INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

XIIIth PLENARY ASSEMBLY

GENEVA, 1974

VOLUME III

FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz
(STUDY GROUP 3)

Published by the
INTERNATIONAL TELECOMMUNICATION UNION
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FIXED SERVICE
AT FREQUENCIES BELOW
ABOUT 30 MHz

RECOMMENDATIONS AND REPORTS

3A Complete systems

3B Radiotelephony

3C Radiotelegraphy and facsimile

QUESTIONS AND STUDY PROGRAMMES,
DECISIONS, RESOLUTIONS AND OPINIONS

(Study Group 3)

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DISTRIBUTION OF TEXTS OF THE XIIIth PLENARY ASSEMBLY OF THE C.C.I.R. IN VOLUMES I TO XIII

Volumes I to XIII, XIIIth Plenary Assembly, contain all the valid texts of the C.C.I.R. and succeed those of the XIIth Plenary Assembly, New Delhi, 1970.

1. Recommendations, Reports, Decisions, Resolutions, Opinions

1.1 *Numbering of these texts*

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

In conformity with the decisions of the XIth Plenary Assembly, when one of these texts is modified, it retains its number to which is added a dash and a figure indicating how many revisions have been made. For example: Recommendation 253 indicates the original text is still current; Recommendation 253-1 indicates that the current text has been once modified from the original, Recommendation 253-2 indicates that there have been two successive modifications of the original text, and so on.

The XIIIth Plenary Assembly adopted a new category of texts known as Decisions, by which Study Groups take action, generally of an organizational nature, relative to matters within their own terms of reference, particularly the formation of (Joint) Interim Working Parties (see Resolution 24-3, Volume XIII). Although the Plenary Assembly did adopt in the form of Resolutions a number of texts which fell into the category of Decisions after amendment of Resolution 24-2, these texts are published in the Volumes of the XIIIth Plenary Assembly as Decisions, for practical reasons. When one of these texts is so published, a reference to the Resolution on which the text is based, is given in parenthesis below the title.

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

1.2 *Recommendations*

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(1) Published separately.

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2. Questions and Study Programmes

2.1 *Text numbering*

2.1.1 *Questions*

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

— Question 1/10 would indicate a Question of Study Group 10 with its text in the original state;

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

2.1.2 *Study Programmes*

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

Examples:

— Study Programme 1A/10, which would indicate that the current text is the original version of the text of the first Study Programme deriving from Question 1/10;

— Study Programme 1C/10, which would indicate that the current text is the original version of the text of the third Study Programme deriving from Question 1/10;

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

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

2.2 *Arrangement of Questions and Study Programmes*

The plan shown on page 8 indicates the Volume in which the texts of each Study Group are to be found, and so reference to this information will enable the text of any desired Question or Study Programme to be located.

PLAN OF VOLUMES I TO XIII
XIIIth PLENARY ASSEMBLY OF THE C.C.I.R.

(Geneva, 1974)

VOLUME I	Spectrum utilization and monitoring (Study Group 1).
VOLUME II	Space research and radioastronomy (Study Group 2).
VOLUME III	Fixed service at frequencies below about 30 MHz (Study Group 3).
VOLUME IV	Fixed service using communication satellites (Study Group 4).
VOLUME V	Propagation in non-ionized media (Study Group 5).
VOLUME VI	Ionospheric propagation (Study Group 6).
VOLUME VII	Standard frequency and time-signal services (Study Group 7).
VOLUME VIII	Mobile services (Study Group 8).
VOLUME IX	Fixed service using radio-relay systems (Study Group 9). Coordination and frequency sharing between systems in the fixed satellite service and terrestrial radio-relay systems (subjects common to Study Groups 4 and 9).
VOLUME X	Broadcasting service (sound) including audio-recording and satellite applications (Study Group 10).
VOLUME XI	Broadcasting service (television) including video-recording and satellite applications (Study Group 11).
VOLUME XII	Transmission of sound broadcasting and television signals over long distances (CMTT). Vocabulary (CMV).
VOLUME XIII	Information concerning the XIIIth Plenary Assembly. Structure of the C.C.I.R. Complete list of C.C.I.R. texts.

Note. — To facilitate reference, page numbering is identical in all three versions of each Volume, that is, in English, French and Spanish.

VOLUME III*

INDEX OF TEXTS**

FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz

(Study Group 3)

RECOMMENDATIONS

* Although the working documents mentioned in this Volume bear the reference "Period 1970–1973" for documents published during 1971 and 1972 and "Period 1970–1974" for those published during 1973 and 1974, they are, of course, all documents of the period 1970–1974, between the Plenary Assembly of New Delhi and that of Geneva. For this reason, all references to these documents in this Volume take the form "Period 1970–1974".

** In this Volume, Recommendations and Reports dealing with the same subject are collected together. These texts are numbered in such a manner that they cannot be presented in numerical order and at the same time, in numerical sequence of pages. Consequently, this index, in numerical order of texts, does not follow the numerical sequence.

REPORTS

QUESTIONS AND STUDY PROGRAMMES

DECISIONS

There are no Decisions concerning the work of this Study Group.

RESOLUTIONS

There are no Resolutions concerning the work of this Study Group.

OPINIONS

There are no Opinions concerning the work of this Study Group.

FIXED SERVICE AT FREQUENCIES BELOW ABOUT 30 MHz

STUDY GROUP 3

Terms of reference:

To study questions relating to complete systems for the fixed service and terminal equipment associated therewith (excluding radio-relay systems). Systems using the so-called ionospheric-scatter mode of propagation, even when working at frequencies above 30 MHz, are included.

Chairman: S. ARITAKE (Japan)

Vice-Chairman: T. DE HAAS (United States of America)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP 3

1. Introduction

During the XIIIth Plenary Assembly, Geneva, 1974, one new Recommendation and three new Reports were adopted and five Recommendations, eight Reports, one Question and two Study Programmes were replaced. It was decided that one Question was to be transferred from Study Group 1 to Study Group 3, two Questions, from Study Group 1 to Study Groups 3 and 8, and that Recommendation 337-1 was to be transferred from Study Group 3 to Study Group 1. The cancellation of the following Recommendation and Question was also approved:—

Recommendation 340 Fading allowances for various classes of emission

Question 16/3 Transmission characteristics of HF radiotelephone circuits

The following gives a brief review of the texts and the work accomplished during the period 1970–1974 for Study Group 3.

2. Complete systems

2.1 *Antennae*

Concerning antennae for the fixed services, one Recommendation and three Reports constitute the answer to Question 3/3 and Study Programme 3A-2/3. For the period 1974–1977, more data, especially on the observed directivity, should be invited to support Recommendation 162-2.

Recommendation 162-2 Use of directional antennae in the bands 4 to 28 MHz

This Recommendation deals with the practical standard characteristics of typical directional antennae. These characteristics, considered from both technical and economical points of view, are recommended to avoid harmful interference due to unnecessary radiation outside the main beam.

Report 106-1 Improvement obtainable from the use of directional antennae

This Report contains various technical data observed in many countries on the directivity of rhombic antennae which are mostly used for transmission.

Report 107-1 Directivity of antennae at great distances

This Report refers to the directivity of antennae used for reception, including directivity in the vertical plane.

Report 356-2 Use of directional antennae in the bands 4 to 28 MHz

This Report gives a fundamental method for calculating the directivity of antennae, with some examples of experimental data measured in relation to Recommendation 162-2 and a summary of theoretical studies, added during 1970–1974, concerning the effect of snow, ice or tidal change on the radiation pattern of antennae.

2.2 *Bandwidth, signal-to-interference and signal-to-noise ratios required for the systems of various services*

The bandwidth, the signal-to-interference and signal-to-noise ratios for a given type of service are essential factors in the planning of radio circuits in band 7 (HF) and in designing transmitting and receiving equipment and antennae for the circuits. These factors are also important for international and national allocation of the radio frequency spectrum in band 7 (HF).

In the three Recommendations described below, among which two were revised during 1970–1974, summarized values of the data measured and reported by various Administrations are given in reply to Question 1/3 and Study Programme 1A-2/3. However, in the tables of the Recommendations 240-2 and 339-3, there are many vacant cells where no value is shown. Because these values are essential for the allocation of HF radio frequencies and for the design of HF radio systems, there is an imperative and urgent need for contributions from Administrations to supply these missing values.

Recommendation 240-2 Signal-to-interference protection ratios

This Recommendation shows the minimum protection ratios and frequency separations between a wanted and an interfering signal that are required for various classes of emission and the fading allowances thereof.

Recommendation 338-2 Bandwidth required at the output of a telegraph or telephone receiver

This Recommendation deals with the necessary bandwidth at the audio-frequency output of receivers for telegraph and telephone services.

Recommendation 339-3 Bandwidths, signal-to-noise ratios and fading allowances in complete systems

This Recommendation gives the values of signal-to-noise ratios for the various classes of emission required at the inputs of receivers in terms of RF signal-to-noise density ratios and at the audio-frequency stages of the receivers in relation to the bandwidths at pre-detection and post-detection stages. RF signal-to-noise density ratios for fading condition are also shown.

2.3 *Single-sideband, independent-sideband telephone and telegraph systems*

Nowadays, single-sideband and independent-sideband systems are operated widely not only for radiotelephone services but also for multi-channel telegraph services. In operating the systems, overall frequency stability must be well maintained. Such stability is required also for frequency-shift and four-frequency diplex telegraph systems. There are two Recommendations and one Report which deal with the permissible frequency error for those systems and pilot carrier level in the single-sideband and independent-sideband systems by which the overall frequency stability could be maintained.

Recommendation 349-2 Frequency stability required for single-sideband, independent-sideband and telegraph systems to make the use of automatic frequency control superfluous

This Recommendation gives the values of permissible frequency error that may be produced in transmitters and receivers for typical services, if automatic frequency control devices are to be dispensed with.

Recommendation 454 Pilot-carrier level for HF single-sideband and independent-sideband reduced-carrier systems

This Recommendation arises from the conclusions from the studies in connection with Study Programme 1B/3, and recommends the application of one standard pilot-carrier level, –20 ± 1 dB relative to the transmitter peak envelope power, for all types of transmission with a reduced carrier.

Report 433 Factors governing the choice of pilot carrier level for independent-sideband radio emissions in band 7 (HF)

The technical background for the standard level of pilot carrier recommended in Recommendation 454 is described in this Report.

2.4 *Miscellaneous*

Report 109-2 Radio systems employing ionospheric-scatter propagation

This text contains sufficient technical information on ionospheric-scatter systems. A report of a test using forward error-correcting-code to improve the quality of performance of the systems was added during 1970–1974. However, the ionospheric-scatter system is not widely used at present.

Report 111 Influence on long-distance HF communications using frequency-shift keying of frequency deviations associated with passage through the ionosphere

This Report, which serves as a partial answer to Question 7/3, refers to the fading and the frequency change due to the drift of the ionosphere which may cause errors in telegraph circuits operated by frequency-shift keying.

Report 203 Multipath propagation on HF radio circuits — Measurements of path-time delay differences and their incidence on typical radio links

This Report deals with the values of path-time delay measured on some typical intercontinental circuits operating in band 7 (HF), which may provide important material especially for the study of multipath distortion in radiotelegraph systems. More contributions are invited from Administrations on the values of delay observed on various actual radio circuits, considering the significant effect of multipath on radiotelegraph systems, as stated in Report 345-1. These contributions will also be useful for the study of Question 21/3 (Ionospheric channel simulators).

Report 357-1 Operational ionospheric sounding at oblique incidence

Here some techniques for applying ionospheric sounding to practical operation on radio circuits operating in band 7 (HF) are explained. On the basis of additional information, this Report was entirely revised and references to problems concerning the use of the systems, including the possible increase of interference, were also added.

Report 549 HF ionospheric channel simulators

The results of various studies on the simulators and the suggested parameter values were summarized in this new Report and typical values of parameters were given in the Annex thereto.

Report 550 Short-term stability of frequency synthesizers

A report on the short-term instability of frequency synthesizers used in band 7 (HF) radio transmitters, especially those employing digital circuitries, and the influence of instability on the quality of various classes of emission are summarized in this Report.

Report 551 Automatically controlled HF radio systems

This Report deals with a new HF radiotelegraph receiving system in which frequency changes are made automatically by detecting telegraph distortions during a pre-set duration of time.

3. Radiotelephony

3.1 *Improved transmission system*

Recommendation 455-1 Improved transmission system for HF radiotelephone circuits

The main principle of the improved system is to link the action of a compressor at the transmitting end with that of an expander at the receiving end by using control tone, which enables the power of radio transmitter to be used to the fullest extent at all times independently of the level of speech. The Recommendation describes the standard characteristics of radiotelephone terminal equipment and its operating conditions, such as level setting in radio transmitters, for the system which is also called Lincompex, an abbreviation for "*Lin*ked *Comp*ressor and *Ex*pander".

Report 354-2 An improved transmission system for use over HF radiotelephone circuits

The Lincompex system can provide a radiotelephone circuit of superior quality to that operated with conventional equipment. In this Report summaries of the observed data obtained through tests and actual services for the system are introduced. Furthermore, Lincompex equipments including echo control function are introduced. Further information for large signal transient response in the Lincompex equipment should be invited for further improvement of the system.

3.2 *Semi-automatic operation*

During the period before the XIIIth Plenary Assembly of the C.C.I.R., the C.C.I.T.T. had asked the C.C.I.R. to study the possibility of improving the operation of semi-automatic HF radiotelephone circuits using the C.C.I.T.T. standard signalling systems; this was done under Question 16/3 which was subsequently withdrawn at the request of the C.C.I.T.T. From the study of the Question, it was concluded that the C.C.I.T.T. standard signalling systems were unusable on HF radio circuits and that FSK voice-frequency signalling was effective for semi-automatic operation.

A new Recommendation and a revised Report mentioned below were then approved. Administrations are asked to supply contributions concerning the practical operation of the newly recommended signalling on HF radiotelephone circuits.

Recommendation 480 Semi-automatic operation on HF radiotelephone circuits

As the result of studies concerning semi-automatic operation on HF radiotelephone circuits, summaries of which are described in Report 434-1, this Recommendation giving the international standard signalling system for semi-automatic operation on HF radiotelephone circuits was approved unanimously.

The FSK voice-frequency signalling was recognized as the most effective means for semi-automatic operation. The devices for transmitting and receiving the signalling for remote connection and the conditions of signalling are shown in this new Recommendation.

Report 434-1 Transmission characteristics of HF radiotelephone circuits

Summaries of the results of tests concerning semi-automatic operation on HF radiotelephone circuits by various types of signalling, including those standardized by the C.C.I.T.T., are described in this Report which was revised on the basis of the contributions received in the period 1970–1974.

3.3 *Miscellaneous*

Recommendation 335-2 Use of radio links in international telephone circuits

This Recommendation gives general principles for radiotelephone circuits.

Recommendation 336-2 Principles of the devices used to achieve privacy in radiotelephone conversations

This Recommendation describes the standards of privacy devices. In this context, the necessity of maintaining the use of band-splitting systems as standard could be discussed, taking account of the introduction of systems using linked compressor and expander and the complexity of the privacy device.

Recommendation 348-2 Arrangement of channels in multi-channel single-sideband and independent-sideband transmitters for long-range circuits operating at frequencies below about 30 MHz

This Recommendation shows the standard arrangement of telephone channels for single-sideband and independent-sideband transmission. The references to the exceptional arrangement for two-channel transmission were deleted in view of the improvement in the linearity of radio transmitters.

Report 353 Use of common-frequency systems on international radiotelephone circuits

This Report deals with technical arrangements for operating a radiotelephone circuit at a common radio frequency at both transmitting and receiving ends and constitutes an answer to Question 23/3, which was transferred from Study Group 1. These arrangements may be helpful in solving the problem of the shortage of radio-frequency spectrum in band 7 (HF) for radiotelephone services.

Report 355-1 Use of diversity on international HF radiotelephone circuits

This Report describes, in connection with Question 13-1/3, three diversity techniques useful for improving the quality of radiotelephone services in band 7 (HF).

4. Radiotelegraphy and facsimile

4.1 *Frequency-shift keying*

There are two Recommendations concerning the frequency-shift keying. The first refers to the F1 system and was revised during 1970–1974 and the second to the F6 system (Four-frequency diplex system).

Recommendation 246-3 Frequency-shift keying

This revised Recommendation gives, at first, standard values of frequency-shift for which new narrower values are recommended for new equipments in view of the improvement of the frequency stability in radio transmitters and receivers.

Secondly, the correspondence between, on the one hand, the higher and lower frequencies of the frequency-shift keying and, on the other hand, the significant conditions of modulation for various types of international standard code is also indicated in this Recommendation. The correspondence is shown in a new single comprehensive table.

Recommendation 346-1 Four-frequency diplex systems

This Recommendation deals with the standard arrangement of two telegraph channel systems using frequency-shift keying with four equally-spaced frequencies. This system is sometimes called "Twinplex" or "Diplex".

4.2 *Voice-frequency telegraphy*

Voice-frequency telegraphy on single-sideband systems is operated widely in the HF fixed services especially for heavy traffic circuits. There are four Recommendations for the systems including one relating to data transmission and six Reports which give the technical basis of the Recommendations. Not one of these was revised during 1970–1974.

Recommendation 106-1 Voice-frequency telegraphy on radio circuits

This Recommendation describes the diversity techniques essential for voice-frequency telegraph systems.

Recommendation 347 Classification of multi-channel radiotelegraph systems for long-range circuits operating at frequencies below about 30 MHz and the designation of the channels in these systems

This Recommendation deals with the designations of sub-carriers, multiplex systems on the sub-carriers, time-division channels and sub-channels, to achieve uniformity and to avoid possible confusion in the arrangement and operation of complex multi-channel systems using voice-frequency telegraphy.

Recommendation 436-1 Arrangement of voice-frequency telegraph channels working at a modulation rate of about 100 bauds over HF radio circuits

Two types of channel arrangement for the international standard are given in this Recommendation. It should be noted that for radio circuits in band 7 (HF), an arrangement differing from the standard widely used for circuits other than radio systems in band 7 (HF), is recommended in which sub-carriers, separated by 170 Hz and starting from 425 Hz, should be applied as shown in Table I of this Recommendation. The first type is a frequency-shift system for channels with a modulation rate of approximately 100 bauds employing 2-channel ARQ on each sub-carrier. The second is a frequency-exchange system, a typical arrangement of which is to use two sub-carriers separated by 340 Hz for the same modulation rate. The first type is usually preferred for actual services, for the reasons mentioned in Report 345-1.

Recommendation 456 Data transmission at 1200/600 bit/s over HF circuits when using multi-channel voice-frequency telegraph systems and frequency-shift keying

This Recommendation describes a standard system for data transmission operated with the arrangement of voice-frequency telegraph systems with frequency-shift, described in Recommendation 436-1.

Report 19-1 Voice-frequency telegraphy over HF radio circuits

This Report deals with the general technical considerations which should be taken into consideration when using voice-frequency telegraph systems over radio circuits operating in band 7 (HF).

Report 42-2 Use of radio circuits in association with 50-baud 5-unit start-stop telegraph systems

This Report describes the superiority of synchronous systems in radiotelegraph circuits operating in band 7 (HF) as compared with start-stop telegraphy and also introduces the possibility of an arrangement of voice-frequency telegraphy, with a channel spacing of 120 Hz, differing from the arrangement given in Recommendation 436-1.

Report 198 Voice-frequency (carrier) telegraphy on radio circuits

This short Report gives two different values for the optimum frequency shift as a function of the modulation rate. However, as Recommendation 436-1 has already been adopted, cancellation of this Report could be considered.

Report 345-1 Performance of telegraphy systems on HF radio circuits

This is the main Report containing important material on the basis of which Recommendation 436-1 was prepared. The material covers the results of theoretical studies, laboratory tests using fading simulators and tests on actual radio circuits conducted by many Administrations, comparing typical systems of voice-frequency telegraphy.

In this Report, typical systems are classified: System A, frequency-exchange systems (the second type in Recommendation 436-1), and System B, frequency-shift systems. System B is divided into B1, corresponding to the first type in Recommendation 436-1, and B2, with a channel spacing of 340 Hz and frequency shift of 170 Hz for each sub-carrier operating at modulation rates up to 200 bauds.

As a result of extensive studies, it is reported that the order of merit for these three systems, operated with ARQs of 2 or 4 channels, was A, B1, then B2. Although System A was superior to System B1, especially under poor propagation conditions, System B1 could usually be considered preferable because it has twice the channel capacity as compared with System A. Moreover, it was recognized that not only the signal-to-noise ratio but also signals due to multipath propagation would be important factors affecting the quality of transmission, particularly in System B which uses a narrow-frequency shift.

Report 346 Performance of systems using phase-shift keying over HF radio circuits

Different types of systems using phase-shift keying on voice-frequency sub-carriers, which would be applicable particularly to high-speed data transmission, are described in this Report, together with the results of tests made on radio circuits operating in band 7 (HF).

Considering the possibility of transmission of more digital information, such as data transmission at higher speeds, further studies should be made as to the practicability of multi-phase, phase-shift systems on radio circuits operating in band 7 (HF).

Report 347 Voice-frequency telegraphy over radio circuits

Some information on the actual operation of the arrangement described in Report 42-2 is given here.

4.3 *Automatic error-correcting systems*

As regards automatic error-correcting systems, there are two different systems. The first is for radio circuits with return circuits on which automatic requests for repetition can be transmitted. This system is usually called ARQ. The second system employs forward error-correcting codes which can be operated even when no return circuit is provided. One Recommendation and three Reports deal with the ARQ systems and two Reports, mostly with the forward error-correcting codes.

Recommendation 342-2 Automatic error-correcting system for telegraph signals transmitted over radio circuits

This Recommendation deals with the standard characteristics of an automatic error-correcting system with 4-channel or 2-channel time-division multiplex which has been widely used for telegraph service on radio circuits in band 7 (HF), using the 7-unit International Telegraph Alphabet No. 3. Especially, when telex services, in accordance with C.C.I.T.T. Recommendations, are to be provided on radio circuits in band 7 (HF), this system is essential, not only for protection against errors, but also for provision of the signalling required for the service. Since this Recommendation has been studied thoroughly, no further study is deemed necessary.

Report 348-2 Single-channel simplex ARQ telegraph system

This Report describes an automatic error-correcting system for single-channel telegraph circuits, in which alternate operation is provided over the radio link. The Report was shortened by referring to Recommendation 476-1 because the same type of system is mentioned in that Recommendation for use in the maritime mobile service.

Report 349-1 Single-channel radiotelegraph systems employing forward error-correction

In this Report, the test results obtained both on real circuits and in laboratories using fading simulators, are summarized for various types of forward error-correcting systems, in which errors can be corrected at the receiving end without a return circuit to the transmitting end. This type of system may be used for telegraph services of a broadcasting type, therefore further studies and discussion are required on the need for standardizing the characteristics for such types of automatic error-correcting systems.

Report 350 Single-channel duplex ARQ telegraph system

This Report introduces yet another system for single-channel telegraphy which applies the same principles as those given in Recommendation 342-2.

Report 435 Error statistics and error control in digital transmission over operating radio circuits

A summary of studies mostly concerning the various kinds of code suitable for error control is described. These studies could be considered to be the responsibility of Study Group 1 as they concern communication theory, because this Report is a partial answer to Study Programme 18A/1.

Report 436 Efficient use of HF radiotelegraph channels in the telex network by means of automatic selection and allocation procedures

Besides the four Reports described above, a system called "Flex" is introduced in this Report. The "Flex" is planned to operate telex channels more efficiently, when many ARQ channels for telex services are operated to a single destination, using, for instance, voice frequency telegraphy.

4.4 *Quality of performance*

Concerning the quality of performance of radiotelegraph circuits, one Recommendation and five Reports are the results of various studies. For the evaluation of quality, telegraph distortion is generally considered to be the effective factor and, exceptionally, in the case of ARQ circuits, the efficiency factor could also be effective in practical operation.

Recommendation 345 Telegraph distortion

This Recommendation introduces definitions of various types of telegraph distortion and error-rate, which appear in the List of Definitions published by the I.T.U.

