Paraboloid, D = 22 m	Hemisphere	H-line	1420			In operation		
SIMEIS	Lebedev Physical Institute	Academy of Sciences of U.S.S.R.			Interferometer; 800 m, 2 paraboloids, D = 31 m	Transit	Continuum	50–100			In operation		
LENINGRAD	Pulkova Observatory	Academy of Sciences of U.S.S.R.			Parabola 120 × 3 m	Transit, Zenith distance 0–90°	Solar Continuum	1000-3000-10 000			In operation		
MOSCOW	Serpukhov Radiophysical Station	Academy of Sciences of U.S.S.R.			Interferometer, 2 paraboloids, D = 22 m	Hemisphere	Planets Continuum, H-line	Up to 13 700			In operation		
ZIMENKI	Zimenki Radioastronomical Station	Gorki Physiotechnical Research Institute			Interferometer, 2 paraboloids, D = 15·2 m						Planned		

REPORT 225 *

THE POSSIBILITY OF FREQUENCY SHARING BETWEEN RADIOASTRONOMY AND OTHER SERVICES

(Question 244(IV))

(Geneva, 1963)

1. Introduction

The radioastronomy service is based on the reception of signals from cosmic sources, both within and external to the solar system. Radioastronomical studies of individual sources contribute to our understanding of the physical processes responsible for the radio emissions and, hence, to an understanding of the evolutionary development of energy sources in the universe; radioastronomical studies of the solar system contribute to our knowledge of the composition and nature of the sun and planets and interplanetary space; radioastronomical surveys of weak sources provide statistical information needed to differentiate between possible theories on the origin and development of the universe. These cosmic signals are characteiized by their low power flux levels and the absence of any modulation, other than random noise. The nature of the signals has been described in detail in Docs. IV/24, IV/47, and IV/62 of Washington, 1962, and in Report 224. Several contributions (e.g. Docs. IV/45 and IV/57 of Washington, 1962) have discussed the general aspects of frequency sharing as applied to space telecommunications. This Report will draw from these documents and apply their results to the specific question of the possibility of sharing between radioastronomy and other services.

2. Dependence on time

The dependance on time of radioastronomy signals will be described in general terms only. Observational determination of signal/time relationships is now a central problem in several branches of radioastronomy. Most galactic and extra-galactic sources emit at levels that are either constant or subject to very slow secular changes. There are exceptions; for example, there is a class of stars that flare-up in brightness at unpredictable times. These so-called flare stars are of great scientific interest, because of their bearing on problems of stellar formation and evolution. It is believed that radio signals have been detected from flare stars with existing radioastronomical equipment. Low signal-strength makes the observation difficult; improved equipment now becoming available will facilitate the observation of flare stars.

Some radio sources within the solar system are highly dependent on time in several different ways. The radiation from the sun includes a component associated with sudden solar bursts, that are unpredictable in time. The times of occurrence of emissions by Jupiter, at frequencies in the neighbourhood of 20 Mc/s, are likewise unpredictable. On the other hand, radio signals from the planets vary slowly, owing to the change in distance of the planet from the earth, the distance of the planet from the sun, and the phase angle at which the planet is viewed. Planetary observations must be made over a long period of time to detect these effects. The sun provides an example of another type of time dependency. Because the sun is such a strong emitter at all frequencies, it may interfere through side-lobe reception when the desired celestial source is in the primary antenna lobe. Radioastronomers have found

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

it necessary to restrict some observing programmes to the hours when the sun is below the horizon. Diurnal effects in the atmosphere may also restrict observations to certain hours of the day.

One concludes that radioastronomers are not generally free to observe celestial signals at specific times or over any chosen limited time interval. For many sources, the best times for observation are dictated by natural phenomena, over which the observer has no control.

3. Interference levels

Interference levels for the radiostronomy service have been discussed in Docs. IV/24, IV/49 of Washington 1962, and in Report 224. While there is some variation with frequency, one may say that for radioastronomy programmes requiring the highest sensitivity the tolerable interference level, as defined in Annex I to Report 224 is of the order of 10^{-26} W/m²/c/s as received with an isotropic antenna. If an antenna with 40 db gain were employed, the tolerable interference level in the primary lobe would be 10^{-30} W/m²/c/s. Report 224 points out that for some research programmes, e.g. certain types of solar studies, the tolerable interference level may be 20 db higher.

4. Sources of man-made interference

Question 244 (IV) suggests that interference sources be divided into several classes, one of these including transmitters located on the ground, in aircraft, or in orbiting devices, and another involving the reflection of ground-based transmissions from aircraft and orbiting objects. In the first instance, a simple one-way communication path is involved; in the second instance, the problem is that of bi-static radar with different distances between the reflecting object and the transmitter and receiver stations.

4.1 *One-way path*

If the one-way path is in the line-of-sight, of a transmitter of power P_t (W), operating through an antenna of gain G_t, at a distance R (m) from the radioastronomy observatory, the power flux at the observatory will be $P_tG_t/4\pi R^2$ (W/m²). Assuming that the radioastronomy antenna has an effective reception area $A_e = c^2G_r/4\pi f^2$(m²) ($c = 3 \times 10^8$ m/s, f = operating frequency, G_r = gain compared to isotropic), the power into the receiver will be $c^2P_tG_tG_r/(4\pi Rf)^2$ (W). In Report 224, the tolerable level of interference is defined as no more than $0{\cdot}1\mathrm{k}B\Delta T_e$, where k is $1{\cdot}38 \times 10^{-23}$ J/°K, B is the receiver bandwidth (c/s) and ΔT_e is the r.m.s. fluctuation of the operating noise temperature. From Report 224, one may take as typical values $B = 10^7$ c/s and $\Delta T_e = 10^{-3}$°K for $f = 6 \times 10^8$ c/s. It was shown there that for tolerable interference from the transmitter

$$P_tG_tG_r/R^2 \leqslant 8{\cdot}7 \times 10^{-22} \quad (\mathrm{W/m^2}) \text{ or}$$

$$R \geqslant 0{\cdot}113 \sqrt{P_tG_tG_r} \times 10^{11} \quad (\mathrm{m})$$

As an illustrative example, take a transmitter power of 1W, and assume that neither the transmitter nor the receiver antenna is directed toward the other station, so that, for the far side-lobes that are involved at both stations, one may assume the isotropic case, $G_t = G_r = 1$. For these conditions, $R \geqslant 3{\cdot}26 \times 10^7$ km. The implication is clear: the radioastronomy station will suffer interference over the direct line-of-sight path unless the separation is greater than the above amount. It is also clear that if easily attainable increases are made in the transmitter power, or if either or both antennae should be directed toward the other, the separation would have to be increased to 10^{10} to 10^{12} km, or more.

If the one-way path is not in the direct line-of-sight, a more refined method must be employed to compute the interference levels at the observatory site. An applicable method, and an illustrative example, are given in Doc. IV/63 of Washington, 1962; see also Docs. IV/45, IV/57 of Washington, 1962 and V/23 of Geneva, 1962.

From these studies, one concludes that, if the transmitter operates at the same frequency as the radioastronomy receiver, there may be serious interference even if the one-way path is not in the line-of-sight and the separation is several hundred kilometres.

4.2 *Bi-static configuration*

For this configuration, similar in principle to a radar, but with the transmitter and receiver at widely separated points, we may adopt $(P_t G_t / 4\pi R_t^2)$ as the expression for the power flux at the reflecting object. If this object has an effective cross-section σ (m^2), and is at a distance R_r (m) from the receiving station, the power flux at the receiver station will be

$$S_r = (P_t G_t / 4\pi R_t^2)\,(\sigma / 4\pi R_r^2) \quad (\text{W/m}^2)$$

Because the distance between the transmitter and receiver stations is the sum of R_t and R_r, multiplied by the cosine of the respective angles of elevation, it follows that S_r is a minimum for $R_t = R_r$, and this equality will be adopted for the remainder of this discussion. The power into the radioastronomy receiver will be $S_r A_e$, where the effective area of the antenna is as defined above. For this input to be a tolerable level of interference, it must be less than the level set in Report 224, see above. A rearrangement of terms gives

$$R^4 = c^2 P_t \sigma G_t G_r / 6{\cdot}4\pi^3 f^2 k B \Delta T_e,$$

which is the minimum distance to the reflector for there to be a tolerable level of interference. As an illustrative example, assume $P_t = 1$ W, $\sigma = 1$ m^2, $G_t = G_r = 1$, and let the other symbols have the same values as in the previous example. Substitution gives the minimum $R = 9{\cdot}5 \times 10^3$ m. If the radioastronomy antenna is kept with only the side-lobes directed at the reflector ($G_r = 1$), the minimum R becomes 95 km if the transmitted power is increased to 10^4 W; if the transmitter antenna is intentionally directed toward the reflector (assume $G_t = 10^4$), the minimum R becomes 950 km. For the special, and interesting, case of the moon as the reflector, the proper value of σ will vary with the frequency; for illustrative purposes, take $\sigma = 10^{11}$ m^2.

For $P_t = 10^4$ W, $G_t = 1$ (side-lobe of transmitter antenna) and $G_r = 10^4$ (main-lobe of radioastronomy antenna), we determine $R \geqslant 5{\cdot}2 \times 10^8$ m as the condition for tolerable interference as defined in Report 224. The actual distance to the moon is well inside this value, the average being $3{\cdot}8 \times 10^8$ m. Obviously, if both the transmitter and receiver antennae were directed toward the moon, there would be serious interference unless the transmitter power were reduced below 1W.

5. Harmonics

Up to this point, the discussion has assumed that the transmitter is operating at a frequency within the receiver bandwidth. It is well known that the technical ability to control the transmitter frequency and to design receivers with great selectivity has provided a fundamental basis for present radiocommunications. To explore the protection this offers to radioastronomy, let us assume that the transmitter is operating at a sub-harmonic of the radioastronomy receiver and that the harmonic suppression is 80 db (see Doc. I/43 of Geneva, 1962). From the illustrative example given for the line-of-sight situation, even with 80 db suppression at the transmitter, there may be intolerable interference at separation distances of the order of 10^5 m, for the conservative case of isotropic antennae at both transmitter and receiver.

6. Area of visibility

In view of the possibility of interference to radioastronomy, due to the presence of either transmitters or reflecting objects in the sky over an observatory, it is pertinent to examine the area of visibility of such objects. The area of the spherical earth visible from a satellite is a spherical cap, centred on the sub-satellite point and with dimensions which depend solely on the distance of the satellite from the centre of the earth. Figs. 1 to 3 are coverage charts for sub-satellite latitudes of 10° N, 40° N and 70° N respectively. Pairs of curves are given for satellites at three heights above the surface of the earth; one curve corresponds to the theoretical coverage, the other corresponds to an earth-station telescope raised to an angle of elevation of 10°. These figures show, that even for a relatively low satellite, the area of visibility could cover several nations. For a stationary satellite, at a height of 36 000 km, the coverage is almost hemispheric.

7. Limitation through antenna directivity

If the technical configuration and distances are such that there will be intolerable interference, only if the main antenna lobe enters the problem (rather than the isotropic situation), the coverage curves of Figs. 1 to 3 will be reduced, if it is feasible to limit the positions of the main lobe to elevations larger than some minimum value. Fig. 4 is a set of coverage curves for a stationary satellite and for angles of elevation limited to selected values between 0° and 70°. Even for this last, rather extreme case, the area involved would usually cover several nations.

8. Visibility of moon

We have already shown that the moon is a particularly important object in these interference discussions, because of its large effective cross section. Annex I has been prepared to facilitate a better understanding of the times of mutual visibility of the moon by two terrestrial stations. An equivalent treatment is given by Hahn and Randall [1].

9. Conclusions

9.1 Because of the nature of the phenomena observed in radioastronomy, only under special conditions will it be feasible to devise time-sharing programmes between radioastronomy and other services operating on the same frequencies.

9.2 If relatively high power is beamed at the moon, or at artificial satellites, or if lower power is beamed at aircraft closer to the ground stations, the signal picked up through side-lobes of the radioastronomy antenna may cause interference, if the transmitter frequency corresponds to the reception band in use by the radioastronomy service.

9.3 Considering the large areas of the earth visible to a satellite or the moon, administrative actions to protect the radioastronomy service will need to be on a world-wide (or, at least, regional) basis; a single Administration acting independently cannot cope with the general problem.

9.4 It is not feasible for the radioastronomy service to share frequencies with any other services in which direct line-of-sight paths from the transmitters to the observatories are involved.

9.5 Until harmonic suppression much greater than 80 db is provided in transmitter designs, services employing high transmitter powers will cause interference, if assigned to operate within the line-of-sight at frequencies sub-harmonically related to those employed by the radioastronomy service.

9.6 To obtain maximum usefulness of his equipment, the radioastronomer should place his observatory at a site remote from centres of population and protected from unwanted radiations to the greatest extent possible by the surrounding terrain. While such a site will, in no way, provide protection from interfering radiation at the desired frequency reflected or scattered into the antenna beam, it will provide a significant degree of protection, particularly from radiation of frequencies other than those intended for reception to which the receiver may nonetheless be sensitive.