Report 195 Bandwidth and signal-to-noise ratios in complete systems — Prediction of the performance of telegraph systems in terms of bandwidth and signal-to-noise ratio

This Report deals mostly with basic studies for the prediction of performance of a telegraph circuit in connection with the receiving system. These studies could be useful for evaluating the effect of diversity systems and the signal-to-noise ratio required for a telegraph circuit.

Report 197-3 Factors affecting the quality of performance of complete systems in the fixed service

This Report summarizes several contributions mostly concerning the tendency to variation of telegraphic distortion and error-rate in various kinds of radio circuits operating in band 7 (HF). This Report was partly revised for the distance factor concerning radiotelegraph circuits and may be used to predict the quality of performance.

Report 200-1 Telegraph distortion, error-rate

This Report briefly summarizes studies of distortion and error-rate carried out by the C.C.I.T.T. and the C.C.I.R.

Report 351-2 Quality of performance of radiotelegraph systems

The results of observations on the efficiency factor and distortion of several radiotelegraph circuits are introduced in this Report. It is reported that measurement of distortion could provide a more convenient and direct means for measuring the efficiency factor, although the efficiency factor can give the grade of quality of the total system in both directions.

Amendment to the Satisfactory Operation Factor was made by the latest contribution and it was agreed that the definition of the Satisfactory Operation Factor should be included in the List of Definitions of Essential Telecommunication Terms. Some apparatus used for the measurement of quality of performance of radiotelegraph circuits are also described in this Report.

Report 437 Operational use of the efficiency factor

This is a Report in which abstracts from two contributions concerning the use of the efficiency factor as a measure of evaluating and predicting the performance of an ARQ circuit are introduced. This Report could be a partial answer to Study Programme 1C/3, especially as regards operating ARQ circuits on fully automatic telex networks.

4.5 *Facsimile*

There are two Recommendations and two Reports concerning facsimile, including phototelegraph transmission.

Recommendation 343-1 Facsimile transmission of meteorological charts over radio circuits

The standard characteristics for transmission of meteorological charts are described in this Recommendation.

Recommendation 344-2 Standardization of phototelegraph systems for use on combined radio and metallic circuits

This Recommendation, which was slightly amended at the XIIth Plenary Assembly, gives international standards for phototelegraph transmission and its associated apparatus. In this Recommendation, the views of Administrations are invited as to the need for maintaining the characteristics of apparatus shown as type "b" in § 2, in which an index of cooperation of 264 and drum speed of 90/45 r.p.m. are given.

Report 201-2 Remote control signals for facsimile transmissions

This Report deals with Recommendation T.4 and proposals of the C.C.I.T.T. for the remote control signals for facsimile both for the meteorological and for the subscribers' services.

Report 352 Use of pre-emphasis and de-emphasis for phototelegraph transmission over HF radio circuits

This Report introduces a new technique for the use of pre-emphasis and de-emphasis, by means of which the quality of picture received may be improved.

5. Revised Questions and Study Programmes

Question 13-1/3 Improvements in the performance and efficiency of HF radiotelephone circuits

Concerning Question 16/3 proposed by the C.C.I.T.T., the C.C.I.T.T. was of the opinion that the Question was no longer of importance owing to the decreasing importance of HF radio circuits in the world-wide telephone network and it was agreed to cancel the Question.

However, due to the desires expressed for the continuation of studies on semi-automatic operation of HF radiotelephone circuits, Question 13/3 was amended partially to permit this.

Question 23/3 Use of common-frequency systems on radiotelephone circuits

This Question formerly Question 19/1 was transferred from Study Group 1 without any modification. In Report 353, the technical characteristics of the common-frequency systems are introduced.

Question 24/3 Remotely controlled HF receiving stations in the fixed service

This Question, previously Question 12/1, was transferred from Study Group 1 to Study Groups 3 and 8 and then the text was slightly modified to meet the terms of reference of Study Group 3. Concerning Report 329-1 which is a partial reply to the original Question, this will also be revised to form a Report for Study Group 3 during the period 1974–1977.

Question 25/3 Automatic control of the output power of HF transmitters

This Question, formerly Question 21/1, was also transferred to Study Groups 3 and 8, and the text was slightly modified. For this Question, there is no Report in either Study Group 1 or Study Group 3.

Question 22/3 Transportable fixed service radiocommunication equipment for relief operations

This Question was put by the World Administrative Radio Conference for Space Telecommunications, Geneva, 1971, under No. 190 of the International Telecommunication Convention, Montreux, 1965.

Study Programme 1A-2/3 Factors affecting the quality of performance of complete systems of the fixed service

Taking account of the revision of the Recommendations concerned, this Study Programme was partly amended.

Study Programme 3A-2/3 Improvement obtainable from the use of directional antennae

This Study Programme was also slightly amended, because the importance of knowing the influence of ice and snow on the directivity of antennae was recognized.

6. Others

6.1 *Preparation of the handbook for planning, maintenance and operation of HF fixed service*

In Resolution 33-1, New Delhi, it was decided to prepare a special handbook for planning, maintenance and operation of the HF fixed service. According to the terms of reference for Study Group 3, the preparation of the handbook was discussed during the period 1970–1974. On the other hand, the "IFRB Handbook on recommended techniques for better utilization and reduction of congestion of high frequency spectrum" was published by the I.T.U. in 1973. After examining the I.F.R.B. Handbook, it was recognized that, although the original purpose of the publication was a little different from the handbook stated in the Resolution, the contents of the I.F.R.B. Handbook mostly met the requirements of Resolution 33-1.

Considering that it would be undesirable to have two handbooks of a similar nature within the I.T.U., it was concluded that no further action regarding the preparation of the new handbook referred to in Resolution 33-1 would be taken.

6.2 *List of items for the I.T.U. Yearbook of Telecommunication Statistics*

In accordance with Resolution 37, New Delhi, the list of items for the Yearbook was also discussed and decided; the decision was approved at the XIIIth Plenary Assembly (see Doc. PLEN./8).

SECTION 3A: COMPLETE SYSTEMS

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 162-2

USE OF DIRECTIONAL ANTENNAE IN THE BANDS 4 TO 28 MHz

(Question 20/1)*

The C.C.I.R.,

(1953 – 1956 – 1966 – 1970)

CONSIDERING

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

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

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

(d) that Articles 12 and 14 of the Radio Regulations would seem to justify explicit requirements for the use of directional antennae in these bands;

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

(f) that the request by the Panel of Experts in Recommendation No. 38 of its Final Report, and the urgent question of the I.F.R.B., Question 20/1, ask for specification of reasonable standards of directivity for antennae in the various types of radio services in the bands between 4 and 28 MHz, with due regard to economy of cost;

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

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

UNANIMOUSLY RECOMMENDS

1. Definitions

that the following definitions should be used in specifying the performance of directional antennae:

1.1 *Directive gain* (G_0)**

In a given direction, 4 π times the ratio of the intensity of radiation***, in that direction, to the total power radiated by the antenna.

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

1.2 *Service sector (S)*

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

* This Question replaces Question 10/III.

** See No. 99 of the Radio Regulations for a definition of power gain.

*** The intensity of radiation is the power per unit solid angle (steradian).

1.3 *Interference sector (I)*

The horizontal sector outside the main beam

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

1.4 *Minimum standard antenna*

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

1.5 *Economic standard antenna*

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

1.6 *Antenna directivity factor (M)**

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

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

$$M = 0{\cdot}1\, f^2$$

f being the operating frequency in MHz;

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

$$M = 0{\cdot}25\, f^2;$$

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

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

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

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

Explanatory notes

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

Operating frequency f (MHz)	Minimum standard antenna			Economic standard antenna		
	M	G_0(dB)	S°	M	G_0(dB)	S°
5	2·5	13·8	54	6·25	17·5	35
10	10	16·6	39	25	20·4	25
15	22·5	18·3	32	57	22·1	21
20	40	19·4	28	100	23·3	18

* The derivation of the value of the directivity factor for any given antenna is explained in Report 356-2.

The antenna gain relative to a half-wave dipole above earth may be obtained by subtracting 8 dB from the value of G_0. It should be noted that the S value is the minimum bound at the directive gain specified and has been derived on the assumption that at least 40% of the total power is radiated in the main beam (a value appropriate to many rhombic antennae). Where (as is commonly the case) the (power) gain of the antenna (No. 99 of the Radio Regulations) is known, a suitable adjustment should be made to account for the efficiency of the antenna in deriving the directive gain.

Furthermore, when calculated gains, based on constant-current formulae, are used to determine the M-factor, adjustment should be made to allow for the current decay along the actual antenna. Methods of making these adjustments are described in Report 356-2.

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

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

RECOMMENDATION 240-2

SIGNAL-TO-INTERFERENCE PROTECTION RATIOS

(Question 1/3, Study Programme 1A-2/3)

(1953 – 1956 – 1959 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

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

UNANIMOUSLY RECOMMENDS

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

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

3. that the studies in connection with Recommendation 339-3 and Study Programme 1A-2/3 should be continued, in conjunction with those of Study Programme 16A-2/6 for the purpose of determining whether the provisional values given for the fading allowances may be accepted or should be modified;

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

TABLE

*Minimum required protection ratios and frequency separations**

WANTED SIGNAL		INTERFERING SIGNAL CLASS OF EMISSION																																			
		A1 telegraphy												A2 telegraphy								F1 telegraphy															
Class of emission		Manual				50 baud(1)				100 baud				Manual				24 baud				50 baud 2D = 280 Hz(1)				50 baud 2D = 400 Hz(1)				100 baud 2D = 400 Hz				200 baud 2D = ...			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz		
A1 telegraphy aural reception																																					
A1 telegraphy 50 baud printer B = 500 Hz						11	0·36	0·44	1·41	(2) 12	(2) 0·25	(2) 0·35										13	0·46	0·54	1·24					(2) 3	(2) 0·40	(2) 0·55					
A1 telegraphy 100 and 120 baud recorder B = ...																																					
A2 telegraphy aural reception																																					
A2 telegraphy 24 baud																																					
F1 telegraphy(3) 50 baud, printer $2D$ = 280 Hz; B = 500 Hz						1·0	0·2	0·28	0·6													7·0	0·32	0·39	0·67												
F1 telegraphy 50 baud, printer $2D$ = 400 Hz; B = 500 Hz										(2) 3	(2) 0·35	(2) 0·50																		(2) 2	(2) 0·45	(2) 0·60					
F1 telegraphy 100 baud, printer ARQ $2D$ = ... B = ...																																					
F1 telegraphy 200 baud, printer ARQ $2D$ = 400 Hz; B = 500 Hz										(4) 4	(4) 0·40	(4) 0·55																		(4) 4	(4) 0·50	(4) 0·70					
F6(3) 50 baud printer $2D$ = 1200 Hz B = 1200 Hz	channel 1																									8	0·85	0·95	1·51								
	channel 2																									18	0·98	1·1	2·06								
A4A phototelegraphy																																					
F4 phototelegraphy 60 rpm, B = 1000 Hz										15	1·00	1·20														15				15	1·10	1·20					
A3 telephony Double sideband	just usable																																				
	marginally commercial																																				
	good commercial																																				
A3A telephony single-sideband reduced carrier(6)	just usable																																				
	marginally commercial																																				
	good commercial																																				
A3J telephony single-sideband suppressed carrier(6)	just usable																																				
	marginally commercial																																				
	good commercial																																				
A7J multichannel V.F. telegraphy																																					
A7A multichannel V.F. telegraphy reduced carrier																																					

**Note.* — Under "class of emission", B represents the receiver bandwidth and $2D$ represents the total frequency shift. Column No. 1 gives the limiting values of signal-to-interference protection ratio (dB) when the occupied band of the interfering emission either falls entirely within the passband of the receiver, or covers it completely. Columns Nos. 2, 3 and 4 indicate the frequency separation necessary between the assigned frequency of a wanted signal and that of an interfering signal when the level of the latter is respectively 0, 6 and 30 dB higher than the wanted signal. (As defined in No. 85 of the Radio Regulations the assigned frequency is the centre of the assigned frequency band.)

(1) Bandwidth of interfering signals limited to 500 Hz.
(2) For a probability of character error P_c = 0·0001.
(3) For a probability of character error P_c = 0·001.
(4) For a traffic efficiency of 90 %.
(5) Average degree of modulation 70 %; sideband components extended to ± 3 kHz.

TABLE

*Minimum required protection ratios and frequency separations**

INTERFERING SIGNAL CLASS OF EMISSION																																				Provisional total fading allowances ([11]) for the protection of a fading signal against an interfering signal subject to fading and day-to-day intensity fluctuation. (See note 10) (dB to be added to values in columns numbered 1)	
F6 telegraphy				Phototelegraphy								Telephony([6])																Multichannel V.F. telegraphy									
50 baud 2D = 1200 Hz				A4A				F4				A3 DSB([5])				A3H full carrier				A3A reduced carrier				A3J suppressed carrier				A7J suppressed carrier				A7A reduced carrier					
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4		
dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			dB	kHz			non-diversity	diversity
																																					27(7)
																																					27(7)
																																					12(8)
8	1·24	1·33	2·32																																		
18	1·33	1·51	3·08																																		
																																				20	
																																				20	
																																				17(9)	
																																				17(9)	
																																				17(9)	

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

([7]) For protection 99·99% of the time.

([8]) Based on 90% traffic efficiency.

([9]) Based on 90% protection.

([10]) The probability distribution of the ratio of two signals fading independently has been applied in accordance with Doc. 443 (U.S.A.) London, 1953. The combined intensity fluctuation allowance for two signals has been taken as 7 dB, which represents a compromise between the 0 dB allowance, appropriate to perfectly correlated intensity fluctuations of the two signals, and the 14 dB allowance appropriate to uncorrelated intensity fluctuations of the two signals.

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

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

RECOMMENDATION 338-2

BANDWIDTH REQUIRED AT THE OUTPUT OF A TELEGRAPH OR TELEPHONE RECEIVER

(Question 1/3)

(1953 – 1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

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

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

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

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

UNANIMOUSLY RECOMMENDS

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

1.1 for class of emission A1, the bandwidth in hertz, after the final detector stage, should be equal to 2·5 times the modulation rate in bauds;

1.2 for class of emission F1, the bandwidth in hertz after the discriminator, should be equal to 1·4 times the modulation rate in bauds.

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

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

2.1 in accordance with Recommendation 335-2, the upper limit frequency should be reduced to 3000 Hz or less but no lower than 2600 Hz. In the case of the improved radio telephone system using a linked compressor-expander (Recommendation 455-1), the bandwidth should be strictly preserved to not less than 3000 Hz;

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

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

RECOMMENDATION 339-3

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

(Question 1/3, Study Programme 1A-2/3)

(1951 – 1953 – 1956 – 1963 – 1966 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that the studies requested in Study Programme 1A-2/3 have not yet been completed, and that it is desirable to classify the important points with which future studies will have to deal;

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

(c) that, however, the information contained in Reports 248-3 and 266-3 give some results from which provisional data on fading allowances can be derived;

UNANIMOUSLY RECOMMENDS

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

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

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

4. that the studies in connection with Study Programme 1A-2/3 should be continued, in conjunction with those of Study Programme 16A-2/6, for the purpose of determining whether the provisional values given in the Table may be accepted or should be modified.

Note 1. — In these studies, the procedures given in Reports 195, 413, 414 and 415 should be given full consideration.

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

TABLE I

Required signal-to-noise ratios

Class of emission	Pre-detection bandwidth of receiver (Hz)	Post-detection bandwidth of receiver (Hz)	Grade of service	Audio signal-to-noise ratio (1) (dB)	RF signal-to-noise density ratio (2) (3) (dB)		
					Stable condition	Fading condition (4) non-diversity	Fading condition (5) dual diversity
A1 Telegraphy 8 baud	3000	1500	Aural reception (6)	−4	31	38	
A1 Telegraphy 50 baud, printer	250	250	Commercial grade (7)	16	40		58
A1 Telegraphy 120 baud, recorder (undulator)	600	600		10	38		49
A2 Telegraphy 8 baud	3000	1500	Aural reception (6) (19)	−4	35	38	
A2 Telegraphy 24 baud	3000	1500	Commercial grade (7) (19)	11	50	56	
F1 Telegraphy 50 baud, printer $2D$ = 200 Hz to 400 Hz	1500	100	Pc = 0·01 Pc = 0·001 Pc = 0·0001 } (8)		45 51 } (9) 56	53 63 } (9) 74	45 52 } (9) 59
F1 Telegraphy 100 baud, printer $2D$ = ..., ARQ			(10)				
F1 Telegraphy 200 baud, printer $2D$ = ..., ARQ			(10)				
F6 Telegraphy							
A4A Phototelegraphy 60 rpm	3000	3000			50	59	
F4 Phototelegraphy 60 rpm							
A3 Telephony double sideband	6000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 } (18) 33	50 59 67 (14)	51 64 } (20) 75 (14)	48 60 } (15) (20) 70 (14)
A3H Telephony single-sideband full carrier	3000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)				
A3A Telephony single-sideband reduced carrier	3000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)				
A3J Telephony single-sideband suppressed carrier	3000	3000	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 } (18) 33	47 56 64 (14)	48 61 } (20) 72 (14)	45 57 } (15) (20) 67 (14)
A3B Telephony independent sideband 2 channels	6000	3000 per channel	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 } (18) 33	49 58 66 (14)	50 63 } (20) 74 (14)	47 59 } (15) (20) 69 (14)
A3B Telephony independent sideband 4 channels	12000	3000 per channel	Just usable (11) Marginally commercial (12) Good commercial (13)	6 15 } (18) 33	50 59 67 (14)	51 64 } (20) 75 (14)	48 60 } (15) (20) 70 (14)
A7J Multichannel V.F. telegraphy 16 channels 75 baud each	3000	110 per channel	Pc = 0·01 Pc = 0·001 Pc = 0·0001 } (8)		59 65 } (21) 69	67 77 } (21) 87	59 66 } (21) 72
A7J Multichannel V.F. telegraphy 15 channels 100 baud each with ARQ	3000	110 per channel	(10)				
A7A Multichannel V.F. telegraphy reduced carrier							
A9B Composite 16 channels 75 baud each 1 telephony channel (16)	6000	110 per telegraphy channel 3000 for the telephony channel	Pc = 0·01 Pc = 0·001 Pc = 0·0001 } (8)		60 66 } (17) 70	68 78 } (17) 88	60 67 } (17) 73

Footnotes to Table I

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

(2) The figures in this column represent the ratio of signal peak envelope power to the average noise power in a 1 Hz bandwidth except for double-sideband A3 emissions where the figures represent the ratio of the carrier power to the average noise power in a 1 Hz bandwidth.

(3) The values of the radio-frequency signal-to-noise density ratio for telephony listed in this column, apply when conventional terminals are used. They can be reduced considerably (by amounts as yet undetermined) when terminals of the type using linked compressor-expanders (Lincompex) are used (see Report 354-2). A speech-to-noise (r.m.s. voltage) ratio of 7 dB measured at audio-frequency in a 3 kHz band has been found to correspond to just marginally commercial quality at the output of the system, taking into account the compandor improvement.

(4) The values in these columns represent the median values of the fading signal power necessary to yield an equivalent grade of service, and do not include the intensity fluctuation factor (allowance for day-to-day fluctuation) which may be obtained from Report 252-3 in conjunction with Report 322-1. In the absence of information from these reports, a value of 14 dB may be added as the intensity fluctuation factor to the values in these columns to arrive at provisional values for the total required signal-to-noise density ratios which may be used as a guide to estimate required monthly-median values of hourly-median field strength. This value of 14 dB has been obtained as follows:
The intensity fluctuation factor for the signal, against steady noise, is 10 dB, estimated to give protection for 90% of the days. The fluctuations in intensity of atmospheric noise are also taken to be 10 dB for 90% of the days (see Study Programme 1A-2/3). Assuming that there is no correlation between the fluctuations in intensity of the noise and those of the signal, a good estimate of the combined signal and noise intensity fluctuation factor is

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

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

(6) For protection 90% of the time.

(7) For Al telegraphy, 50 baud printer; for protection 99·99% of the time. For A2 telegraphy, 24 baud; for protection 98% of the time.

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

(9) Atmospheric noise (V_d = 6 dB) is assumed (see Report 322-1).

(10) Based on 90% traffic efficiency.

(11) For 90% sentence intelligibility.

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

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

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

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

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

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

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

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

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

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

RECOMMENDATION 349-2

FREQUENCY STABILITY REQUIRED FOR SINGLE-SIDEBAND, INDEPENDENT-SIDEBAND AND TELEGRAPH SYSTEMS TO MAKE THE USE OF AUTOMATIC FREQUENCY CONTROL SUPERFLUOUS

(1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

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

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

(c) that the frequency stability, which can now be achieved, is much higher than that laid down in Appendix 3 to the Radio Regulations, and is approaching a value which could provide sufficient inherent stability to enable automatic frequency control to be dispensed with;

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

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

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

UNANIMOUSLY RECOMMENDS

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

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

3. that, however, for multi-channel voice-frequency telegraph systems and telephone systems using the principle of constant overall transmission loss, as set forth in Recommendation 455-1, the use of automatic frequency control may be retained (see Annex).

TABLE I

System	Maximum permissible overall error (Hz) (1)	Frequency error due to:		Frequency error due to the radio-frequency translating stages at both ends and to the propagation path (Hz)([3]) (4)
		Modulator stages (Hz) (2)	Demodulator stages (Hz) (3)	
1. Single-sideband and independent-sideband telephony	20	5	5	10
2. Radiotelegraphy:				
2.1 Two-tone multi-channel telegraphy with 340 Hz tone spacing and MCVF frequency-shift telegraphy with 340 Hz channel spacing	12([1])	3	3	6
2.2 Frequency-shift telegraphy (F1) (e.g. 50 baud, 200 Hz shift) and four-frequency diplex telegraphy (F6) using narrow-band filters at the receiving end	12	3	3	6
2.3 F1 and F6 systems using a limiter/discriminator at the receiving end, modulation index $\approx$ 2; (e.g. 196 baud 400 Hz shift)	20([4])	3	3	14
2.4 Phototelegraphy([2])	16	4	4	8

([1]) See Doc. III/27, Geneva, 1962.

([2]) For short-term frequency stability, see Recommendation 344-2. The figures under line 2.4 of this Table should be considered as provisional pending a reply by the C.C.I.T.T. to the questions put to it by the C.C.I.R. (see Doc. III/66 (Rev.), Geneva, 1962).

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

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

ANNEX

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

1. Introduction

The above Recommendation, which is a reply to Question 182, tabulates the permissible overall frequency errors for various systems. It excludes, however, narrow-shift telegraphy.

2. Relationship between distortion and frequency error

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

Measurements made on various well-designed frequency-shift telegraphy receivers have indicated an increase in element distortion of approximately 1·25 % for each 1 Hz frequency error. Poorer band-pass filter designs or narrower channelling will raise this distortion considerably.

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

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RECOMMENDATION 454*

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

(1970)

The C.C.I.R.,

CONSIDERING

(a) that independent-sideband reduced-carrier systems often operate with reduced pilot carrier levels of –26 dB relative to transmitter peak envelope power;

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

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

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

* The Administration of Pakistan reserved its opinion on this Recommendation.

(e) that the levels of reduced-carrier in use by various Administrations range from –16 to –26 dB relative to peak envelope power;

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

(g) that the linearity of modern transmitters is much improved over that of transmitters which were in use at the time independent-sideband working was introduced;

RECOMMENDS

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

2. that Administrations should make appropriate bilateral arrangements to introduce the new level as soon as is operationally convenient.

3A: *Reports*

REPORT 106-1*

IMPROVEMENT OBTAINABLE FROM THE USE OF DIRECTIONAL ANTENNAE

(Question 3/3)

(1953 - 1956 - 1959 - 1970)

1. Introduction

Contributions by Administrations to the VIIIth Plenary Assembly, Warsaw, 1956, and to the Interim Meeting of Study Group III, Geneva, 1958, provide a basis for a preliminary report on the question of signal power gain and signal-to-interference discrimination, afforded in practice by rhombic antennae. The experimental observations given by Docs. III/4 and III/31, Geneva, 1958, are summarized, as well as Docs. 19, 139, 265, 320 and 532, Warsaw, 1956, which also refer to this Question. The relation of these preliminary results to the median gain, given by Recommendation 162 (Geneva, 1963), is indicated.

In the text below:

l = length of leg (m),
φ = half the obtuse angle (degrees),
h = height above ground (m).

2. Summary and discussion of reported results

Doc. III/4 (Federal Republic of Germany), Geneva, 1958, contains a summary (Table I below) of median values of measurements made, using a rhombic of a type in general service in the Post Administration, having $l = 115$ m, $h = 20$ m, $\varphi = 75°$. This first set of measurements was made relative to a *vertical antenna;* the results are otherwise expressed in Recommendation 162 (Geneva, 1963).

TABLE I

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

In Doc. III/31, Geneva, 1958, there are also reported the results of observations of the gain of the rhombic antenna in the main lobe, relative to a half-wave horizontal antenna. These observations were, in the main, made at 15 MHz receiving WWV which transmits with an omnidirectional antenna, but there is also one set of observations made at 18 MHz receiving PPZ which transmits with a directional antenna. The data show the realized gain to be less than the plain-wave gain in the direction of maximum response and to have a striking variability with time of day and/or signal strength. The data are not adequate to establish a systematic diurnal variation, but the 15 MHz data suggest that the greatest values of gain are realized at times of high signal intensity. This result is contradicted by the observations at 18 MHz of transmissions from a distant directional antenna, which emphasizes the need for additional observations and draws attention to the virtually certain dependence of all such observations on the *directivity of antennae at both ends of the path.* Table II below gives the decile and median values of the gain realized in these tests.

* Adopted unanimously.

TABLE II

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

Doc. 139 (United Kingdom), Warsaw, 1956, gives results of the power gain and discrimination of rhombic receiving antennae, that is, off-azimuth response relative to maximum response. The measurements were made receiving distant transmissions at 13 and 20 MHz, using a ring of 30 antennae having $l = 81$ m, $h = 23$ m, $\varphi = 70°$. The results are given in Table III for the main lobe and the forward arc (180°) excluding the main lobe, and for the backward arc.

TABLE III

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

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

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

TABLE III*a*

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

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

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

Doc. 265 (Netherlands), Warsaw, 1956, summarized experimental observations of the power gain in the main azimuth, and for certain discrete directions off the main azimuth. The values of gain are for receiving rhombic antennae, expressed relative to a horizontal half-wave antenna at the same height. Directional antennae were also used at the transmitters for the measurements. The design data for the receiving antennae used at Amsterdam, for which observations are summarized in this document, are as follows:

Antenna	*A*	*B*
Length *l* (m)	120	174·5
Height *h* (m)	33	29·5
Angle φ (degrees)	71	70
Design frequency (MHz)	14·5	7·5

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

Doc. 320 (Japan), Warsaw, 1956, concludes that discrimination of greater than 15 to 20 dB cannot be relied upon; a number of observations are cited for values of discrimination (response outside the main lobe, relative to response in the main lobe), for a rhombic antenna having values of $l = 120$ m and $\varphi = 70°$ (height unspecified). These are shown in Table V; there were not enough data available to permit statistical analysis in terms of the arcs of Recommendation 162 (Geneva, 1963).

TABLE IV

Antenna	Frequency (MHz)	Gain relative to half-wave horizontal antenna (dB)									
		Main lobe				Distance (km)	Azimuth relative to main lobe (degrees)	Off-azimuth			
		Hours of obs.	Gain 10 %	Gain 50 %	Gain 90 %			Hours of obs.	Gain 10 %	Gain 50 %	Gain 90 %
A	7·7	83	9·4	8·3	6·7	2000	317	17	8·5	5·6	2·4
	13·7	158	13·4	11·4	8·8	3200	236	49	−7·3	−8·7	−10·3
	13·7					9300	143	56	−2·9	−10·7	−13·5
	13·7					2000	14	14	1·8	0·5	− 1·4
	13·7					5800	37	42	6·1	4·5	0·2
	17·6	46	14·2	13·3	12·1						
B	7·7	30	15·0	11·4	7·6						
	13·7	50	13·7	11·0	9·2						
	17·6	34	9·9	7·8	6·0						

TABLE V

Median values of discrimination in decibels

(Off-azimuth response relative to main lobe)

Difference in azimuth (degrees)	Frequency ranges (MHz)					
	10·3 to 12·2		13·3 to 14·5		14·5 to 15·6	
	Discrimination (dB)					
	Median	Median standard deviation	Median	Median standard deviation	Median	Median standard deviation
6					3·8	2·1
12½			12·5	2·0	8·9	2·5
18½					8·0	3·2
21					9·8	1·4
22			7·5	2·9		
25½	9·3	1·4				
27					13·5	1·7
39½					12·5	2·1
46½					14·5	1·4
52½					17·6	2·0
79½			19·8	2·8		
93			12·5	3·6		
109½			20·3	3·8		
117	15·5	2·1				
168½			11·8	3·4		

Doc. 19, Warsaw, 1956, draws attention to azimuthal variations of signals propagated over great distances via the ionosphere, in relation to realized directivity of antennae at great distances. Measured azimuths show only slight differences among the values of deviation for propagation paths of various lengths. 80 % of the measurements showed less than $\pm 2°$ average deviation; 98 % showed average deviation less than $\pm 4°$. The shortest link observed (2000 km), showed the greatest deviation and the longest path the least deviation.

3. Conclusions

The results show striking variability of gain and/or discrimination with time, especially time of day and, to some extent, season of the year. There are undoubtedly important effects near times of sunrise and sunset, at times of signal failure on operating frequencies near the MUF, and at times of ionospheric disturbance when great azimuth deviations can be observed. Statistical correlation of values of gain with values of transmission loss would be of interest and the data expected from Study Programme 3A-2/3 may show whether, and under which circumstances, such a correlation exists. The data given above suggest the extent of azimuth deviation encountered during normal propagation conditions. It must be noted that, because of the influence of irregularities in the ionosphere, such as give rise to azimuth deviations, the directivity gain realized at the receiving terminal depends in a fundamental way on the directivity of the transmitting antenna—and vice versa. It is, therefore, important in carrying out observations (such as those outlined in Study Programme 3A-2/3) to specify the directivity of antennae at both terminals.

REPORT 107-1*

DIRECTIVITY OF ANTENNAE AT GREAT DISTANCES

(Question 3/3)

(1959 - 1966)

1. Introduction

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

— the "statistical method", a comparison of numerous observations of the same signal on different fixed antennae at the same location but at different orientations [C.C.I.R., 1951 and 1953];

— mechanical rotation of antenna structures with various approaches to data statistics [Pession, 1935, 1936, 1948; Silberstein, 1957];

— the "back-scatter" method, a comparison of back-scatter signals in a method similar to that of the statistical method [Beckmann and Vogt, 1955].

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

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

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

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

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

— Question 3/3—Directivity of antennae at great distances.

— Study Programme 3A-2/3—Improvement obtainable from the use of directional antennae.

— Recommendation 162-2—The use of directional antennae.

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

2. Directivity in the vertical plane**

The results of measurements of the vertical angles of wave-arrival on a number of long-distance HF routes received in the United Kingdom are reported (Doc. III/25, 1963-1966). Some of the experiments and the method of measurement used are more fully described elsewhere [Low and Harris, 1963].

* Adopted unanimously.

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

TABLE I

Statistical summary of measurements of vertical angles of wave-arrival in the United Kingdom

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

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

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

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

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REPORT 109-2*

RADIO SYSTEMS EMPLOYING IONOSPHERIC-SCATTER PROPAGATION

(Question 4/3)

(1959 – 1966 – 1974)

A contribution, relating to Question 4/3, has been received from the United States of America (Doc. III/29, Geneva, 1958); references are cited in which information on ionospheric-scatter propagation relevant to exploitation of systems has been published [Bailey *et al.*, 1955; I.E.E., 1958]. Basic propagation characteristics are given in Report 260-2.

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

For estimation of the performance of fixed systems, it is important to know the variation with frequency of the mean signal intensity, the fading characteristics, such as short-term amplitude distribution and fading rate, and the background galactic noise level. For practical purposes, received power may be considered inversely proportional to approximately the 7th power of the frequency, using scaled antennae. The background galactic noise is inversely proportional to the 7/3 power of the frequency. The resulting signal-to-noise ratio, using scaled antennae, is proportional approximately to f^{-5}. Studies have shown that the frequency dependence during hours of weakest signal intensity is not significantly different from that observed for the mean signal intensity. The short-term amplitude distribution of signal intensity approximates a Rayleigh distribution at frequencies observed in the range of 30 to 74 MHz. The typical measured fading rate (median crossings), at 50 MHz, is approximately 1 Hz; the fading rate is proportional to operating frequency raised to a power of 0·7 to 1·2, depending on conditions.

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

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

The propagation modes, most significant in long-distance interference between scatter services and other services, are sporadic E and F2. Adequate world-wide measurements of sporadic E are not yet available to permit a complete evaluation of the percentage of time that interference is likely to occur. A comprehensive study of world-wide occurrence of Es observed at HF by ionosphere recorders has been published [Smith, 1957; Smith and Davis]. For practical purposes, ionospheric-scatter circuits, to avoid sporadic-E interference, should have their transmitting and receiving terminals geographically separated from other circuits or services by at least 2500 km. Figs. 1 to 3 of Report 260-2 represent contours of the F2-4000 km MUF exceeded for 1 % of the hours for the December solstice, the June solstice and the Equinox, at sun-spot maximum. These are derived from standard C.R.P.L. F2-prediction data, using measured distributions of day-to-day values of F2 MUF about the median. A circle of 2000 km radius centred on the station gives the locus of frequencies at which propagation over 4000 km paths occurs 1 % or 10 % of the time during the season indicated. The percentage of the time is less for paths longer or shorter than 4000 km.

* Adopted unanimously.

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

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

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

— a single voice channel of response from 300 to 3100 Hz using single-sideband, or narrow-band frequency modulation with a peak deviation of 3 kHz;

— four to sixteen channel, time-division multiplex, at a rate of 150 to 600 bauds with frequency-shift keying; a separation of 6 kHz is commonly used between mark and space frequencies, to minimize errors due to Doppler components;

— combinations of the above, using linear transmitters, such as a voice channel and a frequency-shift keying system or two independent frequency-shift keying systems; as an alternative, two transmitters may be used, one carrying voice intelligence and the other teleprinter;

— a system has been proposed with a single voice channel and four teleprinter channels, using error correction and detection techniques at 177 bauds. A typical channel arrangement for 20 kHz spectrum occupancy is shown in Fig. 1;

— a frequency-shift radioteleprinter system using heterodyne frequency-changing, the oscillator frequency being chosen between the frequencies representing the two significant conditions of modulation (see Doc. III/112 (U.S.S.R.), 1963–1966) in such a manner that the upper beat frequency corresponding to one condition and the lower beat frequency corresponding to the other condition are both within a narrow band; among the advantages found for this method may be cited an increase in the signal-to-noise ratio and low cost.

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

— diversity reception is beneficial for voice teleprinter operation. Dual or triple diversity is commonly used;

— the coherence bandwidth, as determined by multipath considerations of the transmission medium, is limited to approximately 3 kHz;

— meteoric multipath will, in general, limit the maximum modulation rate;

— during periods where the MUF may be above the operating frequency, F2 propagation may be expected. The above conditions are frequently accompanied by long-delay multipath echoes, ranging up to 50 ms or more. The echo pulses may have amplitudes comparable to or even greater than the desired signal, thus resulting in a very high error rate. Long-delay multipath problems may find solution by the use of antennae having more desirable directivity characteristics, the use of a frequency above the MUF, or by the use of special modulation techniques;

— ionospheric-scatter systems characteristically employ high power and highly directional antennae; during periods of sporadic E or high MUF, they must be considered as potential sources of interference to other services sharing the same frequency band;

— current four-channel teleprinter systems, using dual-space diversity, typically require a signal-to-noise ratio of 24 dB (noise measured in a 250 Hz band), for a binary error rate of 1×10^{-4};

— voice systems currently in use will provide usable operator-to-operator quality over a single link with a radio-frequency signal-to-noise ratio of approximately 14 dB, as measured in a 3 kHz noise bandwidth.

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

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

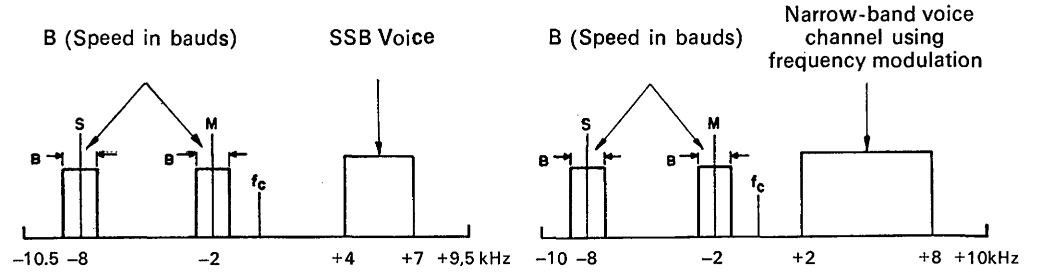

FIGURE 1

Typical 20 kHz channel arrangements for ionospheric-scatter transmission

(B is the frequency in hertz corresponding to the telegraph speed in bauds)

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

The reliability of teletype operation over VHF scatter circuits can be improved through the use of error-correcting codes. Approximately 150 hours of test data were obtained on a 1300 km ionospheric-scatter path at moderate latitude, using a block code with 1/3-rate and interleaving over 8·4 seconds [Juroshek *et al.*, 1971]. The transmitter power was 500 watts, the transmission rate was 108 bit/s, and the frequency-shift was 6 kHz.

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

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REPORT 111*

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

(Question 7/3)

(1959)

1. Introduction

This Report, based mainly on Doc. III/34 (U.S.A.), Geneva, 1958, deals with three aspects of the question. Firstly, the magnitude and time duration of the frequency changes to be expected are considered. Secondly, upper bounds of error rates for frequency-shift systems are calculated. Thirdly, experimental element-to-element phase changes are shown, relevant to phase-modulation techniques.

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

2. Characteristics of frequency changes over HF circuits

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

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

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

$$N_G = 1{\cdot}48\ \sigma$$

where σ is the standard deviation of an assumed Gaussian shaped band-pass filter. (This equivalent noise bandwidth refers to the received signal only and not the noise that may accompany it.) It is equivalent to the 2·17 dB half-bandwidth of the filter. If a rectangular filter is assumed then the fading rate N_R is

$$N_R = B/2{\cdot}32$$

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

Fig. 1 shows the cumulative probability distribution of the instantaneous frequency. This curve has been normalized to the fading rate. For a fading rate of 1 Hz, the instantaneous frequency will be within about 20 Hz of the carrier frequency for 99·96% of the time.

Taking into account the fading rate indicated in Report 266-3, the values of excursion of instantaneous frequency are not inconsistent with the deviations of 3 parts in 10^6 for a few milliseconds duration reported in Doc. III/3 (United Kingdom), Geneva, 1958.

* This Report was adopted by correspondence without reservation.

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

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

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

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

If we assume a fading rate of one per second and a frequency shift of 40 Hz, we find, referring to Fig. 1, that the frequency of either the mark or space channel will change by 20 Hz and cross over into the wrong side of the discriminator for only 0·04% of the time. The 0·04% represents the upper limit of the binary error rate to be expected in the no noise case. If reference is made to Fig. 2, we find that $\overline{\Delta t}$ is only 6·2 ms; consequently, even when the instantaneous frequency does lie on the wrong side of the discriminator, its duration is so short that only rarely will an error be made.

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

4. Experimental data relevant to phase modulation

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

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

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

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

5. Conclusion

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

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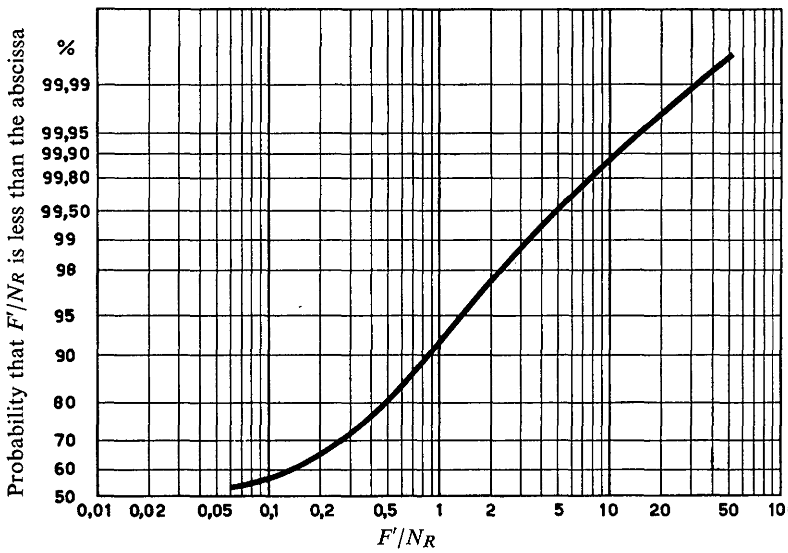


FIGURE 1

Cumulative probability distribution of instantaneous frequency change

F' = Instantaneous departure from centre frequency (Hz)

N_R = Fading rate (fades per second)

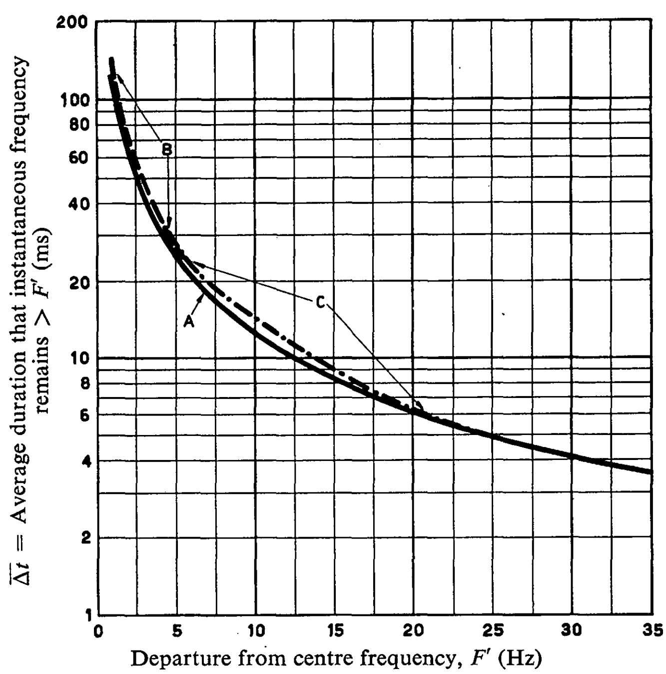


FIGURE 2

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

Curve A: 0·2 fade/second

B: 1 fade/second

C: 5 fades/second

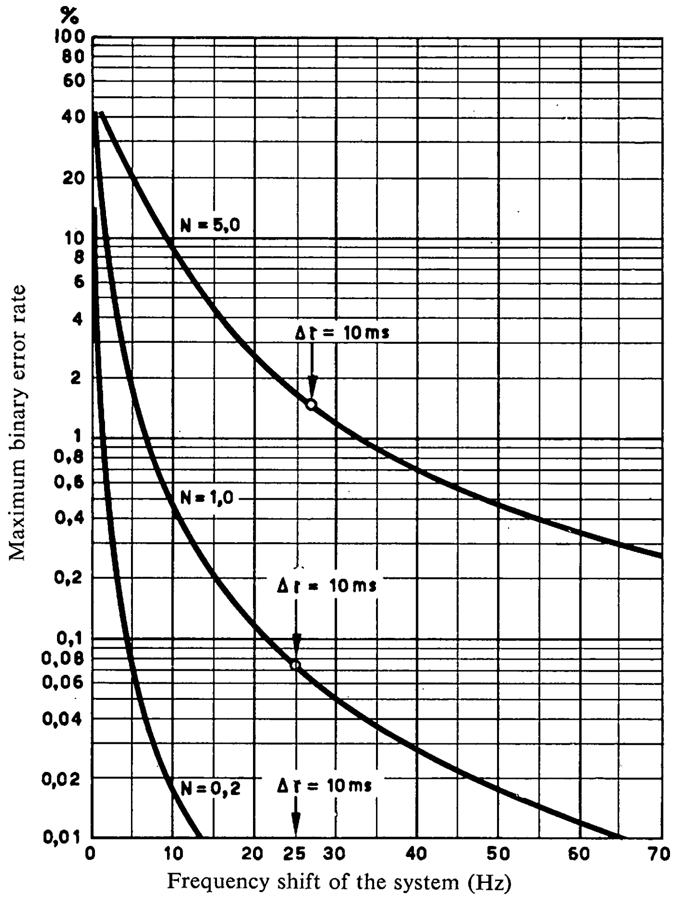


FIGURE 3

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

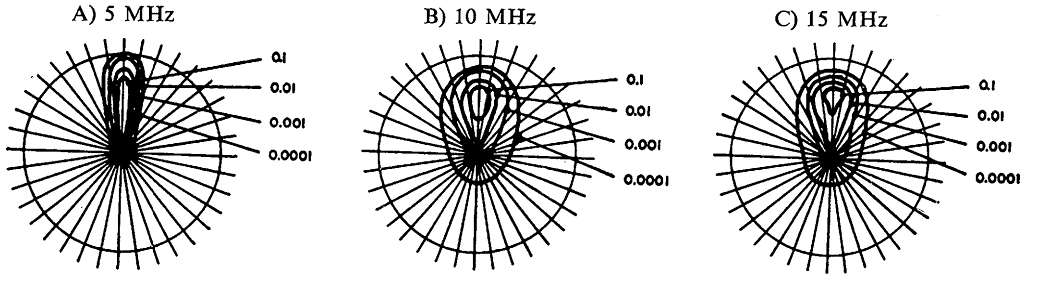


FIGURE 4

Polar probability contours of phase change and amplitude of WWV

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

REPORT 203*

MULTIPATH PROPAGATION ON HF RADIO CIRCUITS

Measurement of path-time delay differences and their incidence on typical radio links

(Study Programme 1A-2/3)

(1963)

1. Measurements on HF radio circuits of the fixed service

1.1 *Summary*

Some 4000 facsimile pictures, received over a number of important radiotelegraph circuits terminating in London, during the period from sunspot minimum to sunspot maximum (1953 to 1957), have been examined, to ascertain the incidence of multipath propagation and to measure the dispersion of path-time delays. Multipath conditions were found to take place for a considerable proportion of the time throughout the whole period and path-time differences were observed up to 2·5 ms. The measurements were made on pictures received from New York (1420 pictures), Melbourne (1600 pictures) and Moscow (350 pictures), together with a few less frequently used circuits. The technique of measurement is outlined below and is similar to that given by Japan in a contribution to the VIIth Plenary Assembly.

1.2 *Method of measurement*

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

The spread in path-time delay, as seen on the facsimile pictures, was obtained by measuring the ripple on a line, at right angles to the direction of scan, which could be safely assumed to be sharp and straight when transmitted. A low-power microscope, having a graticule divided into squares, was used to measure the ripple. The magnification was adjusted so that one square represented a time difference of 2 ms for the machines most generally used. Displacements were estimated to the nearest 0·5 ms and, when a number of different delays were observed, only the maximum delay difference was recorded. In some cases, this maximum delay was not typical of the distortion throughout the picture as a whole.

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

1.3 *Measurement on facsimile pictures*

Each picture was examined to determine the maximum path-time delay difference. Since the values of delay were approximated to the nearest 0·5 ms, the probable distribution of differences in path-time delay between 0 and 2·5 ms was obtained by the usual method of apportioning the number of pictures at each value of delay, other than zero, equally between the adjacent delay ranges.

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

* Adopted unanimously.

For each month, the percentages of pictures received for each range of delay difference and for each category of incidence were obtained. For simplicity, these monthly percentages have been averaged over a complete year, and the results are shown in Fig. 1.