BIBLIOGRAPHY

1. HAHN, P. M. and RANDALL, N. C. Availability of the moon for global communications. *Transactions IRE*-PG Space Electronics and Telemetry, *SET*-7, 57 (September, 1961).

ANNEX *

INSTRUCTIONS FOR THE USE OF CHARTS OF MUTUAL VISIBILITY OF THE MOON

1. Introduction

Selected charts have been prepared to facilitate computation of the times when the moon will be visible simultaneously from two points on the earth. These charts are useful, for example, in determining the operational time to be expected from a lunar-scatter communication link.

2. Moon-rise and moon-set curves for the Greenwich meridian on 2, 4, 6 ... 16 March, 1962

For the selected eight days in March, 1962, these curves show the times of moon-rise (solid) and moon-set (dashed) for the various latitudes of the Greenwich meridian. For Greenwich itself, for instance (latitude approximately 50° N), the moon rises at 0357 h and sets at 1250 h on 2 March, 1962. Only half of the lunar cycle is shown; since for the second half, the picture would merely repeat itself, the two sets of curves being approximately interchanged. Thus, the moon-rise curve for 18 March would look very similar to the moon-set curve of 4 March displaced slightly to the right.

Moon-rise and moon-set for a longitude different from that of the Greenwich meridian may be obtained by a simple shifting of the whole set of curves, to the left or to the right (depending on whether this longitude is to the East or West, respectively, of Greenwich), by a number of hours which is the same fraction of a day as the difference in longitude is of a revolution of 360°. Thus, for Washington, D.C. (which is about 75° W of Greenwich) the curves are shifted to the right by 5 h; then at the latitude of Washington (approximately 40° N), moon-rise occurs at about 0830 GMT and moon-set at 1820 GMT.

To use this chart for the determination of the mutual visibility of the moon between any two points on Earth:

— the curves must be shifted, with respect to themselves, by the difference in longitude of the two points;

— moon-rise and moon-set must be read off for both points, according to their respective latitudes;

— the overlap in the two time intervals, from moon-rise to moon-set, must be established.

* This Annex is a reprint from the paper: NAGY, F. Lincoln Laboratory Report 526-3 (June, 1962).

This overlap is the time of mutual visibility. Using this method, one finds a mutual visibility of about 4 h 20 min between Greenwich and Washington, D.C. on 2 March, 1962 (the difference between the later moon-rise (0830) and the earlier moon-set (1250) is 1250 — 0830 = 4 h 20 min). In calculating these time intervals, it would help to make a copy of all the curves on a transparency, and to shift the transparency by the necessary amount.

3. Curves of mutual moon-coverage

As the curves stand, they give the individual visibility of the moon for a given point on earth for the dates of 2, 6, 8, 10 and 16 March, 1962, that is, for about half the lunar cycle during which visibility in the Northern Hemisphere changes from minimum to maximum. To establish the length of visibility, only the latitude of the given point is needed (beside a knowledge of the phase of the lunar cycle) and the time of visibility may be read directly from the bottom scale. To find the mutual visibility between two points, one of the following methods will be necessary.

3.1 *Two points on the same latitude, but separated in longitude*

Subtract the time (bottom scale) corresponding to the difference in longitude (top scale) from the time of individual visibility (bottom scale). The difference, if positive, will be the mutual visibility.

3.2 *Two points on the same longitude, but separated in latitude*

The shorter of the two individual visibilities is the mutual visibility.

3.3 *Different longitudes and latitudes (general case)*

Add half the difference in visibility for the two stations to the time of the shorter visibility, and subtract the time corresponding to the difference in longitude. The result, if positive, is the mutual visibility. If half the difference in visibilities is greater than the time of longitude separation, the shorter of the two visibilities is the mutual visibility.

4. Maximum and minimum moon-coverage for two stations

This chart shows a particular application of the mutual moon-coverage curves. One station is assumed to be in Washington, D.C. the other at some arbitrary location. Note that, since one station is fixed at latitude 40° N, minimum and maximum coverage south of latitude 40° S is approximately two weeks out of phase with the minima and maxima north of this line.

Note, further, that in every 18 years, the moon gets through a complete cycle of values of maximum declination. The effect of this is, that the difference between maximum and minimum mutual visibilities between two points will slowly increase to a maximum by 1969, while it is about the least now (it was a minimum in 1960).