1.4 *Discussion of results*

The results show that, for each of the four years 1953 to 1957, frequent or continuous multipath was in evidence on between 40 and 50% of the pictures analyzed. Approximately half the pictures affected by multipath showed path-time delay differences of 1 ms or more, and nearly 30% had delay differences of 1·5 ms or more.

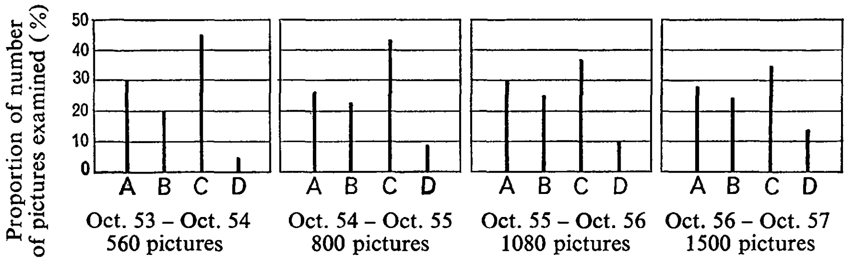
Multipath effects such as these are not particularly troublesome in facsimile transmission. Facsimile pictures have been used merely as a convenient means of obtaining data on incidence and delay difference over a long period on typical high-frequency fixed-service radio links. The effect of such multipath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

2. Measurement on meteorological broadcast services

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

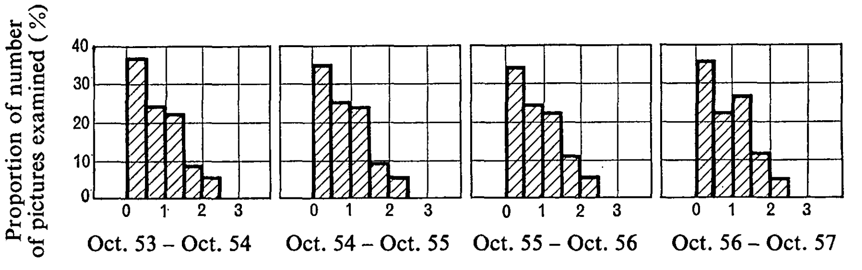
Some 1600 charts received during the period June to September, 1961, have been analyzed. Of these, 1000 were received from Washington and 600 from Japan. The method of measuring the path-time delay differences was similar to that described in § 1 of this Report. The results are tabulated below and are shown graphically in Fig. 2.

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



(a) Incidence of multipath

A – none
B – rare
C – frequent
D – continuous



(b) Range of multipath delay-differences (ms)

FIGURE 1

Multipath propagation on HF radio circuits of the fixed service

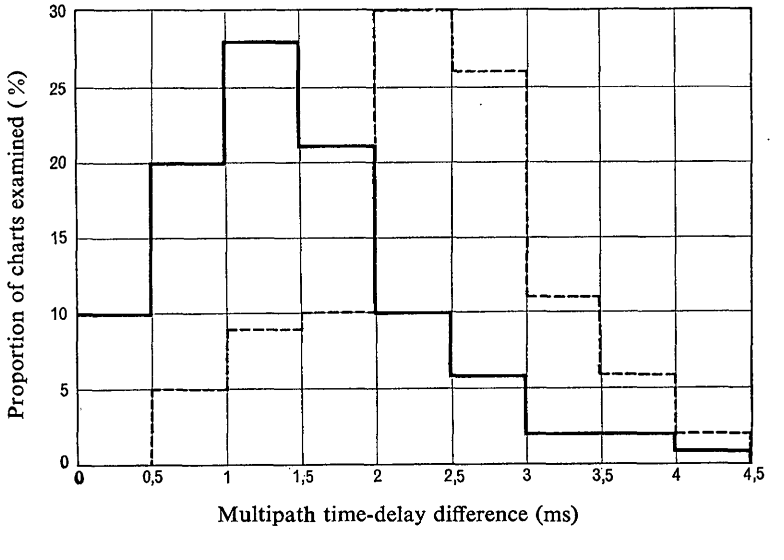


FIGURE 2

Multipath propagation on circuits of the meteorological broadcast service

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

- - - - - - Japan to United Kingdom.

REPORT 356-2*

USE OF DIRECTIONAL ANTENNAE IN THE BAND 4 TO 28 MHz

(Recommendation 162-2)

(1966 – 1970 – 1974)

1. Introduction

Question 20/1 poses the problem of specifying reasonable standards for the directivity of antennae in the various types of radio service, and for various distances, in the bands between 4 and 28 MHz with due regard to economy of cost. This Report is mainly concerned with point-to-point circuits longer than 4000 km but, with suitable modifications, could be applied to shorter range circuits. The technique discussed requires a knowledge of the gain of the antenna under consideration and the angular widths in zenith and azimuth of its main beam of radiation. With this information a directivity factor is derived which, used in conjunction with certain other factors, for example, transmitter power and provision cost, may be used to assess the suitability of an antenna for any particular application.

2. Proposition

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

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

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

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

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

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

$$P' = P_0\theta_0'\,\varphi_0'/K \quad (2)$$

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

$$G' = q\ .\ P_0/P' = qK/\theta_0'\,\varphi_0' \quad (3)$$

$$\text{or } q = G'\theta_0'\,\varphi_0'/K \quad (4)$$

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

* Adopted unanimously.

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

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

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

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

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

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

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

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

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

and we can then write,

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

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

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

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

and expressing θ_0', φ_0' in degrees,

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

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

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

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

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

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

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

3. Determination of directive gain

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

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

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

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

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

All the curves are derived from measurements made on the power efficiencies of rhombic antennae described in Doc. III/21, 1966–1969, in which a linearly tapered current decay along the antennae was assumed. The antennae were of 3-wire construction having a surge impedance of 600 ohms. There is an important dependence of radiation efficiency upon surge impedance [Schelkunoff and Friis, 1952] and the lowest practicable value is desirable. Nevertheless there are constructional problems in reaching a value much below 600 ohms in the HF band.

4. Application

M-values for a number of antennae of various types are plotted in Fig. 5 and provide an indication of the variation with frequency of the performance of single antennae and antenna arrays, assessed from both measured (power) gains and from the gains calculated using the methods described in § 3. Curves, which it is considered represent reasonable standards of performance for these two classes of antenna, have been drawn on the diagram. The lower curve (labelled minimum standard antenna) is a best fit to the available experimental data and may be expressed as $M = 0{\cdot}1f^2$. This is considered to be representative of the standard of performance to be expected from well-designed single rhombic antennae operated within a frequency band in which the ratio of highest to lowest frequency does not exceed 2.

The upper curve (economic standard antenna) which may be similarly expressed as $M = 0{\cdot}25f^2$ represents a standard of performance which will normally only be achieved with antenna arrays. This higher standard necessarily involves a proportionally greater expenditure on antenna plant but, as has been proposed in [Watt-Carter and Young, 1963], some increase above the current level of expenditure can be economically justified.

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

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

Doc. 3/5 (Canada), 1970–1974, reports the results of theoretical studies conducted to determine the effect of varying ground thicknesses of snow and ice on the radiation patterns of a horizontal half-wave dipole antenna and a vertical quarter-wave antenna. Tidal effects on the radiation patterns of these same antennae over sea water were also calculated.

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

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

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

TABLE I

Relative change in dB of the transmitted or received power due to a snow, ice or tidal change for 3 zenith angles at a frequency of 10 MHz

	Zenith angle = 45°	75°	85°
Vertical quarter-wave antenna on a ground plane to which 1·0 metre snow (dielectric constant of 1·2, conductivity of 10^{-5} S/m) is added	−0·5	−0·6	−1·3
Vertical quarter-wave antenna over sea water which is displaced by 1·0 metre salt ice (dielectric constant of 6·0, conductivity of 10^{-3} S/m)	−1·7	−3·4	−8·7
Vertical quarter-wave antenna over sea water which drops by 3·0 metres	−2·9	−0·4	−0·1

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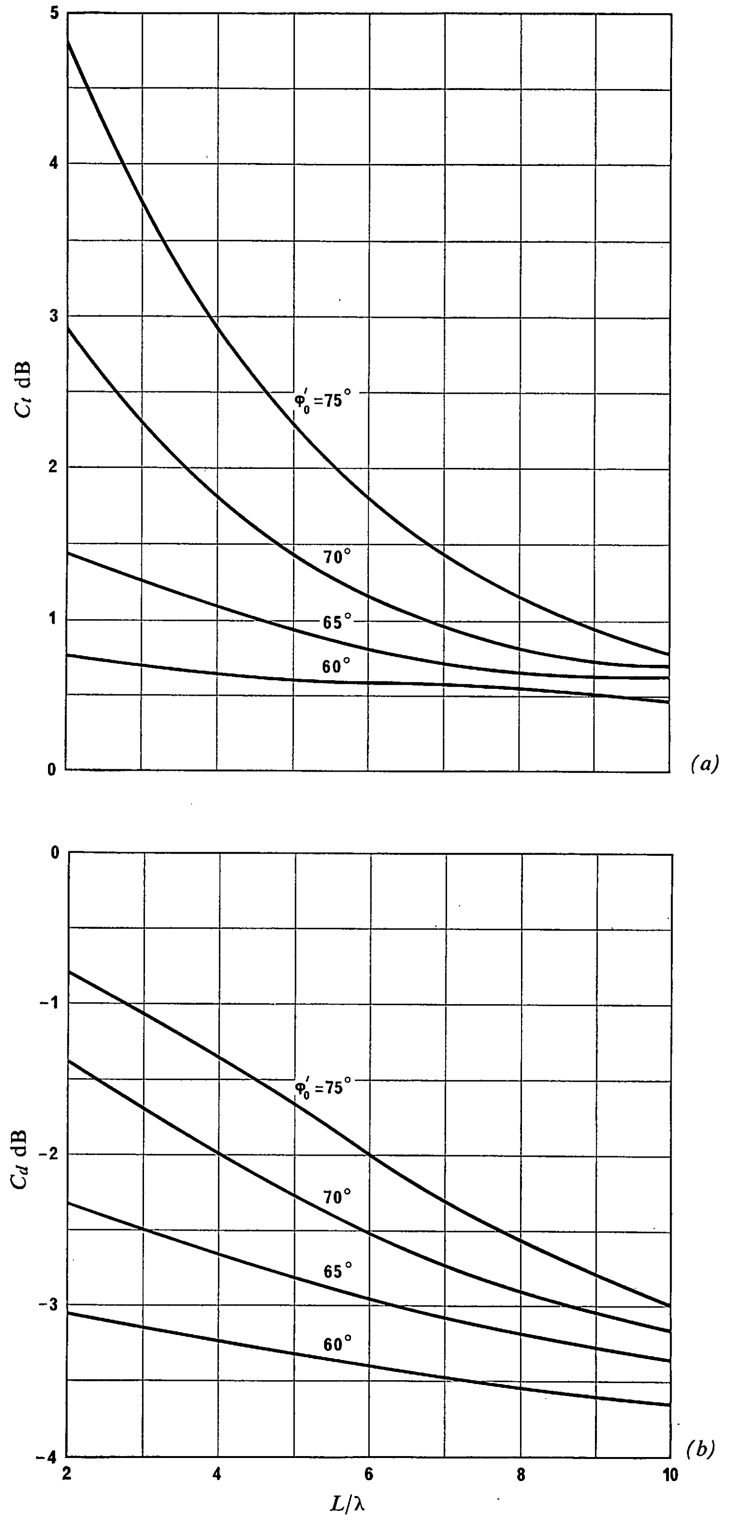

FIGURE 1

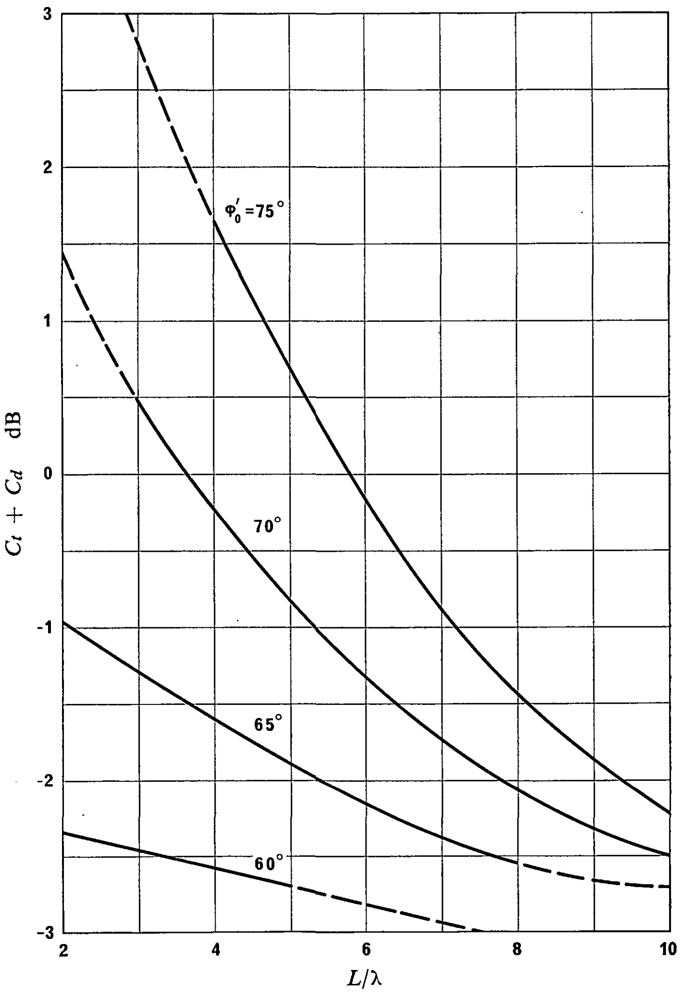

FIGURE 2

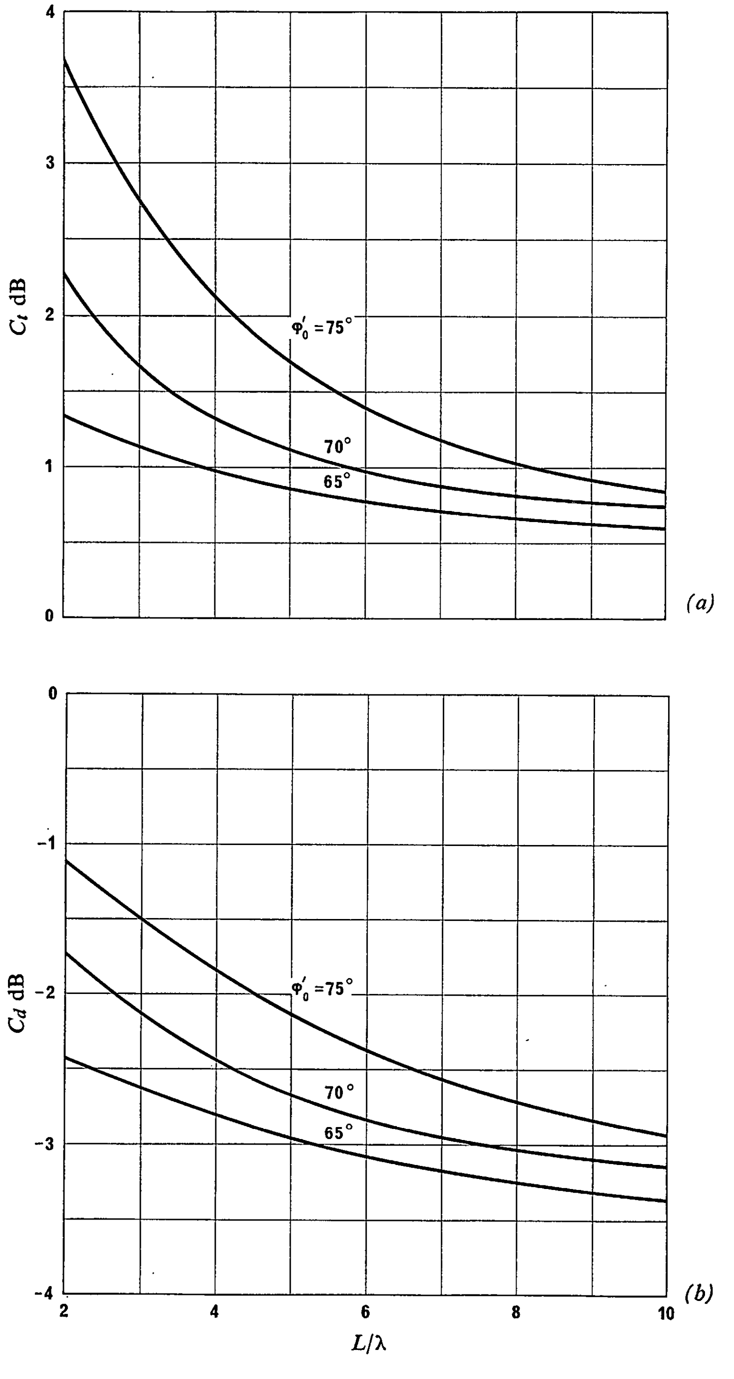
4
3
2
1
0
C_t dB
$\varphi'_0 = 75°$
70°
65°
(a)
0
-1
-2
-3
-4
C_d dB
$\varphi'_0 = 75°$
70°
65°
(b)
2
4
6
8
10
L/λ

FIGURE 3

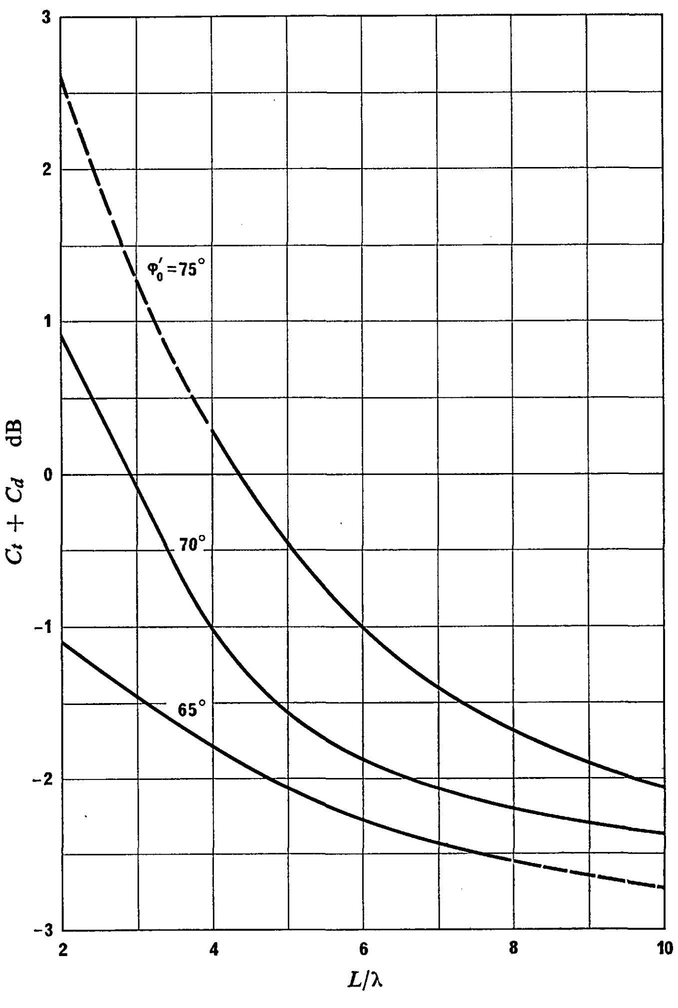

FIGURE 4

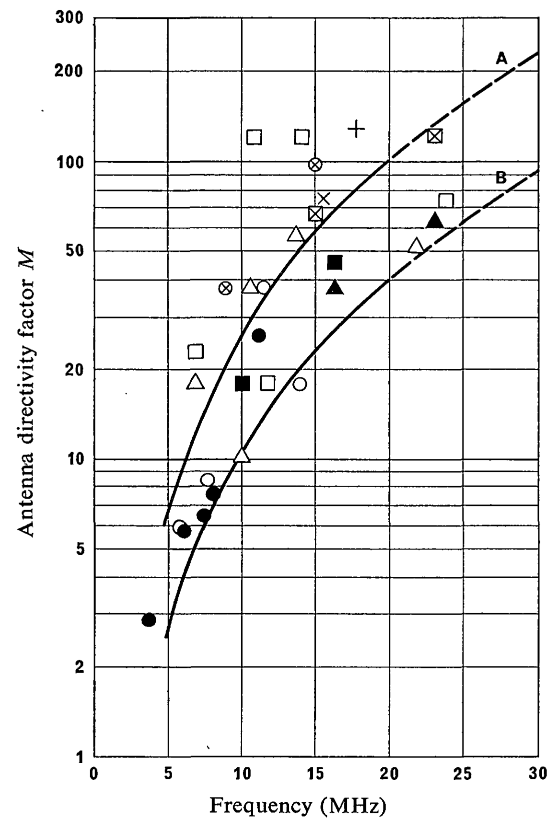

FIGURE 5

Antenna directivity factor, M, based on calculated gains
(see Recommendation 162-2)

Curve A: Economic standard antenna

- ○* Rhombic antenna 125 m/65°/45 m; □* Rhombic antenna 122 m/72·5°/23 m — Complementary antennae
- ⊗ Rhombic antenna 158 m/71°/55 m; ⊠ Rhombic antenna 158 m/75°/37 m — Complementary antennae

Curve B: Minimum standard antenna

- ● Rhombic antenna 98 m/63°/45 m; ■ Rhombic antenna 95 m/67°/32 m; ▲ Rhombic antenna 90 m/69°/29 m — Complementary antennae
- △* Rhombic antenna 96 m/70°/23 m

×* Dipole array HR 4/4/1·0
+* Dipole array HR 8/4/0·5

REPORT 357-1**

OPERATIONAL IONOSPHERIC-SOUNDING SYSTEMS AT OBLIQUE INCIDENCE

(Study Programme 20A/3)

(1966 – 1974)

1. Introduction

Many ways are employed to improve the quality of HF communications. Most of these are concerned with upgrading the system elements, for example, increasing the antenna gain or the transmitter

* Measured values of power gain, using airborne equipment.

** Adopted unanimously.

power. Although these usually result in some improvement, the performance of HF circuits is often still below the level that might be obtained, largely because the optimum operating frequency has not been determined and used [Jelly, 1971].

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

2. Types of sounding systems

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

2.1 *The locally operated and controlled channel sampling system*

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

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

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

2.2 *The common-user system*

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

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

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

2.3 *An idle-tone channel selection system*

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

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

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

— No modification of the apparatus at the user radio-telephone is necessary.

— System costs are relatively low as compared to traditional sounding techniques.

— Non-technical personnel can operate the system.

3. Operational problems encountered using frequency sounding systems

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

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

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

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

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

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

4. Sounders as an aid to communication systems

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

Some of the improvements attained by sounding are as follows:

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

5. Interference

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

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

6. Further study

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

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REPORT 433*

FACTORS GOVERNING THE CHOICE OF PILOT CARRIER LEVEL FOR INDEPENDENT-SIDEBAND RADIO EMISSIONS IN BAND 7 (HF)

(1970)

1. Introduction

Recent experience in the United Kingdom has led to the conclusion that the widely adopted practice of using a carrier level of –26 dB relative to peak envelope power in reduced carrier independent-

* Adopted unanimously.

sideband systems is leading to appreciable losses in circuit efficiency, particularly when such systems are used for the transmission of telegraph signals.

A review of the factors governing the level of pilot carrier necessary for independent-sideband transmissions therefore seems desirable.

2. Historical position

When single-sideband operation was first introduced on HF radiotelephone links, nearly 30 years ago, a pilot carrier of –16 dB relative to p.e.p. was used. With the introduction of independent-sideband working, which quickly followed, it was found necessary to reduce the carrier level by 10 dB to minimize inter-channel cross-talk due to non-linearity arising mainly in the high-power stages of the transmitter. For a number of years thereafter, the standard adopted by many Administrations was –16 dB carrier for single-sideband emissions and –26 dB for independent-sideband emissions. For the telephony emissions used at that time the lower carrier level provided adequate operation of the automatic frequency control and, with the increasing preponderance of independent-sideband emissions, the practice of increasing the carrier level for single-sideband emissions has tended to fall into disuse. The linearity of modern transmitters is much improved over that of transmitters which were in use at the time independent-sideband working was introduced.

A value of –20 dB relative to p.e.p. has been in use by the French Administration for some years.

Recently, the Lincompex terminal equipment has been coming into widespread use and with this development additional factors bearing on pilot carrier level are introduced.

3. Signal-to-noise ratios in sideband and carrier channels

3.1 *Channels with conventional terminals*

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

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

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

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

* See Recommendation 339-3.

3.2 *Channels with Lincompex terminals*

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

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

A speech-to-noise ratio of 7 dB has been found to represent just marginally commercial quality, taking into account the compandor improvement.**

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

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

3.3 *Multichannel telegraph systems*

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

According to Recommendation 326-2, it is typical of present practice that the mean power of each channel of a multi-channel telegraph system (class of emission A7A or A7B) be given by p.e.p./$4n$, when $n > 4$. Thus for a representative number of channels (say $4 < n < 10$), the power in a given telegraph channel will exceed that of a pilot-carrier of –26 dB relative to p.e.p. by at least 10 dB. But the carrier channel has an advantage with respect to noise bandwidth of only 3 to 6 dB since the ratio of the telegraph channel bandwidth to the carrier channel bandwidth is typically in range 2 to 4 (corresponding to a bandwidth range of 70 to 35 Hz). Therefore it is evident that the carrier channel will be at a net disadvantage and that a pilot carrier level of –26 dB relative to p.e.p. is inadequate over a wide range of circumstances to ensure reliable action of the automatic frequency control down to the failure point of the telegraph system.

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

4. Conclusions

An increase in pilot carrier level is desirable for independent-sideband and single-sideband systems carrying either telephone or telegraph signals or in the case of combined emissions. Since it would be desirable to standardize one value regardless of the type of traffic, the value of –20 dB relative to p.e.p. is recommended (see Recommendation 454).

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* In accordance with Recommendation 455-1.

** See Note 5 to Recommendation 339-3.

REPORT 549*

HF IONOSPHERIC CHANNEL SIMULATORS

(Question 21/3)

(1974)

1. Introduction

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

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

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

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

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

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* Adopted unanimously.

2. Gaussian-scatter model

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

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

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

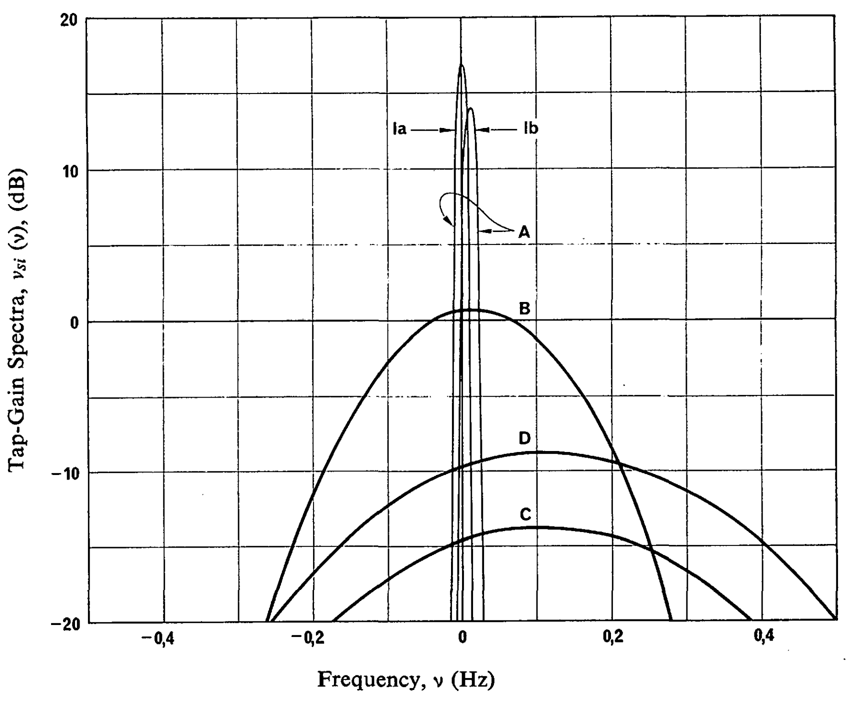


FIGURE 1

Power spectra of the multipath components of a CW signal

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

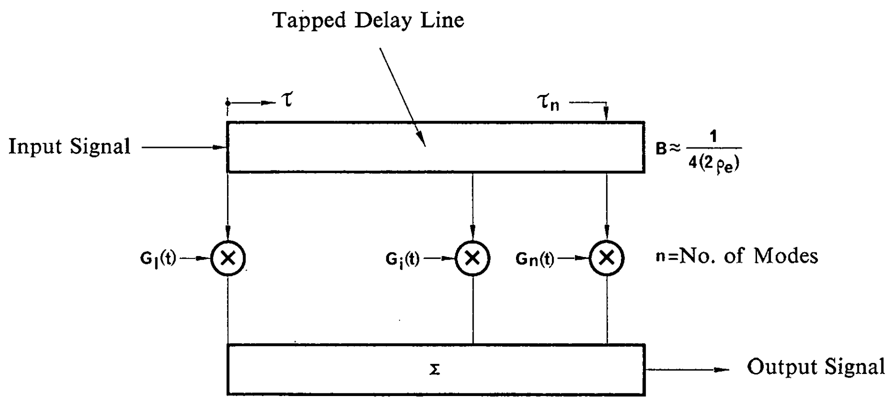


FIGURE 2

Block diagram of HF ionospheric channel models

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

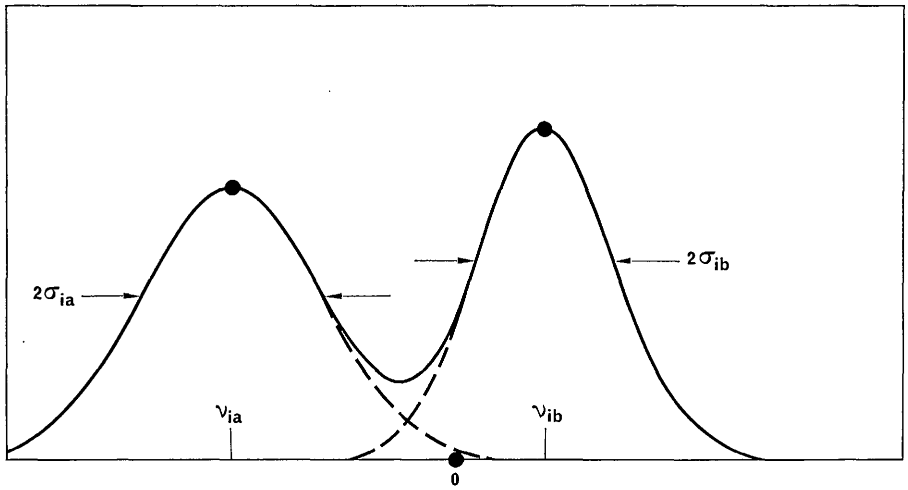
$$v_i(\nu) = \frac{1}{\tilde{A}_{ia}\sqrt{2\pi}\,\sigma_{ia}} \exp\left[\frac{-(\nu-\nu_{ia})^2}{2\sigma_{ia}^2}\right] + \frac{1}{\tilde{A}_{ib}\sqrt{2\pi}\,\sigma_{ib}} \exp\left[\frac{-(\nu-\nu_{ib})^2}{2\sigma_{ib}^2}\right] \qquad (2)$$

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

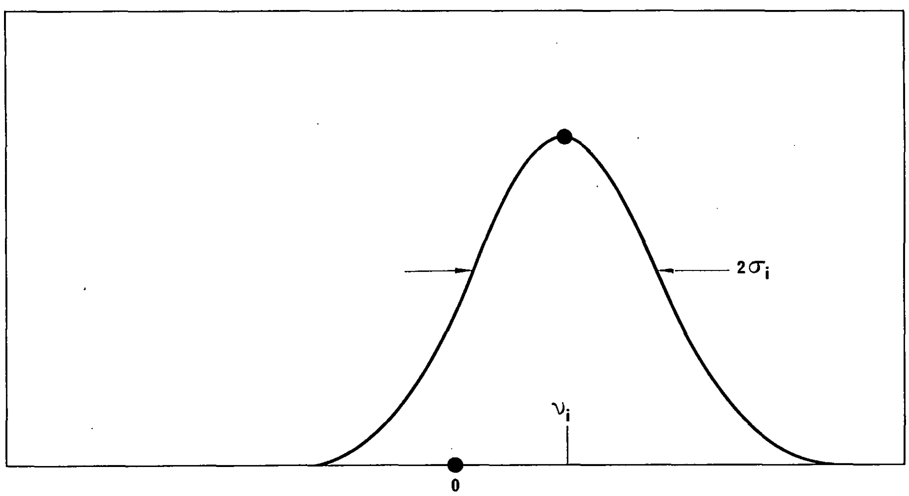
The tap-gain function described by (1)–(2) is general in that it applies when the spectra of the two magnetoionic components are significantly different and when the difference in their delays is negligible (less than about one-fourth of the reciprocal of the channel bandwidth of interest). Only one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

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

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



(a) Two Gaussian-scatter spectra



(b) One Gaussian-scatter spectrum

FIGURE 3

Tap-gain spectra in validated Gaussian-scatter model

3. Experimental verification of Gaussian-scatter model

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

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

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

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

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

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

The statistical tests confirm the validity of all three hypotheses and thereby, the validity of the model. For the three samples of data, the model was found to be accurate over a bandwidth about one-fourth of the reciprocal of the effective time-spread on the ionospheric modes ($2\rho_e$ in Fig. 2); i.e., 2·5 kHz for the night-time sample and 8·0 and 12 kHz for the day-time samples. The experimental verification of the channel model is described in detail in [Watterson *et al.*, 1969b and 1970].

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

4. Specular components

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

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

5. Simulator description

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

The delay unit accepts input signals at baseband (0·3 to 12 kHz) and samples them at a 50-kHz rate. Each serial ten-bit sample is delivered to a chain of LSI shift registers with 20-μs adjacent tap spacings and a maximum delay of 10 ms. The delayed digital signals from the selected taps are reconverted to feed the four tap units.

In each tap unit, the delayed baseband signal is converted to an intermediate frequency (IF) of 525 kHz plus or minus a selectable amount of frequency-shift. The local oscillator used in the frequency conversion is a specially designed synthesizer that provides selectable frequency-shifts of 0, ±0·01, ±0·02, ±0·05, ±0·1, ±0·2, ±0·5, ±1, ±2, ±5, ±10, ±20, ±50, ±100, ±200, or ±500 Hz. Other frequency-shifts can be obtained from external synthesizers. The double-sideband intermediate-frequency signal drives ±45° phasing networks in the tap unit that deliver signals in quadrature. Each quadrature signal is multiplied by independent baseband Gaussian noise with the same low-pass Gaussian power spectrum. The multiplier outputs are summed to form the complex-Gaussian scatter component that is fed via an adjustable attenuator to the summing unit. The intermediate-frequency signal is also fed directly to the summing unit via an adjustable attenuator to provide the specular component. Both the specular and the scatter attenuators are adjustable over a 100 dB range.

The two baseband Gaussian noise generators in each tap unit each consist of a random-binary-sequence generator (with independent bits) that drives a 3-pole active RC filter. The spectrum of the noise, which is determined by the filter response, deviates from the ideal Gaussian shape by less than 0·7% maximum. Because the cut-off frequency of the low-pass filter is about one-hundredth of the bit rate of the random sequence that drives it, the amplitude distribution of the noise from the filter is extremely close to Gaussian. The RC networks in the filters and the frequency of the random sequences are switched to provide frequency spreads of 0·01, 0·02, 0·05, 0·1, 0·2, 0·5, 1, 2, 5, 10, 20, 50, 100, 200, or 500 Hz. The r.m.s. noise voltages from the filters are the same for all values of frequency spread.

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

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ANNEX

PARAMETERS TO BE CONSIDERED IN SIMULATION

1. This Annex based on Docs. 3/46 (Germany, Federal Republic of), 1970–1974, 3/49 (U.S.A.), 1970–1974 and 3/58 (U.S.S.R.), 1970–1974 deals with the question of parameters to be specified when using HF Ionospheric Channel Simulators to evaluate equipment intended for operation over HF radio circuits.

2. Doc. 3/58 notes a relationship between distance, sunspot number and ionospheric modes, which may be of assistance in determining the parameters to be used in HF Ionospheric Channel Simulation.

3. Doc. 3/46 recommends that HF Ionospheric Channel Simulators should be capable of simulating the following channel parameters:

Parameter	*Range*
(1) fading depths	2 to 40 dB (in steps of 2 dB)
(2) *duration of fading (duration of a fade is defined as the time interval that the signal level is below a given reference level)	in the range from 0·05 to 1·5 s (in steps of 0·05 s)
(3) *fading rate	5, 10, 20, 40 per minute
(4) *delay time	0 to 5 ms
(5) *spectral width of a single selective fade	0·1 to 1·2 kHz
(6) *rate at which a selective fade moves through the spectrum	0·5 to 2 kHz/s
(7) frequency drifts	0 to 7 Hz
(8) signal-to-noise ratio using white Gaussian noise having a bandwidth of 2·7 kHz	0 to 40 dB

* These parameters are not all independent of each other.

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

— modulation methods

— diversity procedures

— error correction procedures

simulation of the HF medium should expediently be affected at audio frequencies ranging from 0·3 to 3 kHz, and from 3·3 to 6·0 kHz, respectively.

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

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

4. The Annex to Doc. 3/49 proposes specific conditions to be used in modem tests using an HF Ionospheric Channel Simulator.

It is noted that modem tests with an HF simulator are, in general, performed for either of the following purposes:

(1) to determine if, and in a qualitative sense how well, a particular modem may be expected to perform on HF circuits; or

(2) to compare the relative performance of two or more modems.

For tests of type (1) it will, in general, be acceptable to use a limited number of "representative" channel parameter combinations. However, tests of type (2) are much more critical as different modems may exhibit markedly varying sensitivities to different channel parameters.

Many actual HF paths show two or more multipath components with different relative strengths. In general, however, modem behaviour can be adequately assessed using two multipath components of equal mean strength, and the multipath conditions suggested below are based on a two-path, equal mean-strength configuration. For comparative tests of modems an additional test is suggested to determine sensitivity to relative low strength components with large relative time delays.

Frequency spreads are not normally equal on different path components. However, there appears no advantage for modem testing to have different frequency spreads on different path components, thus the suggested tests are based on equal frequency spreads.

Doppler shifts during normal propagation conditions are rarely a significant factor in modem performance. Where unusual sensitivity to Doppler shifts is suspected for a particular equipment, or where performance under abnormal propagation conditions is to be determined, experience to date has shown that the effect of Doppler shift is most readily seen when the shift is introduced on all path components.

It is desirable to perform all simulator tests in both non-diversity and diversity configuration in order to evaluate the effectiveness of the diversity combining scheme used.

Suggested tests

Before starting simulator tests, the performance of the modem on a back-to-back basis with additive noise only should be measured to ascertain that the equipment performs properly.

4.1 *Tests with representative channel parameter combinations*

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

Suggested values for frequency spread (fading rate): 0·2 Hz and 1 Hz.

— Gaussian noise, multipath and fading: bit error probability as a function of energy-per-bit to Gaussian noise density ratio for two independently fading paths with equal mean attenuation, equal frequency spreads and no frequency-shifts.

Suggested parameter values:

(1) *Good conditions*

Differential time delay: 0·5 ms
Frequency spread: 0·1 Hz

(2) *Moderate conditions*

Differential time delay: 1 ms
Frequency spread: 0·5 Hz

(3) *Poor conditions*

Differential time delay: 2 ms
Frequency spread: 1 Hz

(4) *Flutter fading* (if required)

Differential time delay: 0·5 ms
Frequency spread: 10 Hz

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

Suggested parameter values:

Differential time delay: 0·5 ms

Frequency spread: 0·2 Hz

Range of frequency offset: 0 to 10 Hz

4.2 *Additional tests for comparative purposes*

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

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

Suggested range of frequency spread: 0·1 to 50 Hz

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

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

Suggested parameter values:

Frequency spread: 0·2 Hz and 1 Hz

Range of differential time delay: 0·1 to 5 ms

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

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

Suggested parameter values:

Differential time delay: 5 ms

Frequency spread: 0·2 Hz

Range of mean level ratios: –40 to 0 dB

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

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

REPORT 550*

SHORT-TERM STABILITY OF FREQUENCY SYNTHESIZERS

(Study Programme 1A-2/3)

(1974)

The phenomenon of the short-term instability of frequency synthesizers, i.e. the variation of instantaneous frequency about the mean value over time intervals less than about 0·1 second known as "jitter", is fairly well known. This phenomenon is particularly associated with synthesizers employing digital circuitry which are now being used increasingly in communications systems.

Jitter originates from two basic sources:

— frequency instability of the voltage-controlled oscillator including that due to discontinuous changes induced by the digital circuitry and to power supply ripple voltages,

— noise on the voltage control line to the oscillator.

It is of interest to know the extent to which this jitter is likely to affect various types of communication channels. Doc. 3/4 (U.K.), 1970–1974, records the results of observations of the degradation in quality of transmission brought about by introducing controlled amounts of jitter into communication channels incorporating a synthesizer device having a phase-locked carrier oscillator. The jitter source was either a sinusoidal voltage of frequency varying between about 5 Hz and 1 kHz or consisted of noise limited to bandwidths of between 5 and 50 Hz and was used to frequency modulate the carrier oscillator.

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

(1) just perceptible impairment,

(2) limit of intelligibility.

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

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

Class of Emission	Jitter Modulation	R.m.s. Frequency Deviation (Hz)	
		(1)	(2)
A3A	Sinewave	20	200
A3A Lincompex	Sinewave	6	20
A3A Lincompex	Noise (20 Hz bandwidth)	8	(1)
A7A	Sinewave	20	(1)
A4A	Sinewave Noise (50 Hz bandwidth)	10	50

(1) Not measured.

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

REPORT 551*

AUTOMATICALLY CONTROLLED HF RADIO SYSTEMS

(Question 14/3)

(1974)

Doc. 3/1 (United Kingdom), 1970–1974, describes a method of programming an HF receiving system to operate at pre-arranged times during a 24-hour period on any one of three frequencies in a prescribed sequence based on propagation forecasts and experience.

The method completes the frequency change in two stages. Firstly, time periods during which a frequency change is expected are identified by prior agreement with the transmitting station. A 24-hour timing clock fitted with three cams, each of which is arranged to actuate a switch contact in the control line and is associated with a specific tuned frequency, brings the receiver to a prepared state for a frequency change. This prepared state is set for a period of 15 minutes before to 30 minutes after the scheduled time of frequency change. Secondly, the control circuit is completed by a switch contact operated by a telegraph distortion (short element) monitor (as mentioned in Report 351-2, § 3) which detects persistent distortion or the disappearance of the received signal. If this should happen during a pre-arranged time period, the receiver changes to the appropriate new frequency.

The telegraph distortion monitor actuates when 12½% of incoming signal elements exceeds 30% distortion or in the complete absence of keying. If excessive distortion or circuit failure occurs outside the prescribed frequency-change time periods, the receiver automatic frequency control is inhibited, thus preventing correction on a poor quality signal or on noise. Antenna selection is programmed with the frequency change so that the appropriate antenna is selected for the frequency in use.

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

* Adopted unanimously.

SECTION 3B: RADIOTELEPHONY

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 335-2

USE OF RADIO LINKS IN INTERNATIONAL TELEPHONE CIRCUITS

(1951 – 1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that, at the present time, radiotelephone systems connecting the various countries often employ carrier-frequencies below about 30 MHz*;

(b) that the use of such a radio link, in a long-distance telephone circuit, implies certain special conditions, which introduce particular difficulties not encountered when purely metallic connections are used;

(c) that such a radiotelephone circuit differs from a metallic circuit in the following ways:

c.a such a radiotelephone circuit is subject to attenuation variation with the special difficulty of fading;

c.b such a radiotelephone circuit suffers from noise caused by atmospherics, the intensity of which may reach, or even exceed, a value comparable with that of the signal which it is desired to receive;

c.c special precautions are necessary in the setting up and maintenance of such a radiotelephone circuit, to avoid disturbance of the radio receiver by any radio transmitter and especially by its own radio transmitter;

c.d to maintain the radiotelephone link in the best condition from the point of view of transmission performance, it is necessary to take special measures to ensure that the radio transmitter always operates, as far as possible, under conditions of full loading, whatever may be the nature and the attenuation of the telephone system connected to the radiotelephone circuit;

c.e it is necessary to take measures to avoid or correct conditions of abnormal oscillation or cross-talk;

c.f although the recommended frequency band, to be effectively transmitted by international landline circuits, has been determined by a study of the requirements of the human ear, this band (for a radiotelephone circuit operating at a frequency below 30 MHz) may be limited by the necessity of obtaining the maximum number of telephone channels in this part of the radio-frequency spectrum and so that each telephone channel does not occupy a radio-frequency band larger than necessary;

c.g in general, such a radiotelephone circuit is a long-distance international circuit giving telephone service between two extended networks, and this fact is of great importance from two points of view:

c.g.a on the one hand, international conversations, in general, are of great importance to the subscribers and, on the other hand, they are made in languages which are not always their mother tongue, so that high quality reception is particularly important;

c.g.b the public should not be deprived of a very useful service under the pretext that it does not always satisfy the degree of excellence desirable for long-distance communication;

* Further reference to 30 MHz in this Recommendation means "about 30 MHz".

UNANIMOUSLY RECOMMENDS

1. Circuits above 30 MHz

that between fixed points, telephone communications should be effected wherever possible by means of metallic conductors, or radio links using frequencies above 30 MHz to make the allocation of radio frequencies less difficult; where this can be realized, the objective should be to attain the transmission performance recommended by the C.C.I.T.T. for international telephone circuits on metallic conductors;

2. Circuits below 30 MHz

2.1 that since it becomes necessary to economize in the use of the frequency spectrum, when considering international circuits which consist mainly of single long-distance radio links operating at frequencies less than 30 MHz, it is desirable to use single-sideband transmission to the maximum extent possible, to employ a speech band less than the 300 to 3400 Hz recommended by the C.C.I.T.T. for landline circuits and, preferably, to reduce the upper frequency of the speech band to 3000 Hz or less, but not below 2600 Hz, except in special circumstances;

2.2 that, although it will be necessary to tolerate large variations in noise level on such a radiotelephone circuit, every possible effort should be made to obtain minimum disturbance to the circuit from noise and fading by the use of such techniques as full transmitter modulation, directional antennae and single-sideband operation;

2.3 that, during the time that such a radiotelephone circuit is connected to an extension circuit equipped with echo suppressors (voice-operated switching device), the intensity of disturbing currents should not be sufficient to operate the echo suppressor frequently;

2.4 that such a radiotelephone circuit should be provided with an echo suppressor to avoid singing or echo disturbance on the complete circuit, or, preferably, with terminals using the principles of constant overall transmission loss, as set forth in Recommendation 455-1;

2.5 that such a radiotelephone circuit should be equipped with automatic gain control to compensate automatically, as far as possible, for the phenomenon of fading;

2.6 that the terminal equipment of such a radiotelephone circuit should be such that it may be connected, in the same way as any other circuit, with any other type of circuit;

2.7 that, where privacy equipment is used, this equipment should not appreciably affect the quality of telephone transmission;

2.8 that, when suitable automatic devices are not provided, the circuit controls should be adjusted, as often as necessary, by an operator to ensure optimum adjustment of transmitter loading, received volume and the operating conditions of the echo suppressor.

Note. — Although the requirements contained in § 2 of this Recommendation are much less severe than those imposed on international landline circuits, the objective remains to attain the same standards of telephone transmission in all cases. In view of this, it is desirable that the telephone systems connected to a radiotelephone circuit should conform to C.C.I.T.T. Recommendations covering the general conditions to be met by international circuits used for landline telephony, especially in respect of equivalent, distortion, noise, echoes and transient phenomena.