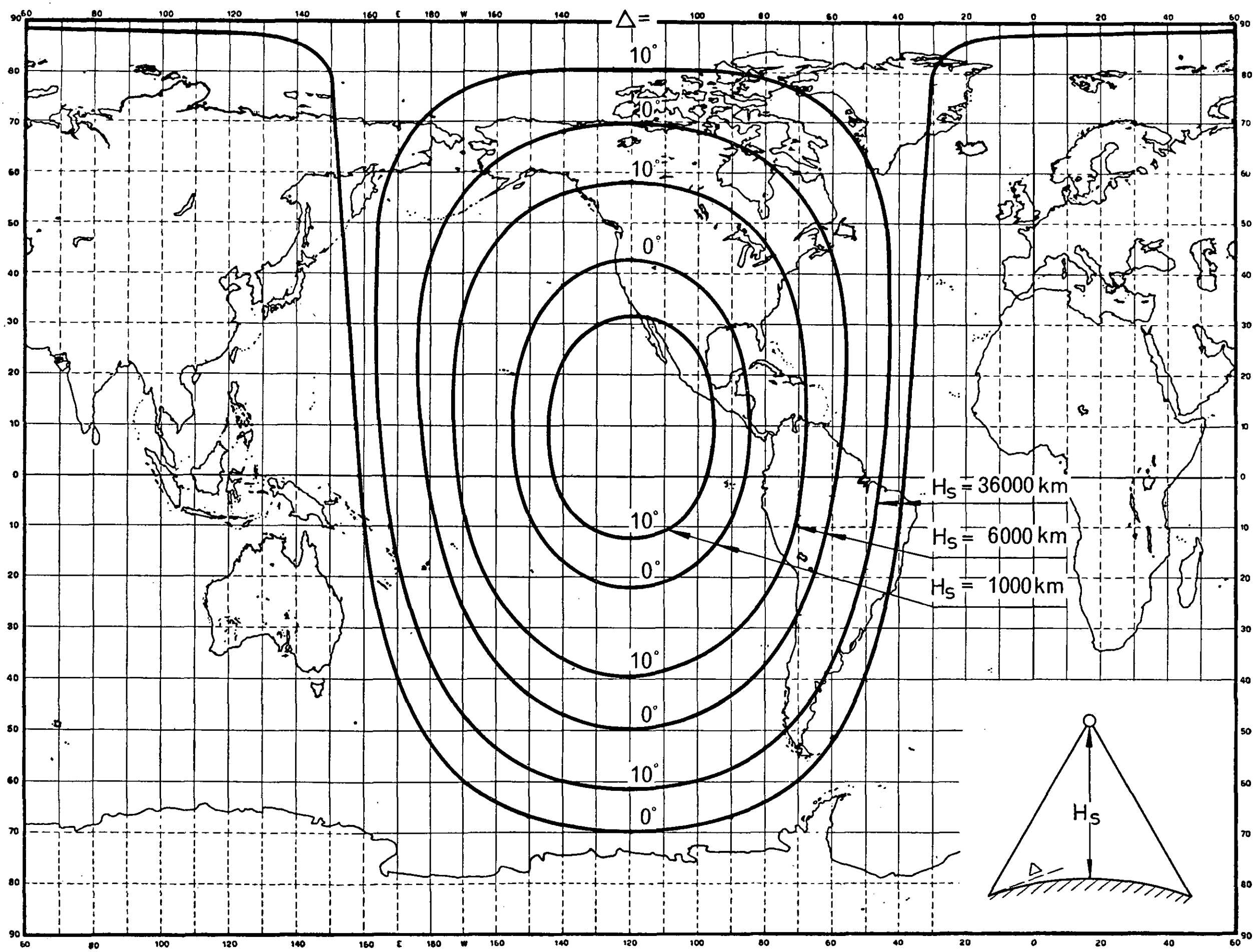


FIGURE 1

Service area of satellites at 10° N

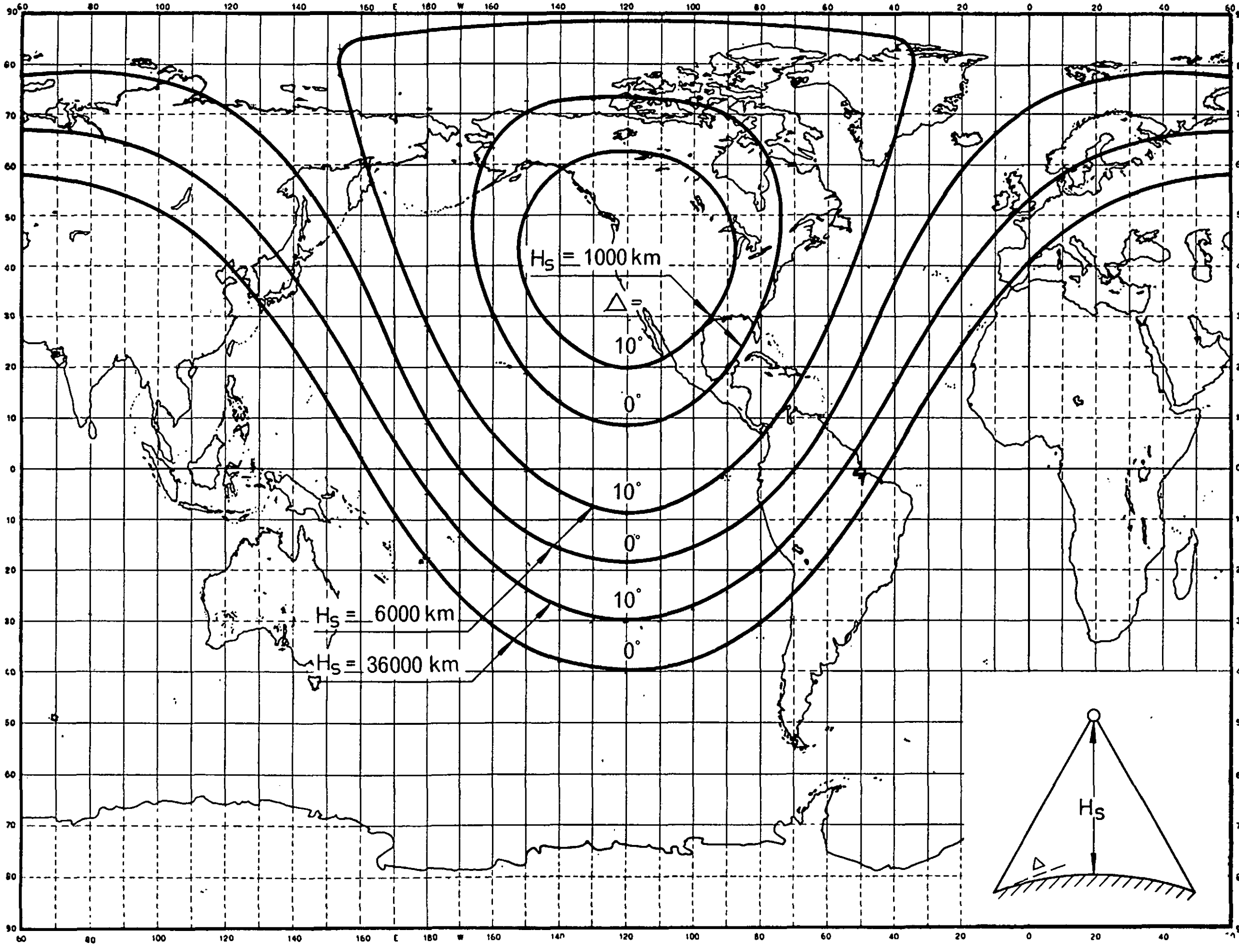


FIGURE 2

Service area of satellites at 40° N

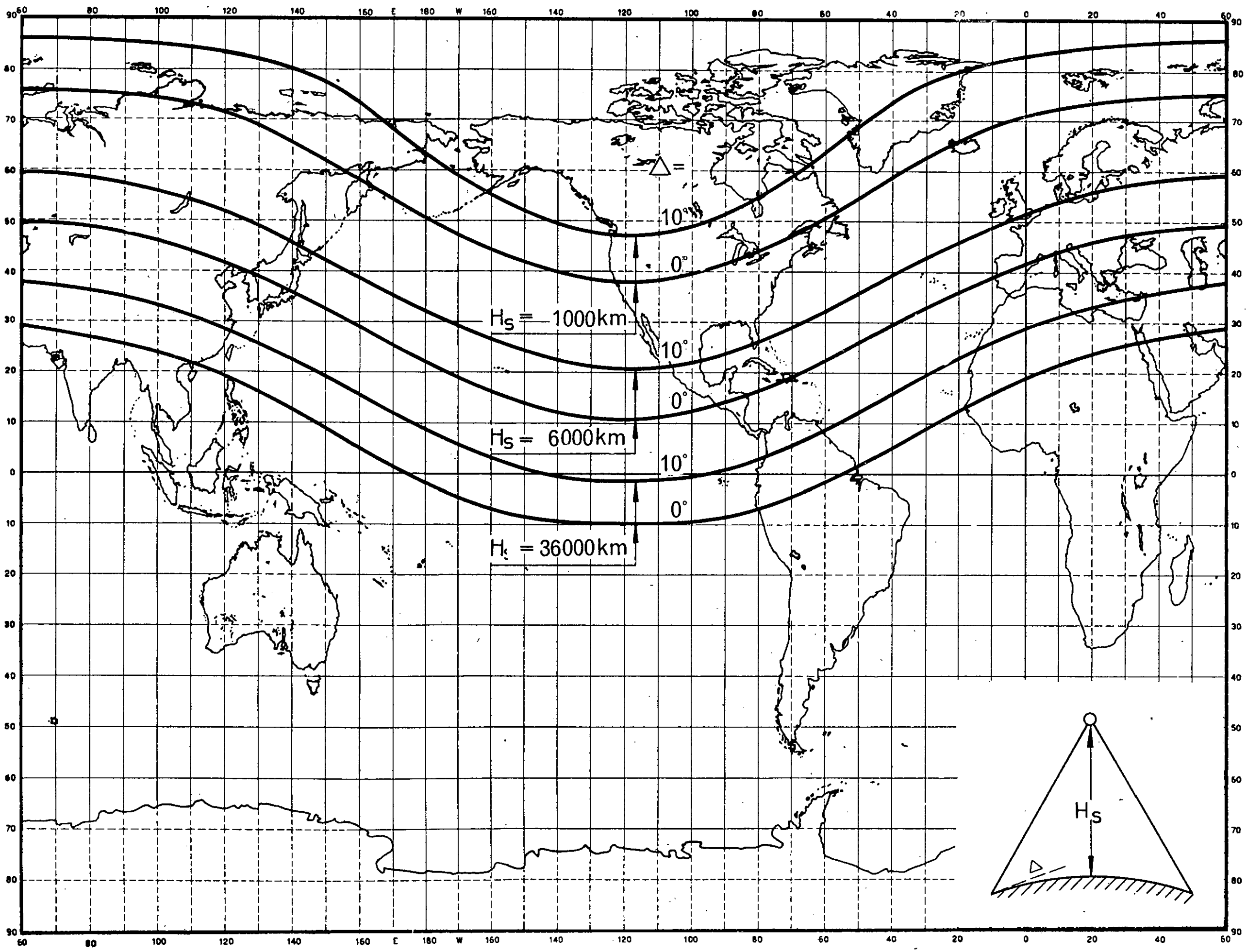


FIGURE 3

Service area of satellites at 70° N

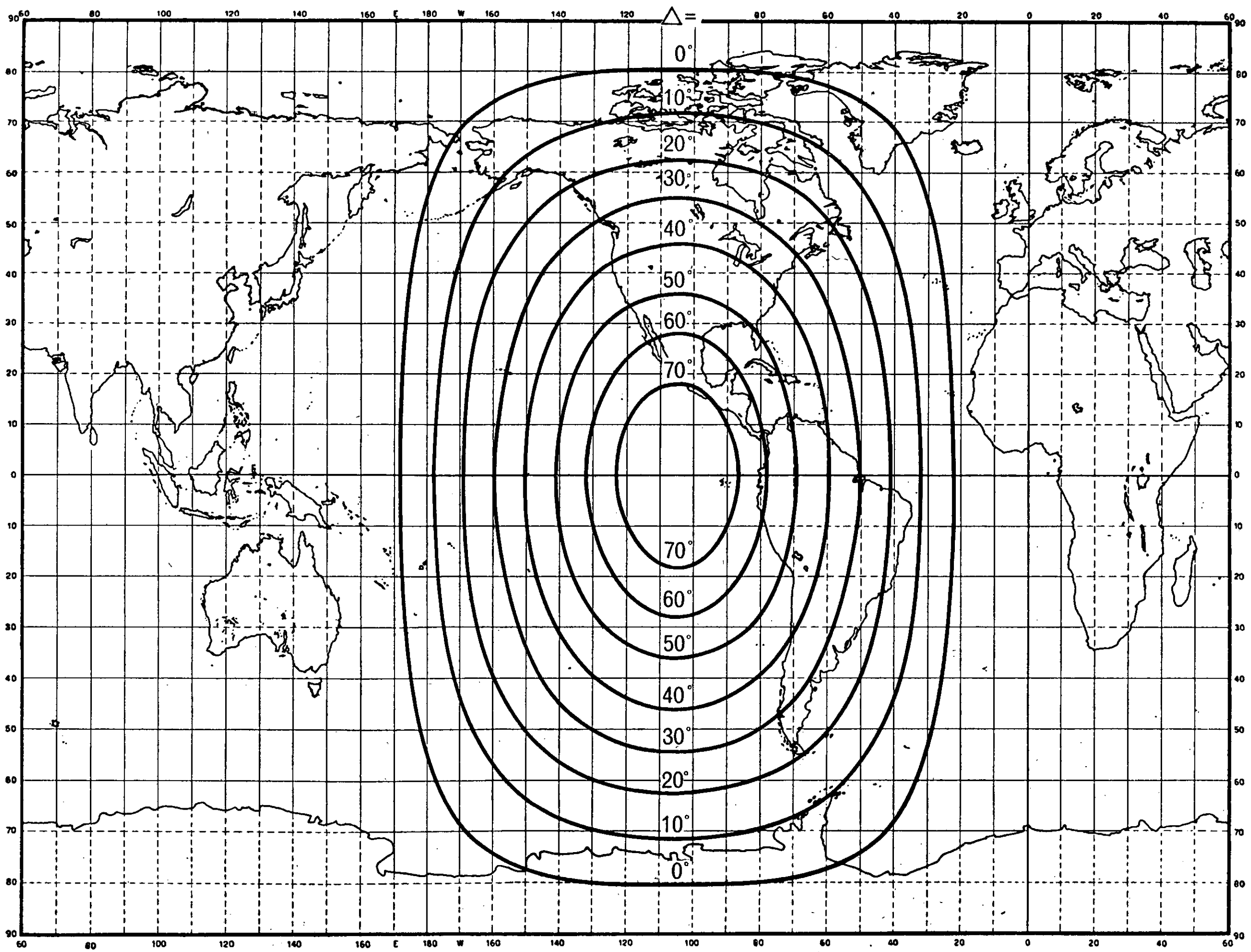


FIGURE 4

Vertical angle (Δ) to a "stationary" satellite at 105° W

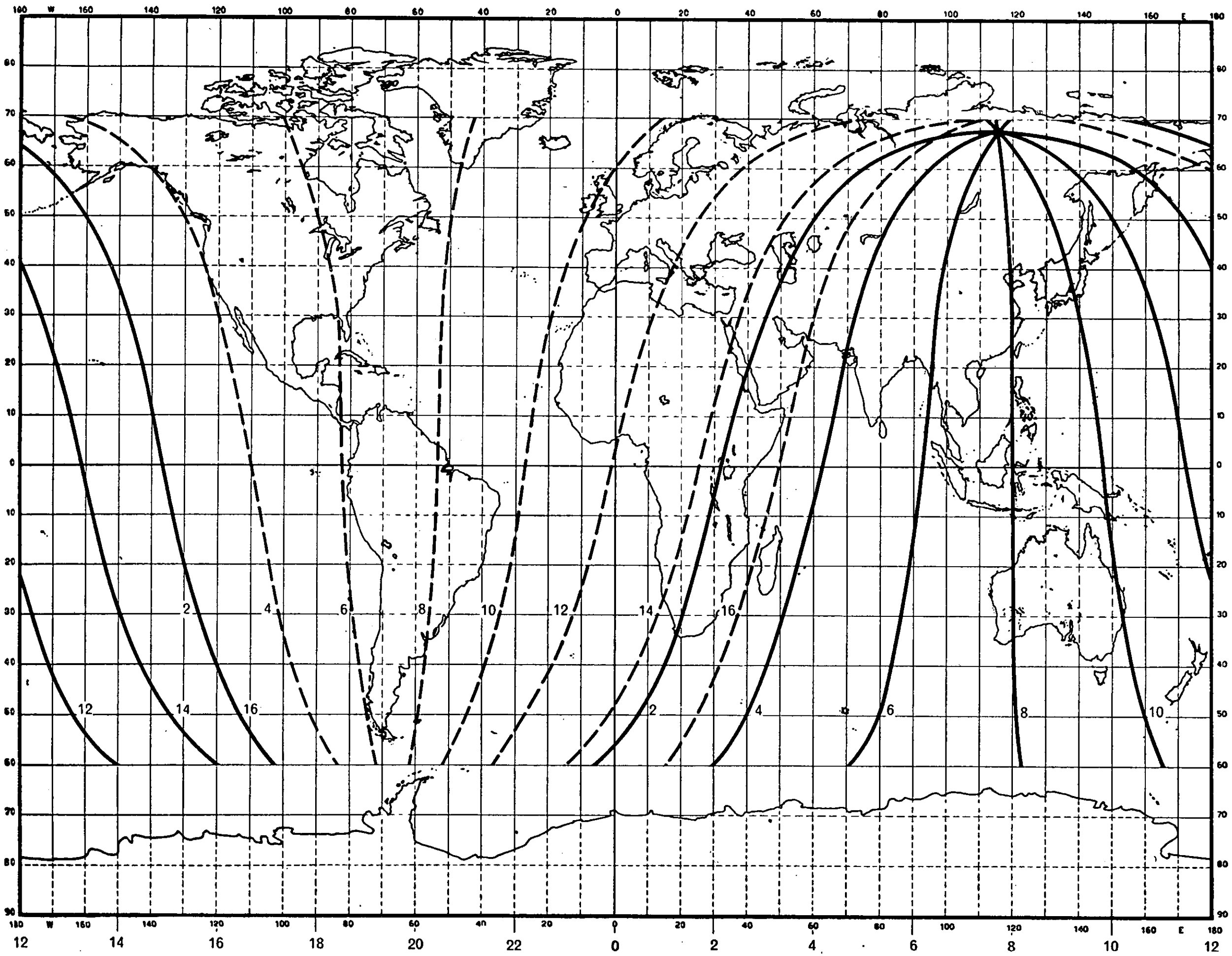
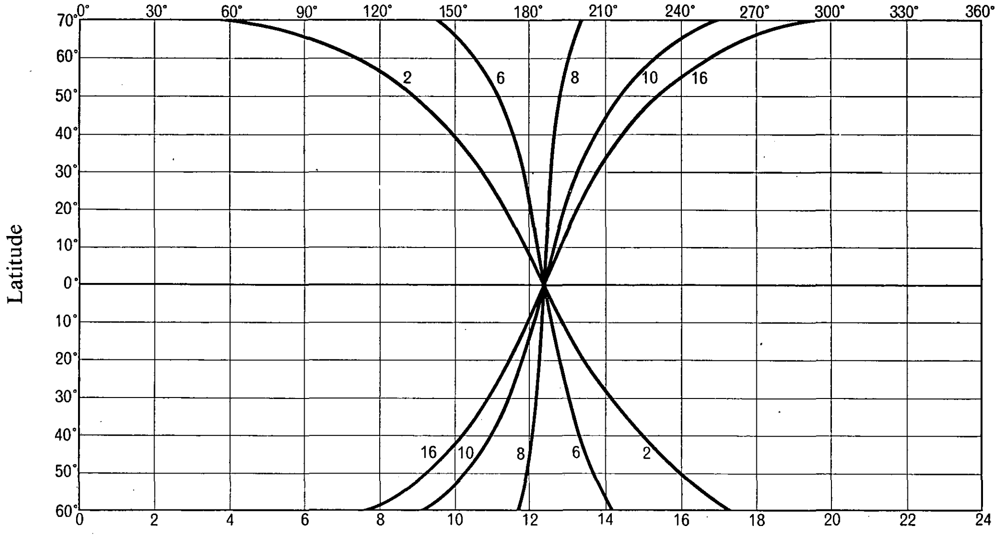


FIGURE 5

Moonrise (————) and moonset (— — —) curves for the Greenwich meridian or certain days of March, 1962 (indicated on the curves)

Difference in longitude



Hours of visibility

FIGURE 6

Curves of mutual coverage of the moon

L. 9 - Radar astronomy

REPORT 226 *

FACTORS AFFECTING THE POSSIBILITY OF FREQUENCY SHARING BETWEEN RADAR ASTRONOMY AND OTHER SERVICES

(Questions 236(IV) and 245(IV))

(Geneva, 1963)

1. Introduction

A radar astronomy system has a paradoxical nature, with regard to factors affecting frequency sharing. Radar astronomy receivers must have sensitivities comparable with the best radioastronomy systems and satellite-communications systems, and so have a similar susceptibility to interference. Radar astronomy transmitters must develop, and antennae radiate, large amounts of power, so that they are capable of interfering with other services over significant distances—distances which may be appreciably extended by scattering from space objects such as the moon, spacecraft or scatterers such as the troposphere, or ionosphere.