Bearing in mind the recommendations contained in §§ 1 and 2, it is desirable that in each particular case, Administrations and private operating agencies concerned should first reach agreement on how far the standards usually employed for international landline circuits may be attained in the case considered. If the technique of § 1 of this Recommendation can be used, the objective should be to obtain, as far as possible, the characteristics recommended by the C.C.I.T.T. for international landline circuits. Otherwise the Administrations and private operating agencies concerned should study the best solution from the point of view of both technique and economy.

RECOMMENDATION 336-2

PRINCIPLES OF THE DEVICES USED TO ACHIEVE PRIVACY IN RADIOTELEPHONE CONVERSATIONS

(1951 – 1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that the devices referred to are intended to achieve privacy rather than secrecy in radiotelephone conversations;

(b) that, in the interest of maximum privacy, the details of the systems employed and of their performance, should be agreed upon between the Administrations and private operating agencies concerned;

UNANIMOUSLY RECOMMENDS

1. that the following statement of principles and characteristics of the devices concludes the study of Question 30 for radio circuits operating at frequencies less than about 30 MHz;

1.1 *Principles of the devices*

Two general types of system are used to achieve privacy in radiotelephone circuits operating at frequencies less than about 30 MHz;

1.1.1 *For double-sideband systems* (see Note)

inverter systems, the speech band being inverted about a fixed frequency.

1.1.2 *For single-sideband and independent-sideband systems*

band-splitting systems, in which the speech band is subdivided into equal frequency bands, the speech components in the sub-bands being interchanged, with or without frequency inversion, and, according to a prearranged sequence, to give "scrambled" speech. The process is reversed at the receiving terminal to reform the speech signals. Accurate synchronization of the switching processes at the two terminals is required.

1.2 *Characteristics of the devices*

1.2.1 the band-splitting system provides privacy superior to that obtained with the inverter system, but for satisfactory operation it can tolerate less distortion;

1.2.2 the apparatus is designed to reduce attenuation distortion and the levels of unwanted products of modulation and of carrier signals to a minimum. The extent of the permissible distortion due to the presence of the privacy devices is, in general, dependent on the type of privacy and is usually agreed between the Administrations or private operating agencies concerned;

2. that, for frequencies above about 30 MHz, the details of the systems to be employed and of their performance should be agreed upon between the Administrations or private operating agencies concerned.

Note. — The attention of Administrations is drawn to No. 465 of the Radio Regulations, which states:

"**465** § 15. (1) Administrations are urged to discontinue, in the fixed service, the use of double-sideband radiotelephone transmissions in the bands below 30 Mc/s, if possible as from January 1, 1970."

RECOMMENDATION 348-2

ARRANGEMENT OF CHANNELS IN MULTI-CHANNEL SINGLE-SIDEBAND AND INDEPENDENT-SIDEBAND TRANSMITTERS FOR LONG-RANGE CIRCUITS OPERATING AT FREQUENCIES BELOW ABOUT 30 MHz

(Question 2/3)

(1953 – 1956 – 1959 – 1963 – 1966 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that the lack of uniformity, in the arrangement and designation of the channels in multi-channel transmitters for long-range circuits operating on frequencies below about 30 MHz, may give rise to certain difficulties when one transmitting station has to work with several receiving stations;

(b) that, since it is necessary to economize in the use of the radio-frequency spectrum, when considering international circuits consisting mainly of single long-distance radio links, operating on frequencies below 30 MHz, it is desirable:

— to use independent-sideband transmissions to the maximum extent possible;

— to transmit a band less than the 300 to 3400 Hz recommended by the C.C.I.T.T. for landline circuits;

— to reduce the upper frequency to 3000 Hz, or less in special circumstances, but never below 2600 Hz;

(c) that there are already in operation international multi-channel radiotelephone circuits, in which the bandwidth allocated to each channel is 3000 Hz, but which are actually transmitting a speech band of 250 to 3000 Hz;

(d) that, in general, the outer channels are liable to cause and receive more interference to and from stations operating on adjacent assigned frequencies, the outer channels being those located furthest from the assigned frequency;

(e) that there are advantages in adopting channel arrangements which are the same in all parts of the HF (decametric) range;

UNANIMOUSLY RECOMMENDS

1. that standard channel arrangements should be adopted for multi-channel radiotelephone systems;

2. that the effective speech channel allocation should be 3000 Hz;

3. that the transmitted band in each speech channel should be from 250 Hz with an upper frequency of 3000 Hz, or lower in special circumstances, but never below 2600 Hz;

4. that in four-channel systems the channel arrangement should be as shown in Fig. 1*(a)*;

5. that, when less than four channels are used, the channels nearest to the carrier should be selected according to the arrangements shown in Figs. 1*(b)*, 1*(c)*, 1*(d)*, 1*(e)* or 1*(f)*;

6. that the effective date of these arrangements be fixed by the next Administrative Radio Conference.

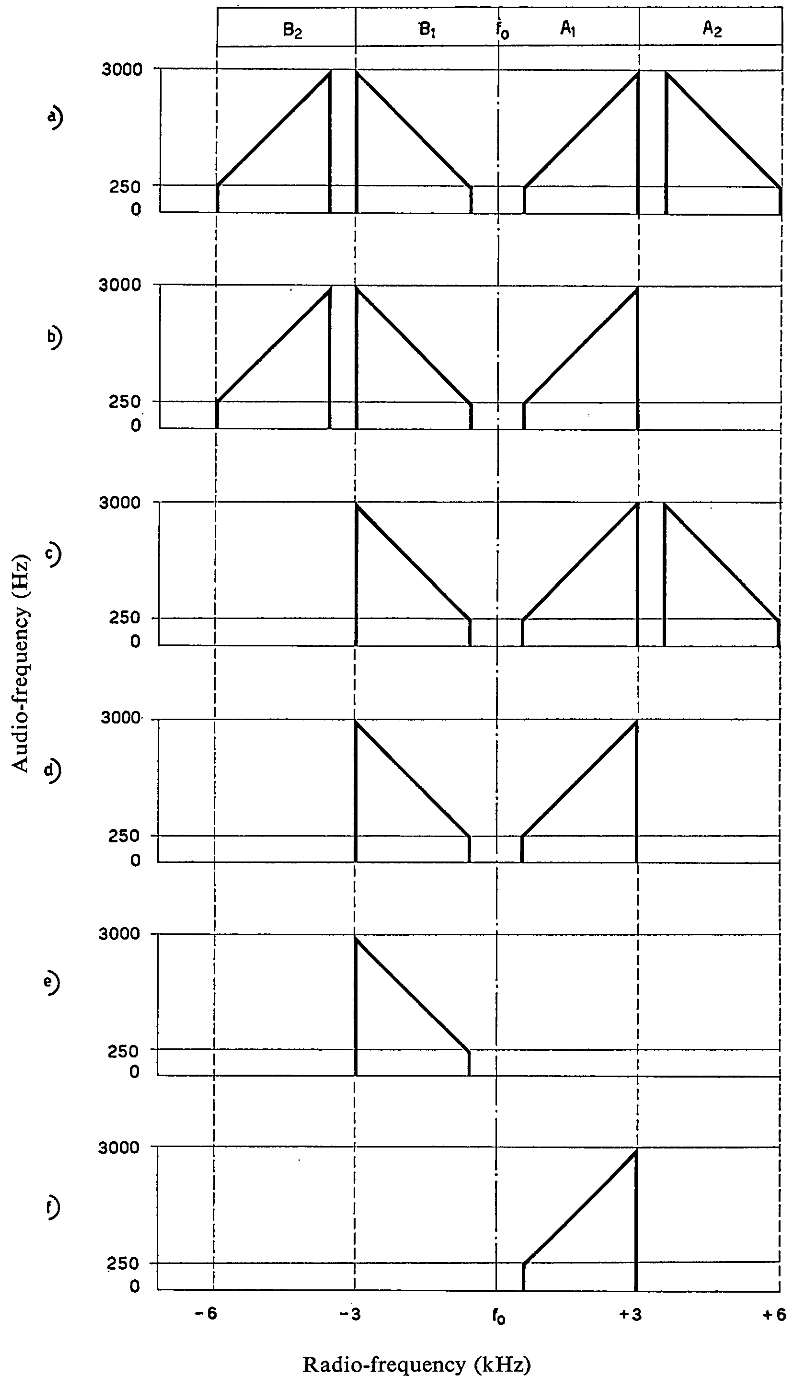


FIGURE 1

Relationship between audio-frequencies and radio-frequencies for the various channel arrangements

RECOMMENDATION 455-1

IMPROVED TRANSMISSION SYSTEM FOR HF RADIOTELEPHONE CIRCUITS

(Question 13-1/3)

(1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that, to maintain a satisfactory standard on international radiotelephone circuits operating at frequencies below 30 MHz and connected to the national network, it is necessary to compensate, at the transmitting end, for most, if not all, of the variations in the subscribers' speech volume and of the losses between the subscriber and the international exchange;

(b) that, as a result, the circuit often operates under a condition of overall gain (two-wire to two-wire) and it is necessary to use a singing-suppressor to maintain stability;

(c) that the singing-suppressor markedly degrades the performance of the circuit, due to its switching action and its tendency to misoperation by noise or interference on the radio path;

(d) that the use of a singing-suppressor to maintain overall stability of the radiotelephone channel inhibits the interconnection, on a four-wire basis (see C.C.I.T.T. Recommendation G.101) of radio circuits and long-distance cable or satellite circuits;

(e) that, if HF radiotelephone circuits were operated at a nearly constant overall transmission loss, the singing-suppressor could be eliminated and a radio circuit could be integrated into an international chain;

(f) that, to maintain a constant overall loss, while catering for variations in subscribers' speech volume and line loss, it is necessary to insert, at the receiving end of the circuit, a loss equivalent to the gain inserted at the transmitting end;

(g) that the advantages of compandor operation, as used on some line transmission systems, are well established, but cannot be directly realized on a radio circuit subject to fading;

(h) that, on such a radio circuit, an alternative means of conveying information as to the state of the compressor is necessary to control the expander;

(j) that these alternative means enable advantage to be taken of a compression ratio in excess of that employed in line compandors, which is generally 2/1;

(k) that the behaviour and advantages of a system employing a linked compressor and expander have been established (see Report 354-2);

(l) that with such an arrangement the two ends of a circuit will be complementary and the essential parameters of the system will have to be standardized;

UNANIMOUSLY RECOMMENDS

1. that, wherever possible, HF radiotelephone circuits should be operated on the basis of a constant overall transmission loss (two-wire to two-wire);

2. that a system comprising a compressor and expander linked by a control channel, which is separate from the speech channel and is resistant to fading distortion, should be used to achieve this performance;*

* Such a system is commonly known as Lincompex which is a convenient acronym for the phrase "linked compressor and expander". Lincompex is neither a proprietary name nor does it refer to the manufacturer of a particular equipment.

3. that the system should maintain optimum loading of the transmitter at all times despite variations in subscribers' speech volumes and line losses;

4. that the speech and control signals should both be contained within a single 3 kHz channel;

5. that such a system should be in accordance with the description and parameters listed below:

5.1 *General*

For convenience, the performance requirements of this document are based on a system configuration (one end is shown in Fig. 1) which on the transmit side employs pre-compressor delay in conjunction with a voice-signal amplitude assessor. This does not preclude other configurations which meet the requirements.

5.2 *Transmit side (Fig. 1(a))*

5.2.1 *Speech channel*

5.2.1.1 *Steady-state conditions*
(compression and overall characteristics)

For input levels between +5 dBm0 to –55 dBm0 (Note 1) the output should lie within the limits shown in Fig. 2.

The overall amplitude/frequency response for the speech channel under both fixed-gain and assessor-controlled conditions at any level within the range +5 dBm0 to –55 dBm0 should be:

Above 250 Hz:	Attenuation relative to the maximum response in the band 250 to 2500 Hz (dB)
For frequencies in the band 250 to 2500 Hz	$\leqslant$ 2
For frequencies in the band 2500 to 2700 Hz	$\leqslant$ 6
For frequencies in the band 2800 Hz and above	$>$ 55
Below 250 Hz:	
Increase in overall gain for frequencies below 250 Hz	$\leqslant$ 1

5.2.1.2 *Transient response*
(overall, including amplitude assessor but excluding additional delay)

Attack time, Fig. 3*(a)* (ms) (Note 2)	7 ± 2
Recovery time, Fig. 3*(b)* (ms) (Note 2)	20 ± 5

5.2.2 *Control channel*

Frequency-modulated oscillator
(frequency controlled by amplitude assessor output):

Nominal centre frequency (Hz)	2900 ± 1
Maximum frequency deviation (Hz)	± 60

Change of frequency for each 1 dB change of input level (Fig. 4) (Hz)	2
Input level to transmit side to produce nominal centre frequency (dBm0)	–25
Oscillator frequency resulting from an input level of 0 dBm0 (Hz)	2850
Oscillator frequency when there is no input to the transmit side (Hz)	⩽2980
For sudden increases in the input that exceed 3 dB, the time taken for the oscillator to complete 80% of the corresponding change in frequency should be (ms)	5 – 7
For sudden decreases in the input that exceed 3 dB, the rate of change of oscillator frequency should lie between (Hz/ms)	1·5 – 3·5
Output spectrum effectively limited to (Hz)	2810 – 2990
Output level relative to test tone level in the speech channel (dB)	–5

5.3 *Receive side (Fig. 1(b))*

5.3.1 *Speech channel*

5.3.1.1 *Steady-state conditions*

The relative overall amplitude frequency response of the speech channel under fixed and controlled gain conditions should be:

Above 250 Hz:	Attenuation relative to the maximum response in the band 250 to 2500 Hz (dB)
For frequencies in the band 250 to 2500 Hz	⩽ 2
For frequencies in the band 2500 to 2700 Hz	⩽ 6
For frequencies in the band 2800 Hz and above (fading regulator at fixed gain)	>55
Below 250 Hz:	
Increase in overall gain for frequencies below 250 Hz	⩽ 1

5.3.1.2 *Fading regulator*

Steady-state conditions

For input levels between +7 dB and –35 dB, relative to the nominal design input level to the fading regulator, the output should be within the limits shown in Fig. 5. The nominal design input level which may vary between Administrations is the value measured at the input of the fading regulator, under steady-state conditions, when 0 dBm0 is applied to the transmit side.

Transient response

Attack time: Fig. 3 *(c)* (ms)	11 ± 2
Recovery time: Fig. 3 *(d)* (ms)	32 ± 6

5.3.1.3 *Expander*
(controlled by the discriminator output)

Effective dynamic range (dB)	60

5.3.2 *Control channel*

5.3.2.1 *Amplitude/frequency and differential-delay characteristics of filter*

Attenuation within the band 2810 Hz to 2990 Hz (relative to that at 2900 Hz) (dB)	–1 to +2
Differential delay within the band 2840 to 2900 Hz (ms)	< 3
Attenuation below 2700 and above 3150 Hz (relative to that at 2900 Hz) (dB)	>55

5.3.2.2 *Discriminator* (Frequency/amplitude translator)

Characteristic at nominal control tone level

Changes in the expander output with changes in the frequency of the control tone between 2840 Hz and 2960 Hz, should lie within the limits shown in Fig. 6.

5.3.2.3 *Amplitude range of discriminator*

The performance quoted in § 5.3.2.2 should be met for control tone input signal levels to the discriminators from 0 dB to –30 dB relative to the nominal input level; with control tone input levels between –30 dB and –50 dB relative to nominal, an additional tolerance of ±1 dB could be added to the limits shown in Fig. 6.

5.3.3 *Overall attack and recovery time*
(A sudden change of 24 Hz in the frequency of the control tone is used to simulate a 12 dB step)

Attack time: Fig. 3 *(e)* (ms)	20 ± 5
Recovery time: Fig. 3 *(f)* (ms)	20 ± 5

5.4 *Equalization (overall) of transmission time*

To ensure a reasonable transmission standard, in particular of tone pulses, such as would be used for ringing or signalling, the overall transmission times of the speech and control channels should be equalized at the input to the expander to within 4 ms. In addition, the differential delay over the section of the passband of the speech channel, i.e., 250 Hz to 2500 Hz, should not exceed 4 ms.

To ensure that this can be achieved with independent designs of equipment, the time equalization provided should be divided equally between the transmit and receive sides of the equipment and should be adjustable so that the time delay encountered in privacy systems can be taken into account.

5.5 *Ringing and dialling*

Care should be taken to ensure that ringing and dialling signals are either passed completely through the equipment at both ends or completely by-pass both ends. The first method is to be preferred.

5.6 *Transmitter loading*

To enable transmitters to be fully loaded whilst keeping intermodulation products and out-of-band radiation to an acceptable level, speech channel and control channel levels for each telephone channel as shown in Table I are recommended. These figures are based on a total mean power output of –6 dB relative to the peak-envelope-power rating (p.e.p.) of the transmitter and a carrier power of –20 dB relative to p.e.p.

TABLE I

Number of channels	Individual channel power dB relative to p.e.p.	
	Speech channel	Control channel
1	−7	−12
2	−10	−15
3([1])	−12	−17
4	−13	−18

([1]) For operational convenience it may be desirable to use the same power levels for 3 channels as are used for 4 channels.

5.7 *Transmission path linearity*

The above loading conditions provide an adequate margin in the radio transmitter to allow for normal changes from the line-up condition on the Lincompex equipment and in the transmission path to the transmitter. Bearing in mind that the compressed nature of the Lincompex signal has a peak-to-mean ratio of about 8 dB with the possibility of transient peaks at the compressor output, adequate linearity margin should be allowed in the transmission equipment between the Lincompex transmit terminals and the transmitter. Similar considerations apply to equipment between the radio receiver output and the Lincompex receive terminals.

Fixed service receivers in current use are adequate for carrying Lincompex channels, but signal levels must be chosen such that adequate linearity margins exist.

5.8 *Frequency stability*

The maximum allowable end-to-end frequency error of each Lincompex channel should be within ± 2 Hz.

Note 1. — For definition of signal-to-test-level ratio (dBm0) see the relevant C.C.I.T.T. texts.

Note 2. — The definitions of attack time and recovery time which are similar to those defined by the C.C.I.T.T. for compandors (Recommendation G.162), are as follows:

the attack time of a compressor is defined as the time between the instant when a sudden increase of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 1·5 times its steady-state value;

the recovery time of a compressor is defined as the time between the instant when a sudden decrease of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 0·75 times its steady-state value.

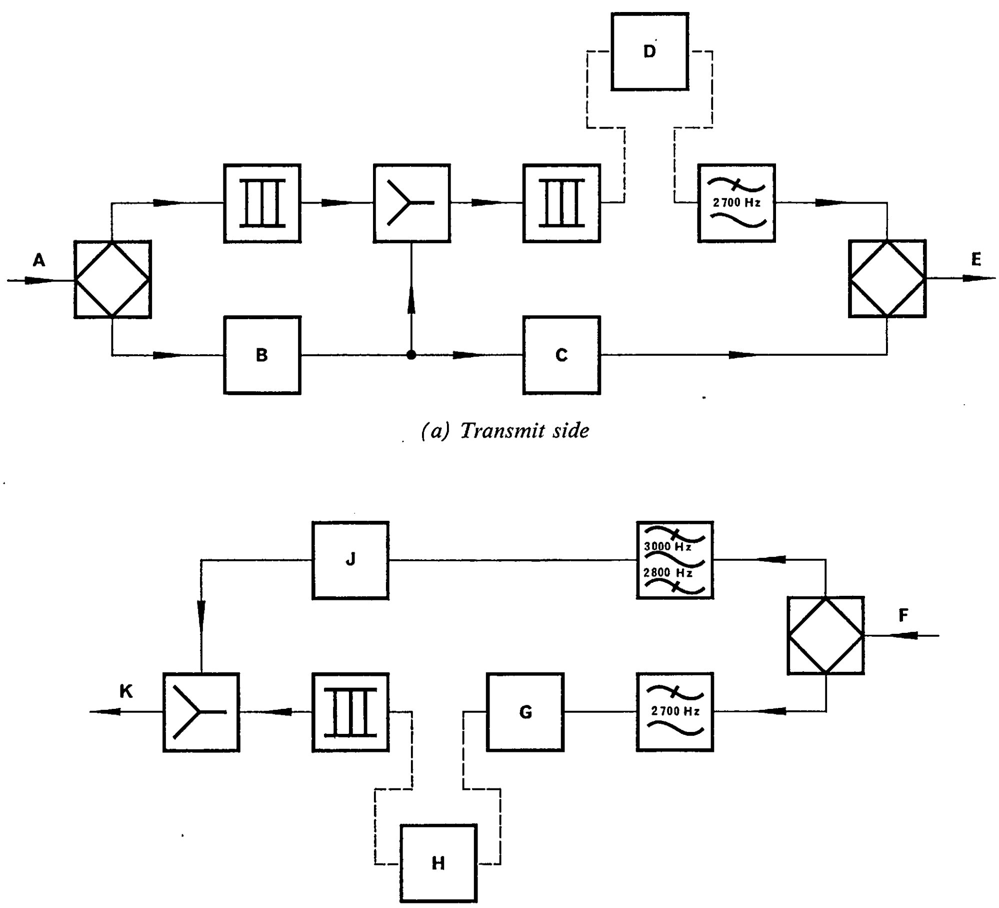
Note 3. — The parameters listed above are considered to be the minimum that should be agreed if compatibility between equipment is to be ensured. In addition, maximum tolerances have been quoted, but it has been assumed that these will not be used as design limits.

Note 4. — The temperature and power source variations with time, over which the parameters should be maintained, will vary between Administrations and have not therefore been included. The C.C.I.T.T., however, in their specification for compandors (Recommendation G.162), state that the performance should be maintained over a temperature range of +10°C to +40°C and with power source variations of ±5% of nominal.

Note 5. — Additional parameters which would normally be included in a specification for this class of equipment, i.e., input and output impedances and levels, signal-to-noise ratio, harmonic distortion, etc., have not been included as their value is not considered essential to compatibility between equipments.

Administrations will wish to add their own values to ensure the satisfactory integration of the equipment into their own networks.

Note 6. — The type of transmission in the control channel according to this Recommendation is not considered as class of emission F3; therefore any provision of the Radio Regulations according to which class of emission F3 is prohibited for the fixed services in the bands below 30 MHz does not apply.