Radar astronomy transmitters are generally outgrowths of component developments made for other services. Indeed, many systems put to radar astronomy use do not have this as a direct raison d'être. Frequency assignments are usually made on the basis of the prime use for which the system was designed. As technology improves, certain crucial radar astronomy experiments may require a clear channel within these bands.

Unlike a radioastronomy system detecting cosmic noise, the channel bandwidth required for radar astronomy can be much smaller, in general only that required to encompass the modulation band, Doppler spread, and Doppler shift encountered. Radio- and radar-astronomy systems are much the same, in that they require large antennae, sensitive receivers, and modest tracking rates. Moreover, many similarities exist between radar-astronomy systems and satellite-communications earth stations.

2. The radar astronomy problem

The salient problem in radar astronomy is the detection and study of targets at long ranges. These targets may be small in angular extent relative to the antenna beam, e.g., the planets, or extended, e.g., the terrestrial ionosphere.

The detection range of a system, as defined in most radar textbooks, for a quasi-point target, at a given wavelength, follows the proportionality:

$$R^4 = \text{Const. } PA^2T^{-1} \qquad (1)$$

* This Report, which was adopted unanimously, has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963.

where R is the range, P the transmitted power, A the effective area of the duplexed antenna, and T the operating noise-temperature. For extended targets, we have

$$R^2 = \text{Const. } PAT^{-1} \tag{2}$$

Both relations point to the fundamental importance of large powers, large antennae and sensitive receivers.

The detectability of Venus by radar has been established by a number of observers. Venus provides a convenient point of reference for considering the detectability of other planets (Fig. 1) [1].

The problem of signal design for radar astronomy has been treated by Green [2] in a way that allows consideration of propagation, multipath, and reflection effects in the optimization of the modulation, as well as the associated detection features. In general, the frequency spectrum, occupied by such transmitted signals and those reflected from the target is narrow compared with that desirable for observation of cosmic noise. The spectral width of radar astronomy signals is more akin to that commonly used in spectral-line radioastronomy. However, because of the coherent nature of radar signals, and because correlation with the transmitted wave-form is generally employed, several orders of magnitude of interference tolerance can be gained as compared with radioastronomy. Unwanted narrow-band emissions are less likely to cause trouble because there is little probability that they will fall in the receiver pass-band. Incoherent interference can be suppressed to a degree by correlation techniques in signal processing. For greater discrimination, the accumulated data of many hours of actual observation can be processed over many more hours by analogue and digital computers.

An estimate of the channel bandwidth required to allow an adequate receiver offset for Doppler shift, can be obtained by considering a specific problem in planetary detection *. Beyond this, little can be said regarding susceptibility of the system to interference without some detailed discussion of a particular system.

Radar astronomy receivers have many features in common with the radiometers used in radioastronomy. Receiver designs have progressed to the point where the sensitivity of the system is limited by environmental background noise. As a result, any generalized approach to the appraisal of the susceptibility to interference of radar astronomy receiving systems would be along lines identical to those used for satellite-communications stations and for radioastronomy. Several reports [3] on this subject have already been prepared.

3. Frequency characteristics of experimental radar astronomy systems

Most experimental radar astronomy systems have operated at frequencies allocated to radio location services, because these services have borne the costs of transmitter component developments and radar astronomy makes use of the available equipment in the interest of economy. However, there are a few specific cases wherein the nature of the scientific study strongly affects the choice of frequency. For example, studies of the solar plasma to certain depths by radar astronomy techniques requires the use of frequencies in the 20 to 60 Mc/s range.

* The radar Doppler shift is given approximately by

$$f_d = f_o \, . \, 2\, v \,/\, c$$

where f_d is the Doppler frequency shift, f_o the carrier frequency, v the radial velocity of the target and c the speed of light. Considering the entire orbit of some planets for example, the fraction $2\, v \,/\, c$, can be about 2×10^{-3} (Jupiter). The Doppler spread is a result of differing Doppler shifts from the various parts of a target reflecting area.

4. Susceptibility of radar astronomy receiving systems to other signals

Any signal that significantly increases the operating noise-temperature of the receiving system would be troublesome to the radar astronomer. This effect is primarily a function of the average power of the interfering signal. To illustrate, the 4 Gc/s system at the Lincoln Laboratory's Millstone Hill site and airborne altimeters share the same band in the frequency allocation table. Ideally, in this specific case, the unwanted signal level at the output terminals of the radar astronomy antenna should not exceed 5×10^{-23} W/c/s. At higher frequencies, where the background noise is lower, the unwanted signal level should be reduced further. To achieve these low levels of protection will require time sharing or other special arrangements, that may not always be possible on a local basis.

5. Indirect sources of interference

Scattering of the transmitted signal (or harmonics thereof), from other sources, for example from the moon, troposphere, and orbiting objects, can, under certain conditions, be a hazard. In questions of sharing, these effects should be considered on a case-to-case basis.

6. Radar astronomy interference with other services

High power is produced by radar astronomy transmitters and this power is usually confined to a fairly narrow beam by the large antenna. In many instances, the antenna beam is directed at such high angles of elevation that interference is limited to that produced in the side lobes. The power in the first side lobes is usually 15 to 30 db below that in the main lobe, and that in the remaining lobes, below isotropic. This holds also for systems operating in the 20 to 60 Mc/s range, where the high angle of elevation limits ionosphere forward-scatter primarily to the side lobes. Typical radar astronomy transmitter powers are given in Table I.

TABLE I

Frequency range (Mc/s)	Transmitter power level (kW)	
	Average	Peak
30–300	500	1000
300–3000	200	5000
3000–30 000	1	50

7. Conclusions

7.1 Adequate management of interference, involving high-power radars, is normally affected on a local basis.

7.2 Many functions of radar astronomy installations can be carried out on a shared basis. There are instances, however, where a channel of modest bandwidth within the radiolocation bands concerned may be cleared or protected on a local or regional area basis for certain radar astronomy experiments.

7.3 For equivalent bandwidths, radar astronomy receiving systems are as sensitive as satellite communications earth stations and radioastronomy installations.

7.4 When the frequency range in use is dictated by natural phenomena (e.g., solar and other plasma investigations), local or regional arrangements may be required.

7.5 From the point of view of availability of equipments, it is desirable that radar astronomy systems be operated in or near frequency bands for which high power transmitting technology has reached a suitable degree of development.

7.6 As with other high-power operations, radiolocation stations used for radar astronomy observations should be sited with great care, to minimize mutual interference problems with stations operating in the same and adjacent bands.

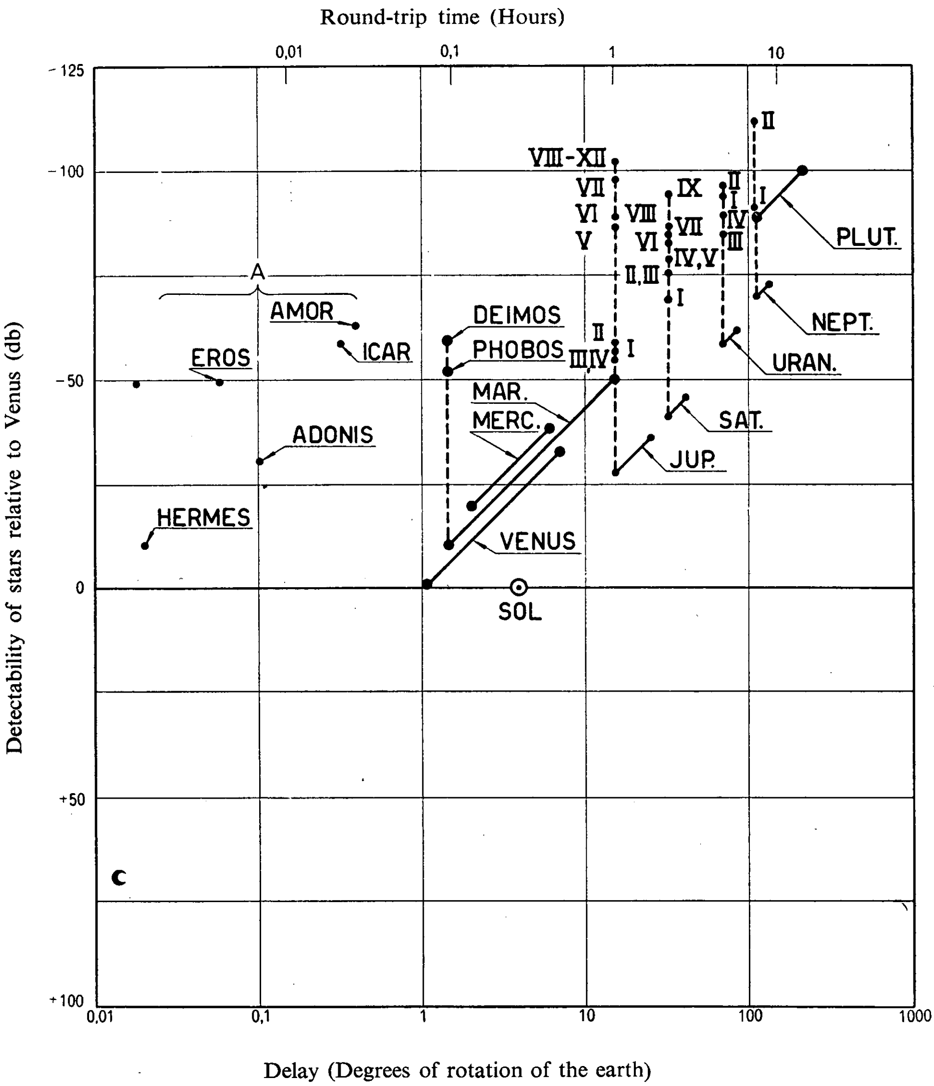


FIGURE 1

Radar detection of the planets
A : Closest approach of Asteroids

BIBLIOGRAPHY

1. HARRISON and EVANS. Radar astronomy, McGraw Hill.

2. GREEN, P. E. Jr. *M.I.T. Lincoln Laboratory Report 34-81*, May, 1959. *M.I.T. Lincoln Laboratory Report 34-84*, January, 1960.

3. C.C.I.R. Docs. IV/24, IV/47, IV/48 and IV/49 (U.S.A.), of Washington, 1962. Reports 224 and 225

STUDY GROUP IV

(Space systems and radioastronomy)

Terms of reference:

To study technical questions regarding systems of telecommunication with and between locations in space.

Chairman: Professor I. Ranzi (Italy)
Vice-Chairman: Mr. W. Klein (Switzerland)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP IV

1. Terminology

Report 204 gives a consistent and clearly defined terminology, avoiding any ambiguity and uncertainty in the use of space telecommunication terms.

2. Factors affecting the selection of frequencies for telecommunications with and between spacecraft

Report 115, revised in detail and completed with more recent results, has been adopted as Report 205.

3. Identification and cessation of radio emissions from spacecraft

It was recommended that Administrations should exchange any information relative to the identification of spacecraft (Recommendation 350) and should ensure that spacecraft be capable of ceasing radio emissions by the use of appropriate devices (Recommendation 351).

4. Hypothetical reference circuit for intercontinental active communication-satellite systems

According to Recommendation 352, such a circuit should consist of one earth-satellite-earth link.

Recommendation 353 establishes the maximum allowable noise power in the basic hypothetical reference circuit for frequency-division multiplex telephony, and Recommendation 354 defines the video bandwidth and the maximum allowable noise power in the same circuit for monochrome television.

5. Data on traffic loading and routing for use in developing communication-satellite system facilities

The Plan Committee has been asked to provide information on these subjects and forecasts for 1968 (and, if possible, up to 1975) (see Opinion 3).

6. Preliminary results of tests on active communication-satellite experiments

Report 207 stresses the satisfactory results of the "Telstar" and "Relay" experiments, and particularly, the possibility of precise tracking of a satellite with very large antennae, on the basis of the predicted orbital data alone. Other important results refer to the absence of interference and to the possibility of very satisfactory operation when the angle of elevation is greater than 5°.

7. Telecommunication links between earth stations and spacecraft for research purposes

Report 218 gives important information on the technical characteristics of such links.

The frequency-bands suitable for telemetering, wide-band data, tracking and telecommand functions for near-earth research satellites are discussed in Recommendation 364 and Report 219.

Frequency bands, bandwidths, and interference protection criteria were established for all functions in deep-space probes (Recommendation 365 and Report 220).

As regards communication links for manned research spacecraft, Report 221 gives information on the preferred frequencies, bandwidths and protection criteria.

8. Communications during spacecraft re-entry

The present state of our knowledge as to the propagation phenomena through the vehicular plasma sheet produced during re-entry was reviewed in Report 222. The need for new studies and research was pointed out in Question 239 (IV) and Study Programme 239 A (IV); Recommendation 367, after considering that frequency bands higher than the plasma critical frequencies are technically suitable, underlines the need for considering the effects of atmospheric absorption as well, when the frequency allocation problem is discussed.

9. Maintenance functions for development and operational satellites

The most suitable frequency bands for use in maintenance, telemetering, tracking and telecommand of developmental and operational radionavigation, meteorological and communication satellites are given in Recommendation 363.

10. Data transmission for radionavigation and meteorological satellites

The frequency bands which are technically suitable are discussed in Reports 216 and 217. Questions and Study Programmes were approved, and Recommendations, giving a broad indication only of the frequency bands to be allocated, were established (Recommendations 361 and 362).

11. Frequency sharing within and between a communication-satellite system and terrestrial services

A great deal of work on this problem, which is of fundamental importance to frequency allocation decisions, was carried out by a special Sub-Group. Report 209 summarizes all the technical aspects of the problem, and gives examples of the calculation of the protection criteria for frequency sharing between communication-satellite systems and terrestrial services.

Two important Recommendations resulted from collaboration with Study Group IX. Recommendation 358 establishes the maximum allowable power flux density at the surface of the earth produced by communication satellites and Recommendation 357 determines the maximum allowable value of interference noise produced in a telephone channel of a terrestrial line-of-sight radio-relay link by the earth stations of a communication-satellite system.

Recommendation 406, prepared by Study Group IX, concerning the maximum power which should be effectively radiated from a terrestrial radio-relay transmitter was approved. Further Recommendations were adopted as to the feasibility of sharing (Recommendation 355), on the criteria for the selection of the preferred frequencies to be shared with terrestrial systems (Recommendation 360) and on the determination of the coordination distance (Recommendation 359), which is particularly mportant when the sharing problem involves Administrations of different countries.

12. Radioastronomy.

Definitions of the tolerable levels of interference for radioastronomy observations and a list of the world radioastronomy observatories, with their characteristics are given in Report 224.

The possibility and the conditions for frequency sharing between the radioastronomy service and other services, are discussed in Report 225, and a list of the highest frequencies of interest to radioastronomy is given in Report 223.

13. Radar astronomy

The difficult problems involved in frequency sharing by radar astronomy with other services are discussed in Report 226.

14. Main subjects for further studies

14.1 *Preferred satellite orbit and type of system, preferred modulation system in communication-satellite systems*

Reports 206 and 211 give introductory information on these problems, the solution of which may result from future experiments.

14.2 *Use of pre-emphasis in frequency-modulation systems*

The preferred pre-emphasis characteristics should be further studied (Report 212).

14.3 *Factors affecting multi-station access in communication-satellite systems*

A general introduction to this problem is given in Report 213.

14.4 *The effects of Doppler-shifts, transmission time-delay and switching discontinuities in a communication-satellite system*

A discussion is given in Report 214. Further data are required, particularly in regard to time-delay problems.

14.5 *Frequency sharing between space and terrestrial services*

Study Programme 190 (V) on the important subject of tropospheric factors affecting frequency sharing was allotted to Study Group V.

There is a need for more experimental data on the screening effect of ground relief and on the possibility of obtaining the high degree of protection required for radioastronomy, deep-space probe and manned spacecraft experiments.

In the field of communication-satellite systems, further studies are needed on the determination of the wanted-to-unwanted signal ratio at the input to the receiver, on the basis of the type of the modulating signals (Study Programme 179(IV)).

There is also a need for further study of the problem of frequency sharing within and between communication-satellite systems (Report 210).

14.6 *Frequencies, bandwidths and protection criteria for manned research spacecraft, and for navigation and meteorological satellites.*

14.7 *Feasibility of direct sound and television broadcasting from satellites.*

OPINION 3 *

DATA ON TRAFFIC LOADING AND ROUTING FOR USE IN DEVELOPING COMMUNICATION-SATELLITE SYSTEM FACILITIES

(Question 235(IV))

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that communication-satellite systems promise to provide a means of communication between countries on a global scale;

(b) that the design and operation of a global communication-satellite system or systems should depend, amongst other factors, upon the traffic density and its characteristics and locations;

(c) that in planning global communication-satellite facilities, it will be necessary to examine the world's regional and inter-regional traffic patterns to forecast the volume and routing of traffic, which might be accommodated via such facilities; and

(d) that the Plan Committee (Joint C.C.I.T.T./C.C.I.R. Committee) is preparing a questionnaire for submission to the Administrations to collect data on global traffic in preparation for its meeting in Rome in November-December. 1963;

IS UNANIMOUSLY OF THE OPINION

that the Plan Committee should provide, for use by interested Administrations at the Extraordinary Administrative Radio Conference, Geneva, 1963, and subsequently:

1. information as to the nature, volume and routing of international, regional and global traffic, from or to the different countries, for 1962 and for such subsequent years for which it might assemble such information;

2. forecasts for 1968, and, if possible, up to 1975, of the volume of global traffic, from or to the different countries, and its routing which might be accommodated via communication-satellite systems, the forecasts being revised as opportunities offer.

QUESTION 234(IV) **

ANTENNAE FOR SPACE SYSTEMS

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

(a) that the limitations on the physical size and beamwidth of antennae for earth and space stations are important factors in determining the useful frequency range for space systems;

(b) that atmospheric effect, ionospheric effect, and techniques of fabrication provide limitations on the size of antennae and on the minimum permissible beamwidth; and

(c) that interference is an important problem;

* This Opinion has been brought to the attention of the Extraordinary Administrative Radio Conference, Geneva, 1963

** This Question replaces Question 216.

UNANIMOUSLY DECIDES that the following question should be studied:

1. what limitations in antenna beamwidth result from atmospheric and ionospheric effects;

2. what is the state of development in antenna design and fabrication;

3. what is the state of development of side and back-lobe suppression;

4. what pointing accuracy is reasonably attainable with antennae of various sizes and types?

QUESTION 235 (IV) *

TECHNICAL CHARACTERISTICS OF COMMUNICATION-SATELLITE SYSTEMS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that active or passive communication-satellite systems may well be an important means in the future for fixed and mobile communication, both regional and global;

(b) that the frequency bands to be used by such systems should be the subject of international agreement, not only to facilitate the setting up of communication links between earth stations in different countries, but also to avoid interference to and from other satellite systems and terrestrial services which may share the same frequency bands;

(c) that the choice of preferred frequency bands for such systems is determined by a number of factors including the characteristics of wave propagation, radio noise levels, the feasibility of frequency sharing with terrestrial services, the beamwidths and size of antennae, tracking considerations and pay-load limitations;

(d) that the scope for development and future application of such systems will depend to a great extent upon the feasibility of sharing frequency bands used by terrestrial services, without mutual interference;

(e) that the total frequency space required by such systems will be determined in part by the technical characteristics employed, including the arrangement and method of modulation of the radio-frequency carriers, having regard to spectrum economy;

(f) that the establishment of such systems would require international agreement on the technical characteristics to be employed, including the baseband, modulation and radio-frequency characteristics;

UNANIMOUSLY DECIDES that the following question shall be studied:

1. what are the preferred types of orbits and characteristics for active and passive communication-satellite systems for the following applications:

1.1 fixed services for multi-channel telegraphy and telephony, television and data transmission;

1.2 mobile services providing telegraphy, telephony and data transmission, between fixed earth stations and/or mobile stations;

---

* This Question, together with Question 242 (IV), replaces Question 209.

2. what are the preferred frequency-bands for these applications;

3. under what conditions and to what extent is it feasible for communication-satellites, operating in the same system or operating in different systems, to share these preferred frequency bands;

4. under what conditions and to what extent would it be feasible for communication-satellite systems to share these preferred frequency bands with terrestrial services;

5. should radio-frequency channelling or preferred reference-frequency arrangements be employed in all or a portion of the preferred bands by communication-satellite systems used for the applications referred to in § 1, and if so, what channelling arrangements are preferred;

6. what are the preferred baseband and modulation characteristics for these applications?

STUDY PROGRAMME 235 A (IV) *

FEASIBILITY OF FREQUENCY SHARING BETWEEN COMMUNICATION-SATELLITE SYSTEMS AND TERRESTRIAL RADIO SERVICES

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

(a) that use of communication-satellite systems will require extensive use of the radio-frequency spectrum;

(b) that for communication-satellite systems, the spectrum should be shared with terrestrial services to the extent practicable, in the interest of spectrum conservation; and

(c) that the feasibility of sharing spectrum space with line-of-sight radio-relay systems should be investigated;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what criteria affect the selection of sites for earth stations in the communication-satellite system, taking into account the various portions of the radio-frequency spectrum;

2. what are the preferred technical characteristics of transmitting and receiving antennae for earth stations at fixed locations, from the standpoint of spectrum sharing with other radio services;

3. what criteria affect the determination of the minimum angle of elevation, which should be employed at the locations of the earth stations;

4. to what degree will physical modification of terminal sites provide electromagnetic shielding between earth stations and stations in other radio services;

5. what criteria affect the selection of satellite power in frequency bands shared with other radio services;

6. what criteria affect the determination of the minimum practicable separation between the transmitting and receiving locations of line-of-sight radio-relay systems and the receiving and transmitting locations of earth stations in the communication-satellite systems?

---

* This Study Programme replaces Study Programme 174.

STUDY PROGRAMME 235 B (IV) *

FREQUENCY SHARING BETWEEN COMMUNICATION-SATELLITE SYSTEMS AND TERRESTRIAL RADIO SERVICES

Wanted-to-unwanted signal ratios

The C.C.I.R., (1962 — Geneva, 1963)

CONSIDERING

(a) that methods are described in Report 209 for determining the conditions under which frequency sharing is feasible between communication-satellite systems and terrestrial services;

(b) that a precise determination depends upon the availability of appropriate values for the acceptance ratios between wanted and unwanted signal powers at the receiver input for specified grades of service;

(c) that acceptance ratios are required between each type of wanted signal and each type of unwanted signal, for appropriate modulation and fading conditions, for which a test of the feasibility of sharing is desired;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. theoretical and experimental determinations of the acceptance ratios required for specified grades of service for various types of wanted and unwanted signal, for appropriate modulation conditions and for various kinds of fading;

2. investigation of those techniques of transmission, reception and modulation which will minimize the acceptance ratios required for a specified grade of service.

STUDY PROGRAMME 235 C (IV) **

COMMUNICATION-SATELLITE SYSTEMS

Feasibility of frequency sharing among communication-satellite systems

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that the use of communication-satellite systems will require extensive use of the radio spectrum;

(b) that the feasibility of frequency sharing among communication-satellites operating in the same system or operating in different systems should be investigated;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what criteria affect interference among communication-satellites in a given system and between communication-satellite systems, taking into account the two directions of transmission, for:

---

* This Study Programme replaces Study Programme 179.

** This Study Programme, together with Question 235 (IV), replaces Question 214.

1.1 systems using stationary satellites;

1.2 systems using station-keeping satellites;

1.3 systems using random satellites;

1.4 satellites operating in various orbits in the same system;

1.5 satellites operating in various orbits in different systems;

2. what are the preferred technical characteristics of transmitting and receiving antennae for earth stations, from the standpoint of frequency sharing within the same system and with other communication-satellite systems;

3. what criteria affect the determination of the minimum elevation angle which should be employed at the earth stations, from the standpoint of frequency sharing among communication-satellite systems;

4. is there an optimum range of powers to be employed by satellites and by earth-station transmitters, to facilitate frequency sharing among communication-satellite systems;

5. what are the effects of baseband and modulation characteristics on frequency sharing among communication-satellite systems;

6. would the selection of preferred reference frequencies facilitate frequency sharing among communication-satellite systems?

STUDY PROGRAMME 235 D (IV) *

STUDY OF PREFERRED MODULATION CHARACTERISTICS FOR COMMUNICATION-SATELLITE SYSTEMS

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

(a) that earth satellites are expected to be used extensively for the relay of communication signals of various types;

(b) that substantial use of communication satellites will place substantial demands upon the radio spectrum;

(c) that, in the interest of conservation of the radio-frequency spectrum, effort should be exerted to use the minimum feasible amount of spectrum space to convey the maximum amount of information;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the preferred characteristics for transmission from earth to satellite to earth in passive communication-satellite systems;

2. determination of the preferred modulation characteristics for transmission from earth to satellite and from satellite to earth in active communication-satellite systems,

3. determination of the extent to which signal compression or signal processing techniques can usefully be employed to conserve radio-frequency bandwidth, and the preferred characteristics which should be employed when such techniques are used for satellite-communication systems.

---

* This Study Programme replaces Study Programme 175.