(a) Transmit side

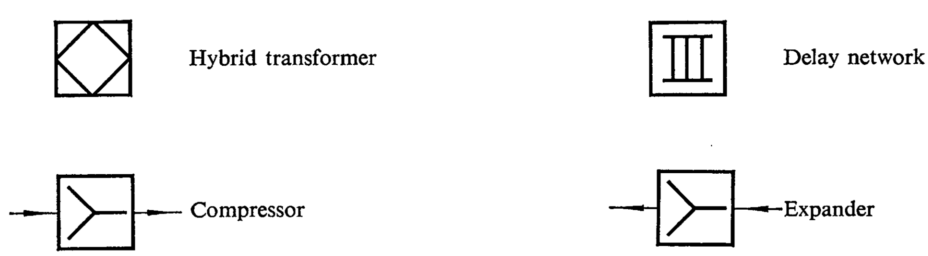
(b) Receive side

FIGURE 1

Schematic diagram of system

A: From landline
B: Amplitude assessor
C: Frequency-modulated oscillator
D: Privacy device
E: To radio transmitter

F: From radio receiver
G: Fading regulator (constant-volume amplifier)
H: Privacy device
J: Frequency discriminator
K: To landline



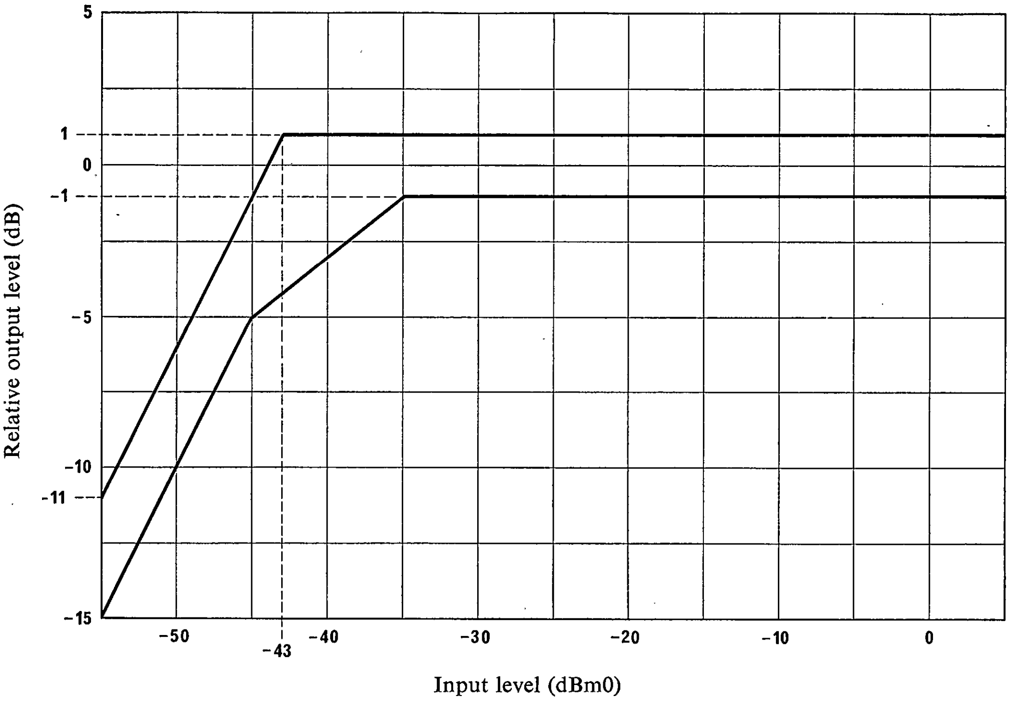
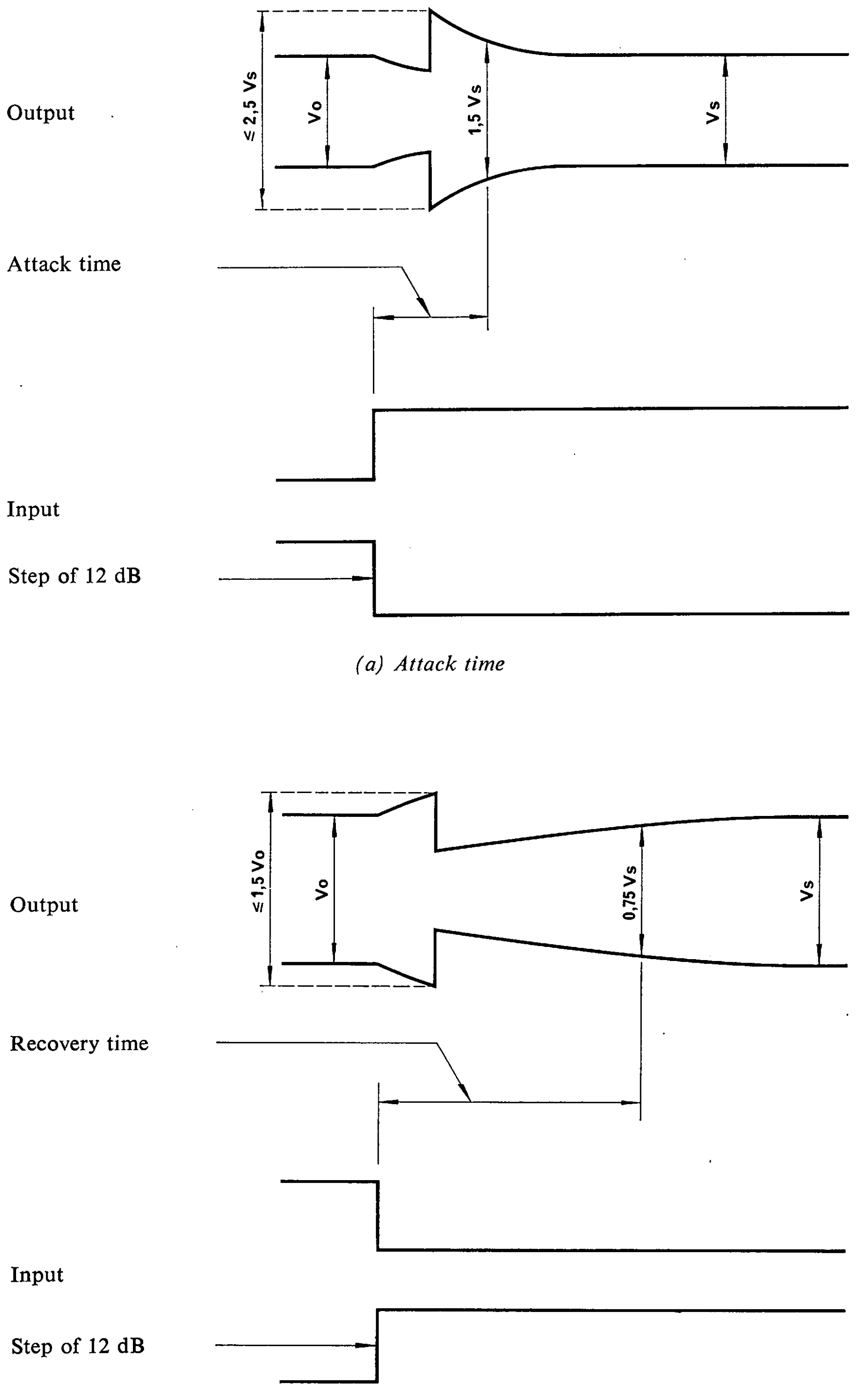


FIGURE 2

Input/output characteristic of transmit side

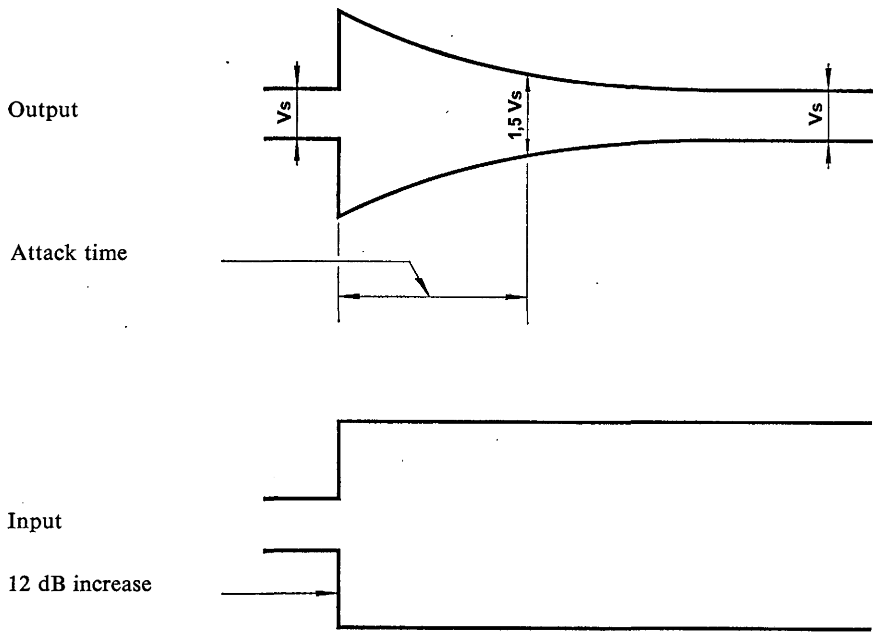


(a) Attack time

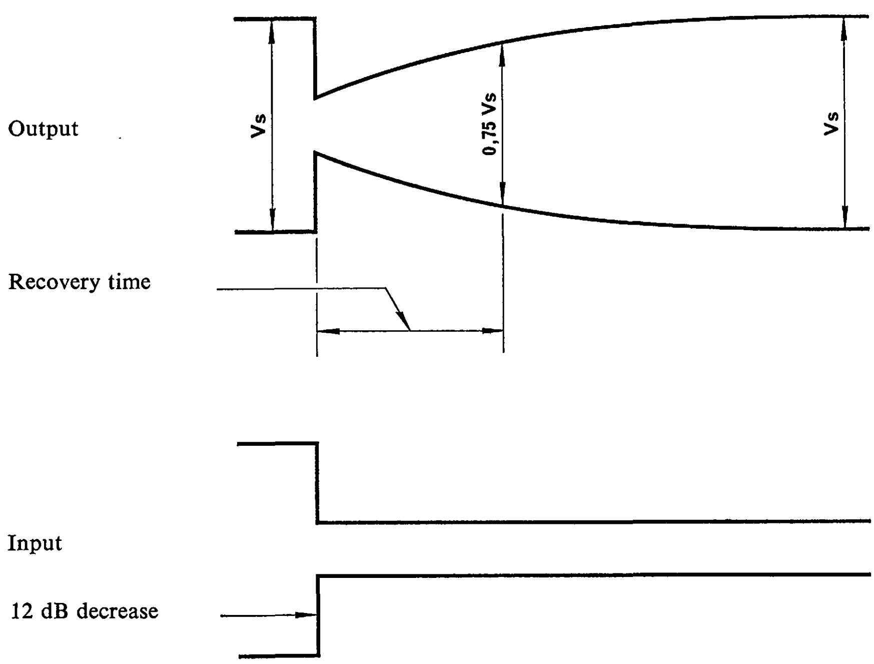
(b) Recovery time

FIGURE 3

Transient response of transmit side



(c) Attack time



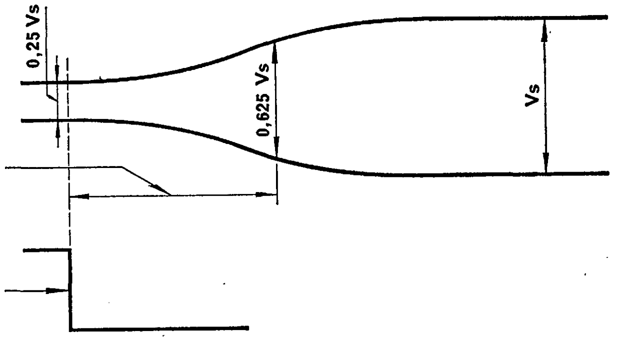
(d) Recovery time

FIGURE 3 (cont.)

Transient response of fading regulator

Attack time

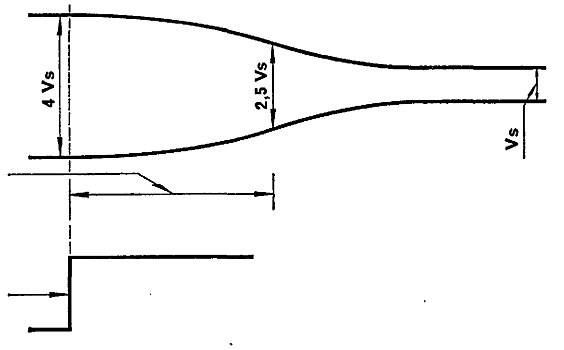
Reduction in frequency of 24 Hz



(e) Attack time

Recovery time

Increase in frequency of 24 Hz



(f) Recovery time

FIGURE 3 (cont.)

Transient response of receive side

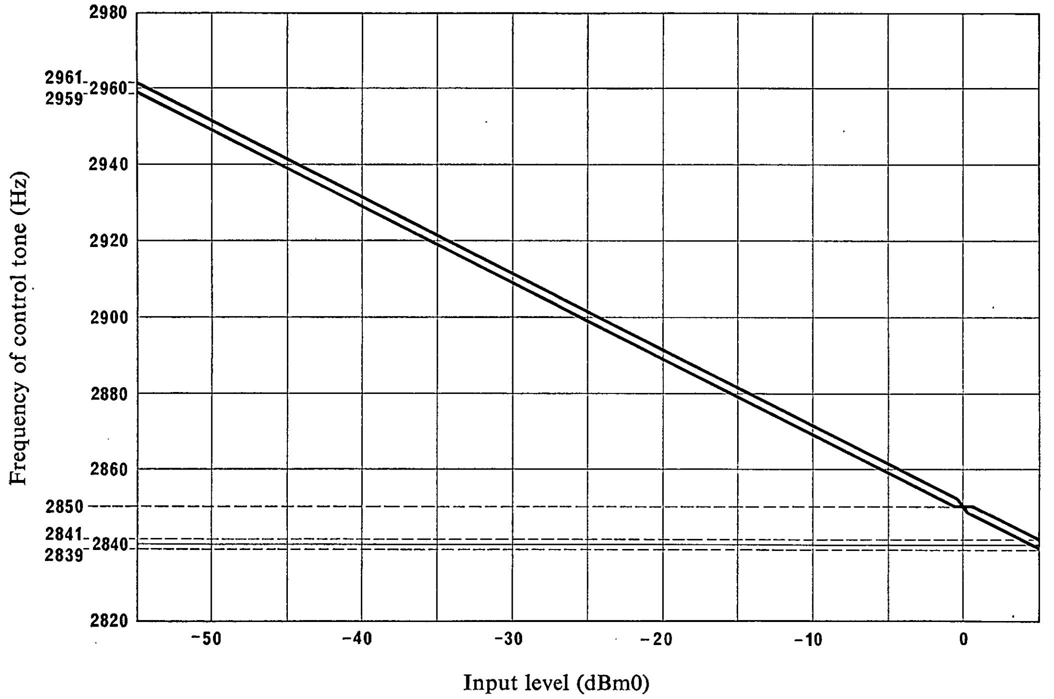


FIGURE 4

Variation in frequency of the control tone with changes of input level to the transmit side

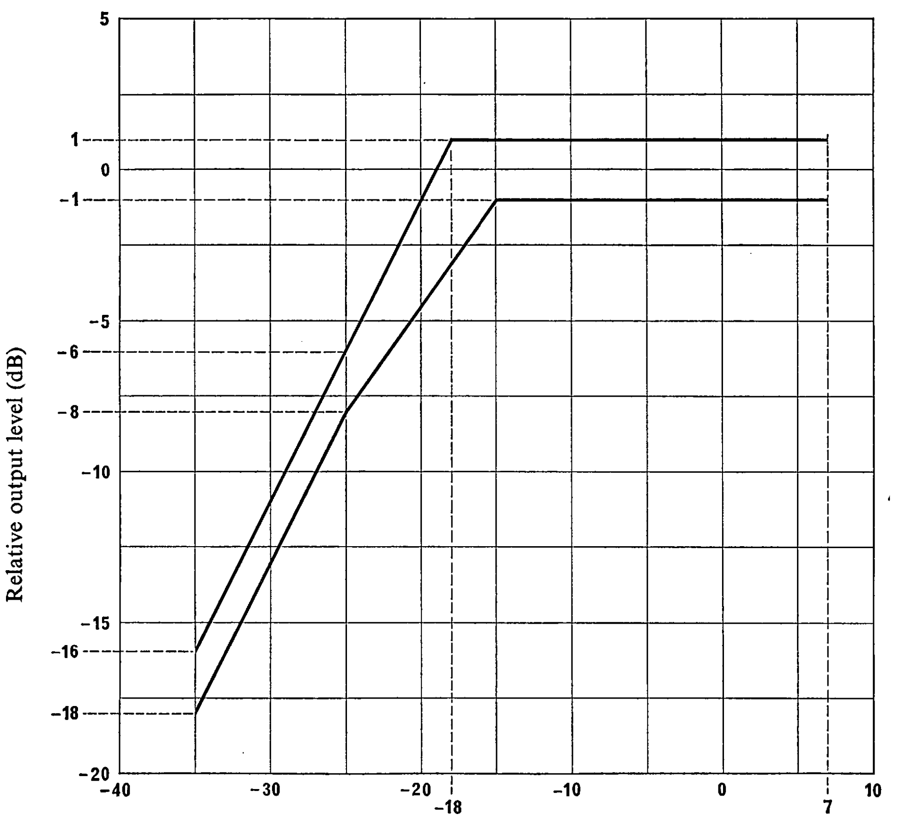


FIGURE 5

Input/output characteristic of fading regulator
(see § 5.3.1.2)

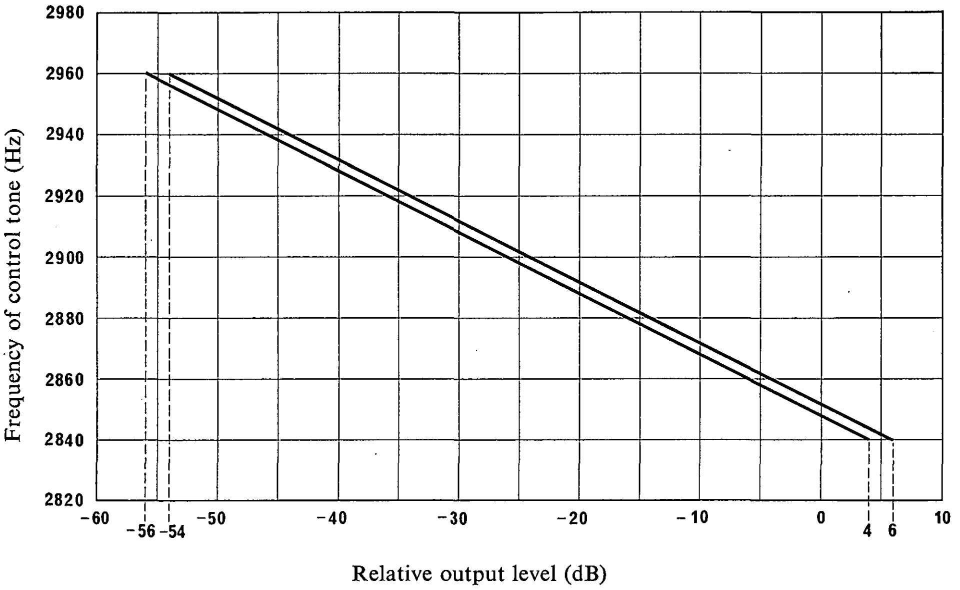


FIGURE 6

Variation in output level at the receiver side with change in frequency of the control tone
(see § 5.3.2.3)

RECOMMENDATION 480

SEMI-AUTOMATIC OPERATION ON HF RADIOTELEPHONE CIRCUITS

Devices for remote connection to an automatic exchange by radiotelephone circuits

(Question 13-1/3)

(1974)

The C.C.I.R.,

CONSIDERING

(a) that telephone circuit operation is substantially improved by the use of semi-automatic instead of manual working;

(b) that HF radiotelephone circuits will continue to be used for many years to come in the international fixed service;

(c) that employment of C.C.I.T.T. signalling codes on such circuits, even when they are equipped with systems of the type described in Recommendation 455-1, is difficult owing to the loss probabilities prescribed for the use of these codes in the international service;

(d) that, on the other hand, the use of signalling methods specially intended for radiotelephone channels makes it possible to transmit the information required for remote connection of an operator in one country to an automatic exchange in another country;

(e) that the FSK signalling system now in use on HF radiotelegraph circuits meets the requirements of *(d)* above;

(f) that Report 434-1 contains precise details on the use of, and tests made by certain countries with devices using the signals mentioned in *(e)* above and that the results are very satisfactory;

UNANIMOUSLY RECOMMENDS

that, when it is desired to provide remote dialling facilities into an automatic exchange via an HF radiotelephone circuit, the system parameters used should preferably conform to those described in the Annex to this Recommendation.

ANNEX

The following specifications concern two devices, a "TRANSMITTING device" in OUTGOING country A and a "RECEIVING device" in INCOMING country B. The TRANSMITTING device is connected to the operating centre of country A (operators) and the RECEIVING device is connected to the automatic switching equipment of incoming country B by a dedicated line. The operator in country A can call a subscriber in country B in the same way as another subscriber in country B would do, since the TRANSMITTING and RECEIVING devices establish a genuine remote connection between the operator in A and the automatic switching equipment in B.

Use by the two countries A and B of the devices described here permits semi-automatic operating, since the operator in A is in a sense a subscriber of the B network. Only terminal traffic will be allowed between the two countries, all transit traffic being excluded. Further, the two countries will have to agree on the facilities afforded to the operators in A (calling of special services such as information, calling in assistance-operators in B or other operators to reach subscribers in B not connected to an automatic exchange).

These specifications are concerned only with the compatibility of the TRANSMITTING and the RECEIVING devices permitting the remote connection of the outgoing operator to the incoming automatic switching equipment.

1. Interconnection

1.1 *The TRANSMITTING device* is connected on one side to the operating centre (operators) and on the other to the radiotelephone circuit:

— on the operating centre side: the operator must transmit to the TRANSMITTING device, for example, by separate wires, the SEIZING, DIALLING, END-OF-DIALLING and CLEARING information;

— on the radiotelephone circuit side: the TRANSMITTING device is placed in series on the *send* direction of the four-wire circuit.

1.2 *The RECEIVING device* is placed in the *receive* path of the four-wire circuit.

The voice circuit and the supervisory and signalling paths from the RECEIVING device are connected to the automatic exchange.

2. Signals transmitted in the forward direction

Information in the forward direction, i.e. from outgoing country A to incoming country B, supplied by the operator in A is converted into signals by the TRANSMITTING device using frequency modulation, which is particularly well suited to transmission on radiotelephone channels.

The TRANSMITTING device contains a voice-frequency FM oscillator of frequency F with a deviation of $\pm \Delta f$. The value of F is selected, by agreement between the two countries*, from the list of frequencies recommended by C.C.I.R. (Recommendation 436-1) with a frequency-shift according to Recommendation 246-3 of $\pm$ 85 Hz.

The table below lists the various types and uses of signals.

Signal	Signal transmitted on the radiotelephonic circuit	Recognition tolerance at the receiving end
SEIZING	frequency $F \pm \Delta f$ modulated at 100 $\pm$ 1 bauds for 300 ms and followed by the frequency $F + \Delta f$ permanently emitted until the beginning of the DIALLING signals	frequency $F \pm \Delta f$ modulated at 100 bauds for a period of 200 to 400 ms followed by the frequency $F + \Delta f$ for at least 300 ms
DIALLING	frequency $F \pm \Delta f$ modulated at the dial pulse rate (66/33 ms or 50/50 ms); the "off" corresponds to the frequency $F + \Delta f$ and the "on" (open) to frequency $F - \Delta f$	Minimum duration of "on" condition (frequency $F - \Delta f$): 25 ms
END-OF-DIALLING	frequency $F \pm \Delta f$ modulated at 100 bauds for 300 ms. No signalling frequency is emitted after this signal	Duration: 200 to 400 ms
CLEARING	frequency $F \pm \Delta f$ modulated at 100 bauds for 600 ms. No signalling frequency is emitted afterwards	Duration more than 500 ms

3. Signals used in the reverse direction

At all times the operator must be able to hear the supervisory signals generated by the distant automatic exchange.

This requires:

3.1 that the TRANSMIT and RECEIVE devices provide control signals to disable any echo suppressors or singing suppressors, included in the circuit, during the period between seizing and the end of dialling;

3.2 that in cases where supervisory signals are too low in frequency to be transmitted directly they must be translated into the voice-frequency band.

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* Different frequencies must be available when there are several circuits equipped with TRANSMITTING or RECEIVING devices in one and the same radiotelephone (transmitting) system to avoid false seizing caused by inter-channel cross-talk.

3B: *Reports*

REPORT 353*

USE OF COMMON-FREQUENCY SYSTEMS ON INTERNATIONAL RADIOTELEPHONE CIRCUITS

(Question 23/3)

(1966)

1. Introduction

This Report deals with the technical characteristics required for common-frequency operation of radiotelephone circuits using single-sideband and independent-sideband emissions.

2. The characteristics to be specified for radiotelephone systems using the principles of common-frequency operation

It is preferable to use the channel configurations shown in Recommendation 348-2 and only to shift the radiated frequency spectra between the two directions of transmission by about 150 Hz when using reduced carrier.