STUDY PROGRAMME 235 E (IV) *

FACTORS AFFECTING FREEDOM OF ACCESS IN COMMUNICATION-SATELLITE SYSTEMS

The C.C.I.R., (1962 — Geneva, 1963)

CONSIDERING

(a) that communication-satellite systems may require simultaneous use by large numbers of earth stations at various locations, this being termed "freedom of access";

(b) that this freedom of access may be affected by the orbital design of the system;

(c) that this freedom of access may be affected by the choice of modulation techniques used;

(d) that this freedom of access may be affected by the interference characteristics of the system or systems used;

(e) that multiple access requirements may dictate a system design, different from that which may be optimum for limited access systems;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what factors determine the accessibility of a communication-satellite system to a number of earth stations simultaneously or in random order;

2. to what extent does the choice of orbital parameters affect this freedom of access, and are there preferred orbits for such freedom of access;

3. to what extent does the type of modulation and channel arrangement employed affect freedom of access, and are there preferred types of modulation and channel arrangement for such freedom of access;

4. what are the effects of the preferred choices resulting from §§ 2 and 3 on the possibilities of sharing with terrestrial services and with other satellite systems of the same and of different type?

QUESTION 236 (IV) **

SHARING OF RADIO-FREQUENCY BANDS BY LINKS BETWEEN EARTH STATIONS AND SPACECRAFT

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

(a) that sharing of the radio spectrum by links between earth stations and spacecraft with all other radio services may be necessary, because of the limited spectrum space available to support the world's communication requirements; and

---

* This Study Programme replaces Study Programme 178.

** This Question replaces Question 210.

(b) that factors which determine the ability to share spectrum space are strongly interdependent;

UNANIMOUSLY DECIDES that the following question should be studied:

1. how do the following factors, among others, affect the practicability of sharing:

1.1 location of space and earth stations of a link and the resulting zones of mutual visibility;

1.2 time of use during period of mutual visibility;

1.3 probability of occupancy of the zones of mutual visibility of links between earth stations and spacecraft by other operating stations during the required times of use of the link and the resulting power levels at all earth stations, as a consequence of this combined occupancy;

1.4 other system parameters, such as modulation techniques, antenna directivity, etc.;

1.5 natural (non man-made) interference;

2. to what extent is spectrum sharing feasible for different links between earth stations and spacecraft; between these links and other space systems; and between these links and terrestrial radio services?

QUESTION 237 (IV) *

TECHNICAL CHARACTERISTICS OF LINKS BETWEEN EARTH STATIONS AND SPACECRAFT

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

(a) that the value of spacecraft will, in the future, depend almost entirely on the ability to use radio-frequency electromagnetic energy for the transmission of all types of information over links between earth stations and spacecraft;

(b) that available bandwidth in useful regions of the radio-frequency spectrum will be limited;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred technical characteristics and system parameters commensurate with technical feasibility which will insure the maximum practical use of radio-frequency spectrum space for the following types of links between earth stations and spacecraft:

1. maintenance telemetering;
2. tracking;
3. telecommand;
4. communication and data transmission?

Note 1. — This Question relates both to space research and to developmental and operational systems.

Note 2. — The following factors should be taken into account in carrying out this study:

— information rate and duty-cycle as they affect bandwidth requirements;

— required signal-to-noise ratio;

---

* This Question replaces Question 211.

— required reliability and lifetime of links between earth stations and spacecraft;
— gain and effective aperture area and pointing accuracy requirements of transmitting and receiving antennae, both at earth stations and at space stations;
— transmitter characteristics (including power, stability, efficiency, etc.);
— receiver characteristics (including sensitivity, effective noise-temperature, etc.);
— operating factors (including maximum distance between earth stations, size and weight limitations, vehicle orientation capability, relative velocities, etc.);
— attenuation due to absorption of energy by the transmission medium;
— interference with other links between earth stations and spacecraft and terrestrial services;
— type of modulation.

QUESTION 238 (IV) *

ACTIVE COMMUNICATION-SATELLITE SYSTEMS FOR FREQUENCY-DIVISION MULTIPLEX TELEPHONY

Transmission characteristics of audio channels

The C.C.I.R., (1962 — Geneva, 1963)

CONSIDERING

(a) that satellites at various altitudes may be used for communication purposes;

(b) that echoes, e.g. due to impedance mismatch at 4-wire/2-wire terminations external to the satellite link, may be present;

(c) that for telephony transmission, it may be necessary to incorporate echo suppressors;

(d) that, for the specification of these echo suppressors and for other reasons, the C.C.I.T.T. will require information on certain transmission characteristics of the communication-satellite system, such as the expected noise value and attenuation variations;

(e) that Recommendation 353 gives provisional values for the mean noise-power in any hour;

(f) that it may be necessary to correct the frequencies of frequency-division multiplex channels affected by Doppler shifts in communication-satellite systems;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what higher noise values are to be expected for small percentages of the time;

2. what attenuation variations in the various audio channels of the baseband are to be expected in the various types of communication-satellite system;

3. what residual frequency variations due to Doppler and other effects are to be expected in audio channels of the baseband for various types of communication-satellite systems?

---

* This Question replaces Question 224.

QUESTION 239 (IV) *

EFFECTS OF PLASMA ON COMMUNICATIONS WITH SPACECRAFT

The C.C.I.R., (Geneva 1963)

CONSIDERING

(a) that ionospheric plasma has been observed to have a considerable effect upon the operation of transmitting and receiving antennae mounted on rockets and spacecraft;

(b) that the plasma produced by the shock wave resulting from the re-entry of a spacecraft into the terrestrial atmosphere, may have analogous effects;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the effects of the surrounding plasma on the operation of the transmitters and receivers, and in particular the antennae on board spacecraft, taking into account laboratory experiments and direct measurements;
2. what factors determine the formation and structure of the induced plasma surrounding a spacecraft;
3. what communication problems (wave propagation and noise) are represented (in particular during re-entry into the terrestrial atmosphere) as a result of the plasma;
4. what influence do these effects exert on the choice of usable frequencies, especially during re-entry of a spacecraft into the terrestrial atmosphere?

Note. — The above Question should be brought to the attention of the U.R.S.I. by the Director, C.C.I.R.

STUDY PROGRAMME 239 A (IV)

FREQUENCY BANDS FOR RE-ENTRY COMMUNICATIONS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that communication with a spacecraft during the re-entry phase may be crucial during many missions;

(b) that the optimum frequency is dependent upon the configuration of the spacecraft and its re-entry speed;

(c) that Recommendation 367 considers only a limited portion of the radio-frequency spectrum;

(d) that, due to the increased transparency of the plasma sheath at higher frequencies, it appears desirable to consider atmospheric windows above the oxygen absorption band at about 60 Gc/s;

(e) that Report 222 mentions the theoretical possibility of communicating at frequencies well below the critical frequency of the plasma sheath;

---

* This Question, together with Study Programme 205 (VI), replaces Question 212 and Study Programme 173.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. investigation of the technical suitability of frequencies above 60 Gc/s for re-entry communication;

2. investigation into the feasibility of communicating at frequencies well below the critical frequency of the plasma sheath.

QUESTION 240 (IV) *

TIME DELAY, ECHOES AND SWITCHING DISCONTINUITIES IN COMMUNICATION-SATELLITE SYSTEMS

(1962 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that satellites at various altitudes may be used for communication purposes;

(b) that, due to the distances to be traversed by the signals and the finite velocity of radio waves, the use of earth satellites for communication purposes will introduce time delay which, if large, may be troublesome for public telephony;

(c) that echoes, e.g. due to impedance mismatch at 4-wire/2-wire terminations external to the satellite link, may also be present;

(d) that time discontinuities, due to the switching of signals from satellite to satellite in non-synchronous satellite systems, may cause difficulties for the transmission of telephony, telegraphy, television and other signals, if the discontinuities are excessive or too frequent:

(e) that the permissible overall time delays, levels of echoes and switching discontinuities, are matters for the C.C.I.T.T. (in the case of television, for the C.M.T.T.) to decide;

(f) that the permissible values of time delay may have a marked effect on the costs of establishing and maintaining communication-satellite systems;

(g) that, whereas high altitude satellites offer increased coverage with fewer satellites, the time delay would be greater than if low altitude satellites were used;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what time delays and switching discontinuities are to be expected in the various types of communication-satellite system;

2. what methods, within the satellite system itself, could be used to minimize or avoid time-delay variations and switching discontinuities in non-synchronous satellite systems;

3. which orbits are most suitable for communication-satellite systems, as regards the maximum permissible values of the time delay, level of echo signals and switching discontinuities for telephony, telegraphy, television and other signals, taking account of the views of the C.C.I.T.T. and C.M.T.T., as appropriate?

---

* This Question replaces Question 223.

QUESTION 241 (IV) *

FEASIBILITY OF DIRECT SOUND AND TELEVISION BROADCASTING FROM SATELLITES

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that there are many parts of the world with little or no broadcasting service;

(b) that there is considerable interest in the possibility of broadcasting from satellites;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the satellite orbits most satisfactory for direct broadcasting to the general public from satellites;
2. what are the preferred transmitter characteristics which should be employed for sound and television broadcasting from satellites;
3. what frequency bands would be technically suitable for such broadcasting from satellites, and could these bands be shared with terrestrial services; if so, on what basis?

QUESTION 242 (IV) **

TECHNICAL CHARACTERISTICS OF RADIONAVIGATION-SATELLITE SYSTEMS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that systems using satellites may well be an important means of world-wide radionavigation in the future;

(b) that the frequencies to be used by such systems should be the subject of international agreement, not only to facilitate the setting up of radionavigation systems, but also to avoid interference to and from other satellite systems and stations of other services, which may share the same frequency bands;

UNANIMOUSLY DECIDES that the following questions should be studied:

1. what are the preferred types and technical characteristics of radionavigation-satellite systems;
2. what are the preferred frequency bands for radionavigation-satellite systems;
3. is the sharing of frequencies with other services feasible, and if so, with what other services and under what conditions?

---

* This Question replaces Question 215.

** This Question, together with Question 235 (IV), replaces Question 209.

QUESTION 243 (IV)

RADIOCOMMUNICATION FOR METEOROLOGICAL-SATELLITE SYSTEMS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

that the value of meteorological-satellites has been demonstrated and that they will soon be operating in a routine manner;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics of radiocommunication for meteorological-satellite systems?

STUDY PROGRAMME 243 A (IV)

RADIOCOMMUNICATION ASPECTS OF METEOROLOGICAL-SATELLITE SYSTEMS

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that meteorological-satellite systems may well, in the future, be an important means of world-wide weather forecasting (World Weather Watch);

(b) that meteorological information is now gathered by meteorological-satellites and relayed to earth stations;

(c) that these satellites may employ different type orbits—polar, equatorial or at intermediate angles and altitudes up to and including the synchronous altitude (36 000 km);

(d) that all of these orbits pass over, or are in view of, many different countries;

(e) that the international character of these systems dictates that the frequency bands employed to relay their collected meteorological data to earth should be subject to international agreement;

(f) that this would facilitate the establishment of an international weather system and would minimize interference situations;

(g) that the evolution of such systems would be facilitated if frequency sharing with other services is practical;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what parts of the radio-frequency spectrum are preferred for meteorological-satellite systems;
2. what are the preferred types and characteristics of radiocommunication for such systems, both under development and in planning;
3. is the sharing of frequencies with other services practical, and if so, with what services and under what conditions?

QUESTION 244 (IV) *

RADIOASTRONOMY

The C.C.I.R., (1961 — Geneva, 1963)

CONSIDERING

(a) that radioastronomy is based on the reception of signals at much lower power levels than are generally employed in other radio services and, hence, is subject to harmful interference from sources that could be tolerated by many other services;

(b) that, for an understanding of the naturally occurring phenomena that produce characteristic line frequencies and the physical processes that result in continuum emission, radioastronomers must observe at both the immutable line frequencies and at several diverse points in the continuum;

(c) that the C.C.I.R., in recognition of the above situation, adopted Recommendation 314, "Protection of frequencies used for radioastronomical measurements" at the IXth Plenary Assembly, Los Angeles, 1959;

(d) that the Administrative Radio Conference, Geneva, 1959, recognized the radioastronomy service and the cosmic origin of the signals used in this branch of astronomy;

(e) that the Radio Regulations, Geneva, 1959, allocated a band at the hydrogen-line frequency (1400 to 1427 Mc/s) for the radioastronomy service on a world-wide basis, and provide some further protection for the radioastronomy service on a regional basis, either by other than primary allocation or by footnote;

(f) that the Administrative Radio Conference, Geneva, 1959, in its Recommendation No. 32, drew attention to the special case of the radioastronomy service and to the failure of the revised Table of Frequency Allocations to meet fully the stated requirements, urged that observatories be located as remotely as possible from sources of radio interference, and recommended that further consideration be given to the question of frequency allocations for radioastronomy;

(g) that the expected expansion of space-communication programmes, noted by Recommendation No. 36 of the Administrative Radio Conference, Geneva, 1959, has occurred;

(h) that space communication signals may nullify the partial protection to radioastronomy observations afforded either by remotely located observatory sites or by other regional or more local administrative provisions;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the characteristics of the signal of interest to radioastronomy? In addition to parameters such as intensity, frequency, bandwidth, polarization, and modulation, or frequency of occurrence, how do the characteristics vary depending on the celestial source, e.g. the sun, planets, extended galactic sources, extragalactic sources with large Doppler shifts;

2. with reference to Article 1, No. 93 of the Radio Regulations, Geneva, 1959, which defines harmful interference as "Any emission, radiation, or induction which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs

* This Question replaces Question 218.

or repeatedly interrupts a radiocommunication service operating in accordance with these Regulations", what is a practical interpretation of this definition for the radioastronomy service;

2.1 with reference to § 1, what are the threshold values of the signal level for there to be harmful interference;

2.2 how are these threshold values modified if reception is via the side lobes only rather than the main beam of the radioastronomy telescope;

3. what interference levels would typical observatory sites (the site at Green Bank, W. Va. might be taken as a typical remote site, and the Observatory of the University of Michigan or Lincoln Laboratory might be typical of sites in more populated regions) experience in the VHF, SHF and EHF bands, as predicted by means of the best available experimental data and accepted theories on atmospheric scatter, diffraction, and related propagation phenomena, from the following types of sources:

3.1 ground-based transmitters, assumed to operate in accordance with accepted standards;

3.2 airborne transmitters, including both fundamental and spurious emissions;

3.3 aircraft illuminated by ground-based transmitters;

3.4 orbiting devices with active transmitters, considered both with and without directional antenna systems;

3.5 orbiting reflectors, illuminated from the ground, including both "Echo" type satellites and unintentional reflectors such as active satellites, carrier rocket cases, and similar debris; and

3.6 orbiting zones or bands of diffuse scattering elements, illuminated from the ground;

4. what are the general areas of interest in the radio-frequency spectrum to the radioastronomy service, in the light of:

4.1 the Table of Frequency Allocations, 1959;

4.2 the advent of operational space telecommunication systems;

4.3 the rapidly improving observational capabilities and techniques now in use and anticipated, such as larger antenna systems, masers, and other forms of improved receivers, and more sophisticated means of handling and analyzing data;

4.4 possible use of higher frequencies than the present limit of 40 Gc/s in the Table of Frequency Allocations; and

4.5 other line frequencies than those listed by the C.C.I.R. in Recommendation 314?

QUESTION 245 (IV)

RADAR ASTRONOMY

The C.C.I.R., (Geneva, 1963)

CONSIDERING

(a) that radar astronomy is a part of pure science, contributing to our knowledge through studies of the reflecting properties of natural and man-made targets, advancing the study of celestial mechanics by direct measurements with great precision, of the motions and distances of orbiting bodies, and through the study of the nature and effects of the propagating medium;

(b) that the receiving techniques of radar astronomy require sensitivities equivalent to those of radioastronomy;

(c) that the problems of detection, location, tracking and determination of ephemeris are common to radar astronomy and communication-satellite systems;

(d) that radar astronomy transmitters are seldom developed solely for this application, but are ordinarily the outgrowths of the most advanced transmitter technology developed for other purposes;

(e) that radar astronomy has immediate applications to space radiocommunication by providing basic data required for the computation of trajectories and ephemerides for space objects;

(f) that there is a close parallel between the objectives of radar astronomy and some communication-satellite systems, because both depend upon radio scattering from objects in space;

(g) that radar astronomy frequencies are not generally tied to the frequencies associated with natural phenomena, the exception being special experiments on the atmosphere of the earth and the planets;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the performance characteristics of radar astronomy systems;

2. what levels and durations of interfering signals are tolerable in radar astronomy reception;

3. what factors, both technological and scientific, are fundamental in the selection of frequencies for radar astronomy experiments?

LIST OF DOCUMENTS OF THE Xth PLENARY ASSEMBLY CONCERNING STUDY GROUP IV

Doc.	Origin	Title	Reference	Other Study Groups concerned
4	Chairman Study Group IV	Report by Chairman of Study Group IV (Prof. I. Ranzi)	—	—
20	C.C.I.T.T.	Subscribers' tolerance of echoes	C.C.I.T.T. Q. 6/XII	—
24	United States of America	Radio spectrum requirements for meteorological satellites	Draft Rep.	—
25	United States of America	Technical characteristics of meteorological satellite systems	Draft Q.	—
26	United States of America	Frequencies suitable for meteorological satellites	Draft Rec.	—
27	United States of America	Use of earth satellites for terrestrial navigation	Draft Rec.	—
29	United States of America	Technical characteristics of communication systems using earth satellites	Draft Rep.	—
30	United States of America	Data on traffic loading and routing for use in developing communication-satellite system facilities	Draft Res.	—
31	United States of America	Active earth satellite communication systems for monochrome television. Form of the hypothetical reference circuits: the video bandwidth and permissible noise level	Rev. of Ann. 4/18	—
32	United States of America	Active earth satellite communication systems for monochrome television. Video bandwidth and permissible noise in the hypothetical reference circuit	Rev. of Ann. 4/6	—
33	United States of America	Active communication-satellite systems for multiplex telephony and monochrome television. Hypothetical reference circuit for intercontinental systems	Rev. of Anns. 4/3 and 4/5	—
34	United States of America	Active communication-satellite systems for multiplex telephony. Allowable noise power in the hypothetical reference circuit	Rev. of Ann. 4/4	—
35	United States of America	Active communication-satellite systems for multiplex telephony. Hypothetical reference circuit and allowable noise standards	Rev. of Ann. 4/16	—
36	United States of America	Factors affecting freedom of access in the communication-satellite service	Draft Rep.	—
37	United States of America	Technical characteristics of earth-space telecommunication links for research	Draft Rep.	—
38	United States of America	Interference considerations for deep-space research telecommunication links	Draft Rep.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
39	United States of America	Deep-space research telecommunications links	Draft Rec.	—
40	United States of America	Interference considerations for near-earth research satellite telecommunication links	Draft Rep.	—
41	United States of America	Near-earth research satellite telecommunication links	Draft Rec.	—
42	United States of America	Tracking, telemetry and telecommand functions of operational active communications satellites	Draft Rep.	—
43	United States of America	Tracking, telemetry and telecommand functions of operational active communications satellites	Draft Rec.	—
45	United States of America	Space bands for re-entry communications	Draft S.P.	—
46	United States of America	Space bands for re-entry communications	Draft Rec.	—
47	United States of America	Factors affecting the selection of frequencies for telecommunications with space vehicles re-entering the earth's atmosphere	Rev. of Ann. 4/22	—
48	United States of America	Feasibility of direct broadcasting from earth satellites; sharing considerations	Q. 215	—
49	United States of America	Method for calculating interference between stations in the communication-satellite service and radio-relay systems in the fixed service	Q. 215 S.P. 174	—
51	United States of America	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	—
52	United States of America	Active communication-satellite service systems	Draft Rec.	—
53	United States of America	Interference from all co-channel radio-relay transmitters to a satellite receiver	Draft Rep.	—
54	United States of America	Interference from several satellite transmitters to the several receivers of a radio-relay system	Draft Rep.	—
55	United States of America	Frequency sharing between co-channel satellite communication systems	Draft Rep.	—
56	United States of America	Control of eclipse interference between co-channel satellite communication systems	Draft Rec.	—
59	United States of America	Radar astronomy	Draft Q.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
60	United States of America	Line frequencies or bands arising from natural phenomena in the frequency range 30 Gc/s to 300 Gc/s of interest to radioastronomy and related sciences	Draft Rep.	—
61	United States of America	The possibility of sharing between radioastronomy and other services	Draft Rep.	—
62	United States of America	Signal levels of harmful interference to the radioastronomy service	Draft Rep.	—
70	United States of America	Meteorological satellites "Nimbus"	Draft Rep.	—
71	United States of America	Use of earth satellites for terrestrial navigation	—	—
72	United States of America	Interference from communication satellites to terrestrial radio-relay receivers	Q. 214 S.P. 174	—
75	United States of America	Frequency sharing between communication-satellite systems and terrestrial radio services	Doc. IV/79-Rev.	IX
76	United States of America	Frequency sharing between communication-satellite systems and terrestrial radio services	Doc. IV/79-Rev.	IX
79	United Kingdom	Active earth-satellite communication systems for frequency-division multiplex telephony	Q. 209 S.P. 174	—
80	United Kingdom	Active earth-satellite communication systems for monochrome television	Q. 209 S.P. 174	—
81	United Kingdom	Active earth-satellite communication systems for frequency-division multiplex telephony and monochrome television	Q. 209 S.P. 174	—
82	United Kingdom	Time delays and switching discontinuities in satellite communication systems	Q. 223	—
83	United Kingdom	Active earth-satellite communication systems for television	Q. 223	—
84	United Kingdom	Active earth-satellite systems for radionavigation	Q. 209	—
85	United Kingdom	Applications of earth satellites for the terrestrial radionavigation service	Q. 209	—
91	United States of America	Report on figures of merit for radio receiving systems in the presence of noise or unwanted-signal interference and the concepts of operating noise-factor and operating noise-temperature	Draft Rep.	II
105	India	Design and performance of VHF receiving equipment for reception of extremely weak signals of solar and galactic origin in the metre wavelength region	—	II
106	I.U.C.A.F.	Recommendation I	Radio-astronomy	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
107	I.U.C.A.F.	Recommendation II	Radio-astronomy	—
108	United Kingdom	Definition of right and left-handed elliptically or circularly polarized electromagnetic waves	—	XIV
109	United Kingdom	Active earth-satellite communication systems for telegraphy, phototelegraphy and data transmission. The effects of transmission time delay and switching discontinuities	Q. 213	
110	United Kingdom	Active earth-satellite communication systems. Baseband characteristics for frequency-division multiplex telephony	Q. 209 and 224	—
111	United Kingdom	Active earth-satellite communication and navigation systems. Preferred characteristics for telemetry, telecommand and tracking	Q. 209	—
112	United Kingdom	Mutual interference between active earth-satellite communication systems using frequency modulation and terrestrial line-of-sight radio-relay systems sharing the 4 and 6 Gc/s bands. Derivation of necessary separation distances between satellite communication system ground-stations and line-of-sight radio-relay system stations	Q. 209 S.P. 174 Q. 192 (IX)	IX
113	United Kingdom	Radio-frequency channelling arrangements for satellite communication systems sharing frequency bands with line-of-sight radio-relay systems	Q. 209 S.P. 178	—
114	United Kingdom	Comparison of methods for the calculation of interference between communication satellite space services (relay) and terrestrial radio-relay services	Q. 209 S.P. 174 and 179	—
115	United Kingdom	Active earth-satellite "Telstar": Preliminary results at the United Kingdom ground station, Goonhilly Downs, Cornwall	Q. 209 and 216 S.P. 174 and 175	—
116	United Kingdom	Mutual interference between active earth-satellite communication system and line-of-sight radio-relay systems sharing the 4 and 6 Gc/s bands. Limitation of the transmitter powers for satellite and line-of-sight radio-relay systems	Q. 192 (IX) and 209 S.P. 174	IX
117	United Kingdom	Active earth-satellite communication systems. Consideration relating to the choice of orbit and type of satellite for a world-wide satellite communication system	Q. 209	—
129	C.C.I.R. Secretariat	Bibliographic references in the volumes of the C.C.I.R.	—	I-XIV

Doc.	Origin	Title	Reference	Other Study Groups concerned
148	United States of America	Factors affecting the possibility of frequency sharing by radar astronomy with other services	Draft Rep.	—
149	United States of America	Telecommunication links for manned research space vehicles	Draft Rec.	—
160	Special Joint Study Group C (C.C.I.T.T./C.C.I.R.)	Communication satellite systems sharing the same frequency bands as line-of-sight radio-relay systems. Maximum allowable values of interference in a telephone channel	Doc. 51	IX
161	C.C.I.T.T.	Noise limits for very long telephone circuits	—	IX
165	I.U.C.A.F.	Allocation of space research frequencies	—	—
167	C.C.I.T.T.	Time delay and echo. Contribution No. 31 Study Group XII of the C.C.I.T.T.	Q. 6/XII C.C.I.T.T.	—
184	United Kingdom	Active earth-satellite communication systems. A comparative study of possible methods of modulation	Q. 209 S.P. 175	—
185	United Kingdom	Terminology and definitions relating to space radiocommunications	—	—
186	C.C.I.R. Secretariat	Supplementary information concerning radio-astronomical observatories	—	—
188	France	Telecommunication by satellite relays. Measurements of intermodulation noise in telephony. Choice of frequency deviation	Q. 209, § 5 S.P. 175	—
189	France	Telecommunication by satellite relays. Variations in noise power	Q. 209 and 224, § 1	—
190	France	Telecommunication by relay satellites. Fluctuations in the power of the wave received	Q. 209 and 224	—
199	I.B.T.O.	Bandwidth for the transmission of video signals via a system of active earth satellites	Q. 209	—
224	Australia	Active earth-satellite communication systems for multichannel telephony	Q. 209	—
242	Canada	Active earth-satellites for broadcasting	Q. 215	—
244	The Telephone Association of Canada	Mutual interference possibilities between communications satellite systems and radio-relay systems	Draft Rep.	—
245	The Telephone Association of Canada	Cessation of radio emissions from satellites and other space vehicles	Draft Rec.	—
246	The Telephone Association of Canada	Radio-frequency channelling arrangements for satellite communication systems sharing frequency bands with line-of-sight radio-relay systems	Draft Rec.	—
247	The Telephone Association of Canada	Frequency sharing between communication-satellite systems and terrestrial radio-relay systems	Q. 209 and 214 S.P. 174 and 179	IX

Doc.	Origin	Title	Reference	Other Study Groups concerned
248	The Telephone Association of Canada	Time delay and noise on telephone connections employing satellite communication systems	Q. 209 and 223	—
249	The Telephone Association of Canada	Computation of baseband interference levels due to mutual interference between communication-satellite systems and radio-relay systems	S.P. 179	—
251	Working Party on definitions and terminology	Terms used in space telecommunications	Draft Rep.	—
252	France	Terms used in space telecommunications	—	XIV
277	Canada	Sharing of the 1-10 Gc/s radio-frequency band between active satellite communication systems and terrestrial radio-relay systems	Q. 209	—
278	Study Group IV	Summary record of the first meeting	—	—
281	United States of America	Research manned space vehicle telecommunication links	Draft Rep. Q. 210 and 211	—
290	I.U.C.A.F.	Radioastronomy	Draft Rec.	—
291	I.U.C.A.F.	Space research service	Draft Rec.	—
307	Sub-Group IV-A	Cessation of radio emissions from satellites and other space vehicles	Draft Rec. Q. 208	—
308	Sub-Group IV-A	Identification for radio emissions from satellites and other space vehicles	Draft Rec. Q. 208	—
312	Sub-Group IV-A	Active earth-satellite communication systems for frequency-division multiplex telephony and monochrome television	Draft Rep. Q. 209	—
320	United States of America	The sharing of frequencies between communication-satellite systems and terrestrial radio systems	Q. 210 S.P. 174	—
322	Study Group IV	Factors affecting the selection of frequencies for telecommunications with and between space vehicles	Draft Rep.	—
323	United States of America	Experiments with "Telstar" satellite	Q. 209, 216 and 224 S.P. 174 and 175	—
331	Study Group IV	Terms and definitions relating to space radiocommunication		—
336	Sub-Group IV-A	Data on traffic loading and routing for use in developing communication-satellite system facilities	Draft Op.	—
337	Sub-Group IV-A	Active communication-satellite systems for multiplex telephony and monochrome television	Draft Rec.	—
341	Sub-Group IV-C	Effects of plasma on communications with space vehicles	Draft Q.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
342	Sub-Group IV-C	Factors affecting the selection of frequencies for telecommunications with space vehicles re-entering the earth's atmosphere	Draft Rep.	—
343	Sub-Group IV-C	Space-bands for re-entry communications	Draft Rec.	—
344	Sub-Group IV-C	Space-bands for re-entry communications	Draft S.P.	—
353	Sub-Group IV-E	Passive radioastronomy	Q. 218	—
366	Study Group IV	Radioastronomy	Draft Rep.	—
375 + Add. 1	Sub-Group IV-E	Modifications to Doc. 59, 60, 61, 148, 290, 353 and 366	—	—
380	Study Group IV	Summary record of the second meeting	—	—
381	Sub-Groups IV-D and IX-A	Communication satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	IX
401	Sub-Group IV-D	Line-of-sight radio-relay systems sharing the same frequency bands as the satellite receivers of active earth-satellite communication systems	Draft Rec.	IX
412	Sub-Group IV-A	Technical characteristics of communication-satellite systems	Draft Q.	—
413	Sub-Group IV-A	Active communication satellite systems for frequency-division multiplex telephony and monochrome television	Draft Rep.	—
414	Sub-Group IV-A	Active communication-satellite systems for frequency-division multiplex telephony	Draft Rec.	—
415	Sub-Group IV-A	Active communication-satellite systems for monochrome television	Draft Rec.	—
420	Study Group IV	Note to the Chairman of the C.M.T.T.	—	—
445	Study Group IV	Telecommunication links for deep-space research	Draft Rec.	—
446	Working Group IV-B-1	Interference considerations for deep-space research telecommunication links	Draft Rep.	—
459	Sub-Groups IV-D and IX-A	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	IX
470	Sub-Group IV-A	Feasibility of direct broadcasting from earth satellites	Draft Q.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
473	United States of America	The use of power density or power flux density criteria	Q. 215 S.P. 174	—
481	Study Group IV	Summary record of the third meeting	—	—
497	Sub-Group IV-B-2	Use of earth satellites for terrestrial navigation	Draft Rep.	—
509	Sub-Group IV-B-1	Telecommunication links for near-earth research satellites	Draft Rec.	—
510	Sub-Group IV-B-1	Interference considerations for near-earth research satellite telecommunications	Draft Rep.	—
522	Sub-Groups IV-D and IX-A	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Draft Rec.	IX
526	Study-Group IV	Summary record of the fourth meeting	—	—
527	Sub-Group IV-B-2	Radiocommunication aspects of meteorological satellite systems	Draft S.P.	—
528	Sub-Group IV-B-2	Radiocommunications for meteorological satellite systems	Draft Q.	—
529	Sub-Group IV-B-2	Frequency requirements of radionavigation systems using earth-satellites	Draft Rec.	—
530	Sub-Group IV-B-2	Radiocommunications for meteorological space satellite systems	Draft Rep.	—
531	Sub-Group IV-B-2	Frequencies technically suitable for meteorological satellites	Draft Rec.	—
532	Sub-Group IV-B-2	Technical characteristics of navigation systems using earth satellites	Draft Q.	—
533	Sub-Group IV-D	Active communication-satellite systems	Draft Rec.	—
542	Sub-Group IV-B-1	Telecommunication links for manned research spacecraft	Draft Rec.	—
543	Sub-Group IV-B-1	Telecommunication links for manned research spacecraft	Draft Rep.	—
544	Sub-Group IV-B-1	Preferred frequency bands for use in functional telemetering, tracking and telecommand of developmental and operational earth satellites	Draft Rec.	—
557	Sub-Group IV-B-1	Technical characteristics of telecommunication links between earth stations and spacecraft for research	Draft Rep.	—
561	Sub-Group IV-A	Communication-satellite systems	Draft Rep.	—
564	Sub-Group IV-D	Communication-satellite systems. Avoidance of interference between earth stations and terrestrial radio stations sharing the same frequency bands	Draft Rec.	—
566	Sub-Group IV-D	Communication-satellite systems	Draft S.P.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
567	Sub-Group IV-A	Feasibility of direct sound and television broadcasting from earth satellites	Draft Rep.	—
568	Sub-Group IV-A	Factors affecting multi-station access in communication-satellite systems	Draft Rep.	—
569	Study Group IV	Communication-satellite systems	Draft Rep.	—
574	Sub-Group IV-A-2	Active communication-satellite experiments. Preliminary results of tests and demonstrations	—	—
575	Study Group IV	Criteria for selection of preferred reference frequencies for communication-satellite systems sharing frequency bands with line-of-sight radio-relay systems	Draft Rec.	—
581	Sub-Group IV-D	Communication-satellite systems frequency sharing between communication-satellite systems and terrestrial services	Draft Rep.	—
593	Sub-Group IV-D	Frequency sharing within and between communication-satellite systems	Draft Rep.	—
594	Study Group IV	Summary record of the fifth meeting	—	—
597	Sub-Group IV-A	Active earth-satellite communication systems. A comparative study of possible methods of modulation	Draft Rep.	—
598	Study Group IV	Summary record of the sixth meeting	—	—
608 *bis*	Study Group IV	Texts to be submitted to the Extraordinary Administrative Radio Conference, Geneva, 1963	—	—
611	Study Group IV	Modifications to be made to Questions and Study Programmes assigned to Study Group IV	—	—
613	Study Group IV	Texts approved by Study Group IV. References to Questions and Study Programmes	—	—
615	Study Group IV	Summary record of the seventh meeting	—	—
618	Study Group IV	Summary record of the eighth meeting	—	—
622	Study Group IV	Summary record of the ninth and last meeting	—	—
2084	Drafting Committee	Cessation of radio emissions from spacecraft	Rec. 351	—
2085	”	Identification of radio emissions from spacecraft	Rec. 350	—
2086	”	Active communication-satellite systems for frequency-division multiplex telephony and monochrome television	Rep. 212	—
2087	”	Active communication-satellite systems for multiplex telephony and/or monochrome television	Rec. 352	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
2167	Drafting Committee	Data on traffic loading and routing for use in developing communication-satellite system facilities	Res. 3	—
2168	”	Effects of plasma on communications with spacecraft	Q. 239	—
2169	”	Factors affecting the selection of frequencies for telecommunications with spacecraft re-entering the earth's atmosphere	Rep. 222	—
2170	”	Frequency bands for re-entry communications	Rec. 367	—
2171	”	Frequency bands for re-entry communications	S.P. 239A	—
2172	”	Technical characteristics of communication-satellite systems	Q. 235	—
2173	”	Active communication-satellite systems for frequency-division multiplex telephony	Rec. 353	—
2174	”	Active communication-satellite systems for monochrome television	Rec. 354	—
2175	”	Factors affecting the selection of frequencies for telecommunication with and between spacecraft	Rep. 205	—
2211	”	Telecommunication links for deep-space research	Rec. 365	—
2212	”	Interference considerations for telecommunication links used for deep-space research	Rep. 220	—
2213	”	Active communication-satellite systems for frequency-division multiplex telephony and monochome television	Rep. 208	—
2214	”	Communication-satellite systems sharing frequency bands with line-of-sight radio-relay systems	Rec. 357	—
2215	”	Radioastronomy	Q. 244	—
2216	”	Line frequencies or bands, of interest to radioastronomy and related sciences, in the 30 to 300 Gc/s range arising from natural phenomena	Rep. 223	—
2217	”	Radioastronomy	Rep. 224	—
2218	”	The possibility of sharing between radioastronomy and other services	Rep. 225	—
2219 (withdrawn)	”	Radioastronomy	—	—
2220	”	Radar astronomy	Q. 245	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
2265	Drafting Committee	Factors affecting the possibility of frequency sharing by radar astronomy with other services	Rep. 226	—
2273	”	Telecommunication links for near-earth research satellites	Rec. 364	—
2274	”	Interference considerations for near-earth research satellite telecommunication links	Rep. 219	—
2275	”	Radiocommunication for meteorological-satellite systems	Q. 243	—
2276	”	Radiocommunication aspects of meteorological-satellite systems	S.P. 243A	—
2277	”	Telecommunication links for manned research spacecraft	Rec. 366	—
2278	”	Telecommunication links for manned research spacecraft	Rep. 221	—
2284	”	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Rec. 356	—
2285	”	Active communication-satellite systems	Rec. 355	—
2286	”	Technical characteristics of telecommunication links for research purposes between earth stations and spacecraft	Rep. 218	—
2287	”	Communication-satellite systems	Rep. 214	—
2288	”	Active communication-satellite experiments	Rep. 207	—
2289	”	Communication-satellite systems	Rep. 206	—
2290	”	Communication-satellite systems	S.P. 235C	—
2291	”	Communication-satellite systems sharing the same frequency bands as line-of-sight radio-relay systems	Rec. 358	—
2341	”	Frequency sharing within and between communication-satellite systems	Rep. 210	—
2342	”	Communication-satellite systems. Avoidance of interference between earth stations and terrestrial radio stations sharing the same frequency bands	Rec. 359	—
2343	”	Terms and definitions relating to space radiocommunication	Rep. 204	XIV
2344	”	Feasibility of direct sound and television broadcasting from satellites	Q. 241	—
2345	”	Feasibility of direct sound and television broadcasting from satellites	Rep. 215	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
2352	Drafting Committee	Technical characteristics of radionavigation-satellite systems	Q. 242	—
2353	”	Frequency requirements of radionavigation-satellite systems	Rec. 361	—
2354	”	Use of satellites for terrestrial radionavigation	Rep. 216	—
2355	”	Frequencies technically suitable for meteorological satellites	Rec. 362	—
2356	”	Radiocommunications for meteorological-satellite systems	Rep. 217	—
2357	”	Preferred frequency bands for use in maintenance telemetering, tracking and telecommand of developmental and operational satellites	Rec. 363	—
2358	”	Communication-satellite systems. Frequency sharing between communication-satellite systems and terrestrial services	Rep. 209	—
2361	”	Active earth-satellite communication-satellite systems. A comparative study of possible methods of modulation	Rep. 211	—
2362	”	Criteria for selection of preferred reference frequencies for communication-satellite systems sharing frequency bands with line-of-sight radio-relay systems	Rec. 360	—
2363	”	Factors affecting multi-station access in communication-satellite systems	Rep. 213	—
2389	”	Modifications to be made to Questions and Study Programmes assigned to Study Group IV	—	—

PRINTED IN SWITZERLAND