3. Minimum difference in level, at the input of the receiver, between the received signal from the distant station, and signals from the nearby transmitting station, to avoid interference between the wanted signal and that from the nearby transmitter operating at the same frequency

In the fixed service, the signal level received from the nearby transmitting station is usually lower than that from the distant station. However, if the signal from the nearby transmitting station exceeds the signal from the distant station by a considerable amount, the distortion products generated in the nearby transmitter will appear as cross-talk in the remaining channels of the distant multi-channel system. Tests have indicated that, where the nearby transmitter has an intermodulation level (see Recommendation 326-2) of 30 dB, the signal from the nearby transmitter should not exceed that from the distant transmitter by more than 10 dB.

4. The extent to which the use of transmitting and receiving antennae with different characteristics reduce the possibilities of application of this technique

For point-to-point commercial communications, where the separation between transmitter and receiver of one terminal is approximately 30 km, it is not normally necessary to take such a problem into account.

5. The extent to which the possibilities of application of this technique are reduced by the presence of different noise levels at the receiving location

The effectiveness of the common-frequency technique is independent of the noise level at the receiving station.

6. Other factors to be taken into account when planning systems

6.1 *Characteristics of the carrier filter*

In several instances of the practical application of this type of operation, the crystal filter used in the carrier branch amplifier for isolating the reduced carrier had a nominal bandwidth of 20 Hz. The actual characteristics of this filter are as follows:

* Adopted unanimously.

Bandwidth (Hz)	Loss (dB)
±10	0±2
±20	10
±50	38
±70	50

In an effort to determine the effect that the carrier frequency received from the nearby transmitter might have on the receiver when it was receiving a signal from the distant transmitter, a test was made to determine the strength of signal required at various separations to make the receiver lose control.

The following data indicate that, if the two frequencies can be kept separate by 50 Hz or more, the near-end transmitter signal level can be considerably greater than that received from the distant transmitter.

Received frequency (MHz)	Separation frequency (Hz)	Signal generator input simulating distant transmitter (μV)	Signal generator input simulating near-end transmitter. Input varied from 0·5 μV to 50 mV
5	50	0·5	The a.f.c. was not affected up to a level of 50 mV
	100	0·5	
	200	0·5	
10	50	0·5	
	100	0·5	
	200	0·5	
15	50	0·5	
	100	0·5	
	200	0·5	
20	50	0·5	The a.f.c. was disturbed at 5 mV

A review of the above data shows that, if the frequency stabilities of the two transmitters are adequate to maintain a separation of greater than 50 Hz, there is no danger of the nearby transmitter taking control of the receiver away from the desired distant end signal. Assuming that the spacing is maintained between 50 and 250 Hz, the distortion products received from the near-end transmitter would be excessive long before its signal strength would be great enough to take control of the receiver.

6.2 *Frequency stability of the equipment*

To prevent an audible beat note in the channel adjacent to the reduced carrier, the frequencies of the two transmitters must not differ by more than 250 Hz, assuming that the passband of the voice circuit is 250 to 3000 Hz. At the same time, because of the characteristic of the carrier filter, the frequency separation must be 50 Hz or more. From this we arrive at the most desirable separation of 150 Hz. This will allow a deviation of ± 100 Hz without exceeding the permissible limits, and is well within the capabilities of modern equipment, even at the highest frequencies.

7. Practical results

A number of systems operating on this basis have been in service since 1951. The experience from this operation has shown that radiotelephone systems using terminals having VODAS equipment will operate successfully on a common-frequency basis. Based on this experience, and the tests noted above, the Annex summarizes the several methods of operation with reduced and suppressed carrier. The left column lists the important characteristics which need to be defined for use of common-frequency systems on radiotelephone circuits and the right column contains associated definitions and remarks which have resulted from the above tests.

ANNEX

1. Reduced carrier multi-channel operation

	Criteria	*Remarks*
1.1	*Recommendation 335-2.* The characteristics of the radiotelephone system shall be as specified in Recommendation 335-2.	The equipments used in the system described above generally agree with the characteristics specified in this Recommendation.
1.2	*Level of signal received from local transmitter.* Important characteristics include physical separation between local receiving and transmitting stations, frequency of operation, physical terrain (hills, etc.), antenna patterns, antenna radiation efficiency, transmitting power, etc.	The physical separation between local receiving and transmitting stations must be great enough that the carrier signal level from the nearby transmitter will normally be less than the signal received from the distant transmitter and will rarely exceed it by as much as 10 dB. The use of transmitting and receiving antennae of differing characteristics will affect this type of operation only to the extent that they influence the strength of the signal received at the local receiver from the local transmitter.
1.3	*Mode of operation.* Reversible simplex operation.	VODAS equipment used on each voice circuit.
1.4	*Intermodulation distortion at the transmitter*	The intermodulation level (Recommendation 326-2) should be lower than –30 dB.
1.5	*Frequency stability of the transmitter*	Transmitter frequencies must be sufficiently stable to maintain a space of 150 ±100 Hz between transmitted carriers.
1.6	*Bandwidth of a.f.c. filter*	The carrier filter should have an attenuation of approximately 40 dB at the ±50 Hz points.

2. Suppressed carrier multi-channel operation

	Criteria	*Remarks*
2.1	*Recommendation 335-2.* The characteristics of the radiotelephone system shall be as specified in Recommendation 335-2.	See Recommendation 335-2.
2.2	*Level of signal received from local transmitter.* Important characteristics include physical separation between local receiving and transmitting stations, frequency of operation, physical terrain (hills, etc.), antenna patterns, antenna radiation efficiency, transmitter power, etc.	The physical separation between local receiving and transmitting stations must be sufficiently great, that the signal level from the nearby transmitter will normally be less than the signal received from the distant transmitter and will rarely exceed it by as much as 10 dB. The use of transmitting and receiving antennae of differing characteristics will affect this type of operation only to the extent that they influence the strength of the signal received at the local receiver from the local transmitter.
2.3	*Mode of operation.* Reversible simplex operation.	VODAS equipment used on each voice circuit.
2.4	*Distortion at the transmitter*	The intermodulation level (Recommendation 326-2) should be lower than –30 dB.
2.5	*Frequency stability of receiver and transmitter*	Transmitter and receiver must be sufficiently stable to maintain an overall frequency difference not exceeding 20 Hz.

3. Suppressed carrier, single-channel operation

Criteria	*Remarks*
3.1 *Recommendation 335-2.* The characteristics of the radiotelephone system shall be as specified in Recommendation 335-2.	See Recommendation 335-2.
3.2 *Level of signal received from local transmitter.* Important characteristics include physical separation between local receiving and transmitting stations, frequency of operation, physical terrain (hills, etc.), antenna patterns, antenna radiation efficiency, transmitter power, etc.	For single-channel operation, the physical separation between the local receiving and transmitting stations must be great enough, that the level of residual noise at the receiver in the desired sideband is not increased by more than 1 dB when the transmitter power amplifier is operating normally but with no modulation applied. Under this condition, the transmitter is producing broadband noise from the exciter and driver which can, if sufficiently high, interfere with the signal received from the distant station. (See § 3.6.)
3.3 *Mode of operation.* Reversible simplex operation.	VODAS equipment used on the voice circuit.
3.4 *Transmitter distortion*	The intermodulation level (Recommendation 326-2) of the transmitters should be lower than –30 dB.
3.5 *Frequency stability of receiver and transmitter*	Transmitter and receiver must be sufficiently stable to maintain an overall frequency difference not exceeding 20 Hz.
3.6 *Residual noise level at the transmitter*	The residual-sideband noise level should not exceed –56 dB relative to the peak envelope power.
3.7 *Blocking characteristics of the receiver*	The receiver blocking characteristics must be such that the receiver will recover from a severe overload in less than 0·1 s if the front end of the receiver is not desensitized during the period of transmission from the local transmitter. In this case, the local transmitter and receiver can be much closer together because there is no a.f.c. problem, only problems of interference and blocking remain. In some cases, the two may be co-located. The receiver can be left operative, during the period of transmission by the local transmitter, if it can receive a signal from the distant transmitter immediately after the local transmitter has ceased operation.

REPORT 354-2*

AN IMPROVED TRANSMISSION SYSTEM FOR USE OVER HF RADIOTELEPHONE CIRCUITS

(Question 13-1/3)

(1966 – 1970 – 1974)

1. Introduction

Terminal apparatus currently employed on HF radiotelephone circuits includes constant-volume amplifiers and singing suppressors in each speech channel. The singing suppressors are susceptible to misoperation by high levels of received noise, and clipping or suppression of speech in the transmit channel can result. Even under good circuit conditions the use of singing suppressors operates against a smooth flow of conversation.

In line transmission, the effects of noise can be reduced by the use of a compandor, but such a system will function correctly only if the loss remains constant between the compressor output and the expander input.

During recent years a number of system techniques have been suggested** for overcoming the difficulties of using compandor principles on HF radio circuits. Most of these systems had the common feature that the voice signal is compressed and the information as to the degree of compression is transmitted over the circuit by means of a separate channel, to control the degree of expansion.

Docs. III/95 (United Kingdom) and III/99 (United States of America), 1963–1966, gave information on field trials with two similar, but not identical, systems and indicated the significant advantages that could be obtained over conventional systems by using compandor techniques.

Docs. III/7 (United Kingdom) and III/29 (United States of America), 1966–1969, describe detailed parameters of a "Linked Compressor and Expander" system called "Lincompex"*** and the principles are summarized as follows.

The speech is compressed to a sensibly constant amplitude and the compressor control current is utilized to frequency-modulate an oscillator in a separate control channel. The speech channel, which contains virtually only the frequency information of the speech, and the control signal channel which contains the speech amplitude information, are combined for transmission over a 3 kHz channel. As each speech syllable is individually compressed the transmitter is more effectively loaded than in current practice. On reception both the speech and the control signals are amplified to constant level, the demodulated control signal being used to determine the expander gain and thus restore the original amplitude variations to the speech signal. Because the output level at the receiving end depends solely on the frequency of the control signal, which is itself directly related to the input level at the transmitting end, the overall system loss or gain can be maintained at a constant value. Operation with a slight loss (two-wire to two-wire) permits singing suppressors to be discarded, although echo suppressors will be needed, as on long-line circuits.

Preferred values for the parameters of the system have been given in Recommendation 455-1.

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* Adopted unanimously.

** See Bibliography.

*** The name "Lincompex" is neither a proprietary name, nor does it refer to a manufacturer of a particular equipment, but is a useful acronym for the phrase "linked compressor and expander", which describes the system.

2. Field trials

Experimental equipment has been tested operationally at the terminal stations of the London-New Delhi radio circuit. The Lincompex equipment and the conventional terminal were applied to the A1 and B1 channels of the radio system, the channels being interchanged at weekly intervals throughout most, but not all, of the 17-week trial period (December 1964–April 1965).

The Lincompex-equipped circuit gave consistently longer commercial time than the conventionally equipped circuit, the average daily commercial periods being 6·6 and 5·8 hours (14 % increase) respectively during a 12-week period when channels were systematically interchanged, but taking the 17-week trial period as a whole, the corresponding figures were 6·2 and 5·2 hours (19 % increase) per day.

Quite apart, however, from the extension of commercial circuit availability, a noteworthy feature was the greater potential call-handling capacity of the Lincompex channel due to the smoother flow of conversation, of operators and subscribers alike, which the omission of singing suppressors made possible. This was clearly demonstrated during a special 4-week service observation period when particular attention was paid to the quality of calls. Of the observed calls, 70 % were graded "excellent" or "good" on the Lincompex channel, the corresponding figure for similar gradings on the conventional channel being 58 %. The improvements were particularly noticeable on transit calls extended over long-distance cable circuits.

Doc. III/19 (Japan), 1966–1969, describes field trials of a radioterminal equipment based on the same principles as Lincompex. Results of comparisons between the performance of a 600 km circuit between Tokyo and Osaka with the new equipment and with conventional VODAS equipment are given. Tests were made in February and August 1967.

In the first comparison, 29 persons participated in an opinion test to assess both speech quality and syllable articulation. Table I shows the results of this assessment, and indicates that the new equipment can provide a significant improvement in both quality and syllabic articulation. Test for syllabic articulation showed that the frequency of repetition with Lincompex was reduced to one-fourth of that obtained with conventional equipment.

TABLE I

Results of the field trial, February 1967

Test item	Grade	Evaluation	Experimental equipment (%)	Conventional equipment (%)
Opinion test	4	Excellent	58·6	31·0
	3	Good	34·4	37·9
	2	Fair	5·2	13·8
	1	Poor	1·8	13·8
	0	Unusable	0	3·5
Repetition	Repetition rate		0·4/100	1·7/100

In the second test, 85 participants engaged in test calls. Table II shows the summary of opinions, obtained by interview. As shown in the Table, 98·8 % of the participants expressed the opinion that the HF radio circuit with the new equipment provides almost the same speech quality as a public telephone circuit routed over a cable or radio-relay system.

TABLE II

Results of listening test, August 1967

Items for interviews	Evaluation	Percentage of calls
Comparisons with public telephone	No difference	47·0
	Lincompex slightly worse than cable	51·8
	Lincompex much worse than cable	0
	No comment	1·2

3. "In service" performance

Docs. III/7 (United Kingdom), III/29 (United States of America) and III/30 (Republic of South Africa), 1966–1969, give information on the "in service" advantages obtained with Lincompex.

3.1 Doc. III/7 (United Kingdom) summarizes the results of special observations carried out by trained personnel on the London–Nairobi and London–Johannesburg circuits. Comparisons were made between a channel fitted with the new arrangement and a conventional channel in the same 4-channel group.

The results may be summarized as follows:

increase in number of calls passed compared with conventional channels	100%
increased chargeable time per call	6% (88% to 94%)
increased average length of call	6%
percentage of calls graded "smooth" increased by	25% (60% to 85%)

This greatly enhanced circuit efficiency was achieved with reduced attention by the traffic operator, it being found practicable for the "incoming" operator to retire once the called number had been dialled, leaving the "outgoing" operator to control the call. No supervision by technical operators was employed at either end. It is significant to note that the percentage paid time per call is now high enough to eliminate the need for observation and timing, and calls can be set up as for a line circuit.

3.2 Doc. III/29 (United States of America) summarizes the improvements that have been obtained with "in service use" of Lincompex equipment since July 1966. Since then regular commercial services using one or more Lincompex systems have been established between the United States and a number of other countries. User reaction has been swift, with favourable comments on the easy flow of conversation and the lack of noise.

In general, one or two Lincompex-equipped channels have been assigned to a particular four-channel radio system. Thus, the increase in commercial time on any given frequency has not been readily observable; the demands of the conventionally equipped channels caused frequency changes to be made prior to that needed by the newly equipped channels. However, it was observed that when the newly equipped circuits were controlling, they remained in service long after the conventional channels were unserviceable. The estimated increase in usable circuit time was from 16% to 20%.

Analysis of traffic patterns on trunk groups having Lincompex-type equipped channels on one or more circuits indicate the following:

— the Lincompex channel handled 26% of the total number of calls in a 12-channel trunk group: almost that of the next three busiest channels in the group;

— the increase in minutes per call on the Lincompex-equipped channel amounted to 16·5%;

— the Lincompex channel accounted for 29% of the chargeable minutes in a 12-channel trunk group.

3.3 Doc. III/30 (Republic of South Africa) comments upon the advantages that have been obtained by the use of Lincompex equipment on the Johannesburg – London circuit over the period September, 1967 to May, 1968. It draws attention to the possibility of staff reductions, as little or no monitoring is required, and the improvement in the quality of reception of special news "broadcasts" which in general is, with Lincompex, of a sufficiently high standard to permit retransmission without further processing, or, in some cases, being re-read locally.

A detailed description is given of the arrangements made to compare a Lincompex circuit with a conventional circuit. The analysis is based on calls passed from Johannesburg to London. The results are given in Table III, from which it will be seen that the Lincompex-equipped circuit carried nearly twice as much traffic as the normal circuit, during the months under consideration.

Considering that the service time of the Lincompex-equipped circuit was longer than that of the normal circuit and that, during March, 241 calls were passed over the Lincompex circuit during the period when the normal circuit was closed, it is concluded that the Lincompex-equipped circuit carried, on average, about 25% more traffic than the normal circuit over the same period of time. The opinion is given that the reason for the higher traffic carrying capability of the Lincompex-equipped circuit is that less time is required by the traffic operators to pass call details.

Table IV shows the relative grade of service offered by the new system during the period 0700 to 2000 GMT when propagation conditions are stable. The marked improvement noticeable with the Lincompex channel is due to the greater ease of conversation and general absence of noise due to the compandor action. The traffic operator remarked particularly on this aspect of performance.

To determine the extent of the improvement in traffic time which could be expected from the use of Lincompex equipment, special tests were conducted throughout the 24-hour day.

Table V indicates the results of these tests.

Although the Lincompex circuit shows practically no improvement in commercial time over the normal circuit between 0600 to 1800 GMT, it provides a circuit which is quiet, for a greater percentage of the available time. During the less stable periods 0000 to 0600 GMT and 1800 to 2400 GMT, the Lincompex circuit is superior in providing a circuit which is not only quiet for a greater percentage of the available time, but also commercial for a greater percentage of the available time.

The document concludes by summarizing the improvements as follows:

— less time required by traffic operators for passing details of booked calls, and consequently a higher traffic carrying capability,

— easier conversation, and consequently a higher percentage effective circuit time,

— transmission of news items of a standard which permits retransmission to broadcast listeners, thus obviating the necessity to re-read locally,

— very little maintenance,

— a minimum of attention by the technical operators.

Effective duration of calls = Overall duration minus time allowed for repetitions

Table III

	Number of calls passed					Duration (min)		Average duration (min)	Percentage effective time
	Jan.	Feb.	March	April	Total	Overall	Effective		
Lincompex	719	633	1198	244	2794	15 574	15 478	5·57	99·38
Normal	377	336	27	719	1459	7 836	7 518	5·37	95·94

Table IV

Period 0700—2000 GMT	Good, quiet (%)	Slightly noisy, commercial (%)	Noisy, un-commercial (%)	Slight interference commercial (%)	Interference un-commercial (%)	Uncommercial due to frequency changes, equipment and line failures (%)	Total time commercial (%)
Lincompex	92	3·9	1·2			2·9	95·9
Normal	66·7	24·6	4·1	1·7		2·9	93·0

Table V

Period		Good, quiet (%)	Slightly noisy, commercial (%)	Noisy, un-commercial (%)	Slight interference commercial (%)	Interference un-commercial (%)	Uncommercial due to frequency changes, equipment and line failures (%)	Total time commercial (%)
0000 to 0600 GMT	Lincompex	57·3	19·7	15·0	1·2		6·8	78·2
	Normal	7·6	22·5	15·3	1·5	46·3	6·8	31·6
0600 to 1800 GMT	Lincompex	96·4	1·3	1·0			1·3	97·7
	Normal	70·0	26·6	2·1			1·3	96·6
1800 to 2400 GMT	Lincompex	57·2	24·6	8·4	0·4	1·1	8·3	82·2
	Normal	7·7	32·3	22·2		29·5	8·3	40·0

4. Modification of Lincompex system to provide echo suppression capability

4.1 Lincompex-equipped radiotelephone circuits normally require conventional echo-suppressor devices (C.C.I.T.T. Recommendation G.161) at the terminal ends of the voice circuit in order to overcome problems of echo created by the imperfect balance of the four-to-two-wire hybrid.

4.2 Doc. 3/47 (Japan), 1970–1974 and Doc. 3/57 (U.S.S.R.), 1970–1974 describe methods that utilize the control channel of the Lincompex system and provide echo-suppression within the Lincompex system. Developed independently by the two administrations the designs are based on almost identical principles.

4.3 Both systems cause the far-end expander to provide maximum loss whenever the near-end received signal level is greater than the near-end transmitted signal level; the far-end expander operates in its normal mode whenever the near-end transmitted signal level is greater than the near-end received signal level.

Three basic differences exist between the two systems:

— In the U.S.S.R. system the far-end expander provides maximum loss until the near-end transmitted signal exceeds a predetermined threshold level.

— In the Japanese system the far-end expander provides maximum loss whenever the near-end received signal exceeds a predetermined threshold level, except during the break-in condition.

— In the Japanese system the near-end expander provides 6 dB additional loss whenever the near-end transmitted signal exceeds the near-end received signal level by a predetermined value.

4.4 Tests on simulated HF radio facilities with one-way propagation times of up to 100 ms (Doc. 3/47), and on long HF radio paths (Doc. 3/57), show that both systems operate satisfactorily, and in addition both systems operate compatibly when the far-end of the voice circuit is equipped with conventional echo-suppressors.

4.5 Doc. 3/47 suggests that the operational parameters of their system are substantially in accordance with the characteristics for echo-suppression devices set forth in C.C.I.T.T. Recommendation G.161.

4.6 Details of the Japanese and U.S.S.R. systems are contained in the attached Annex to this Report.

5. Necessity for additional information

The characteristics of the Lincompex system set forth in Recommendation 455-1 are the minimum requirements necessary to ensure system performance and compatibility. Additional information is desired which will lead to improved performance, particularly in the areas concerning large signal transient response, such as can occur during dialling or at the onset of speech.

Tests wherein the fading regulator characteristics were modified to provide a wider operating margin, a median gain position during the no-signal condition, more rapid gain decrease on attack and syllabically-controlled gain-increase show the possibility for such improvement (Doc. 3/15 (France), 1970–1974).

Recommendation 455-1, §§ 5.2 and 5.3 specify the response of the Lincompex system to sudden changes in input signal level of 12 dB in accordance with C.C.I.T.T. practice. It is not established that the response to greater signal changes, such as occur at the onset of speech, can be satisfactorily extrapolated from the Recommendation.

Further, in the absence of the control channel signal, the gain of the expander could with advantage revert to a predetermined value of gain without exhibiting any disturbing transient phenomena (Doc. 3/15). The value of the predetermined gain would have to be adjustable so as to conform to the noise requirements of the various administrations. (Such a facility is already provided in some existing equipment.)

Further studies leading to the specification of characteristics in the above-mentioned areas are desirable.

ANNEX

A NEW ECHO SUPPRESSION SYSTEM FOR A LINCOMPEX-EQUIPPED CIRCUIT

1. The essentials of the new system comprise a comparator which examines the signal levels at the four-wire side of the system hybrid. The output of the comparator is connected to the frequency-modulated control-tone oscillator. During reception of speech from the distant terminal, the receive-side of the two inputs to the comparator predominates significantly. The comparator produces an output which is used to clamp the control-tone oscillator frequency to the upper end of its range; consequently, the distant-end expander will close down to received signals, preventing the passage of any echoes from the near end. During transmission of speech from the near terminal, the transmit-side of the two inputs to the comparator predominates. The comparator output is inadequate to clamp the control-tone oscillator, which thus operates normally.

To allow for permissible transmission errors in the co-relation of envelope levels and control-channel signals and for protection against undue sensitivity to interference, noise or insignificant signal levels, the comparator is given an operational threshold.

The systems described in Docs. 3/47 and 3/57 (1970–1974), differ mainly in aspects of their comparator configurations, and the essential differences are brought out in the following descriptions.

2. Doc. 3/47 (Japan)

2.1 *General*

Fig. 1 indicates schematically the signal comparator and associated elements of the Lincompex terminal.

Operation of the system is as follows:

2.1.1 In the presence of received signals only (no transmit signals other than echoes):

As the discriminator d.c. output exceeds a pre-set threshold level, the threshold detector M produces an output which passes via the inoperative inhibitor N to clamp the frequency of oscillator C at 2980 Hz. The remote-terminal expander suppresses the receive-side output at that terminal. No signal appears at the output of the level comparator L.

2.1.2 In the presence of transmitted signals only, the threshold detector M produces no output; the level comparator L produces an output; oscillator C functions normally; the discriminator control reduces receive-path output by 6 dB.

2.1.3 In the presence of signals in both paths:

- When the transmitted signal predominates;
  Operation is as in § 2.1.2; however, the threshold detector will operate.
- When the received signal predominates, the level comparator L will produce no output. The frequency of oscillator C will be clamped at 2980 Hz if the threshold detector M is operated.

2.2 *Test results*

2.2.1 The new system worked normally with an echo return loss across the four-wire termination of more than 4 dB.

2.2.2 An acceptable speech quality was obtained in a simulator test for the case of the longest HF circuit with a one-way propagation path time of 100 ms.

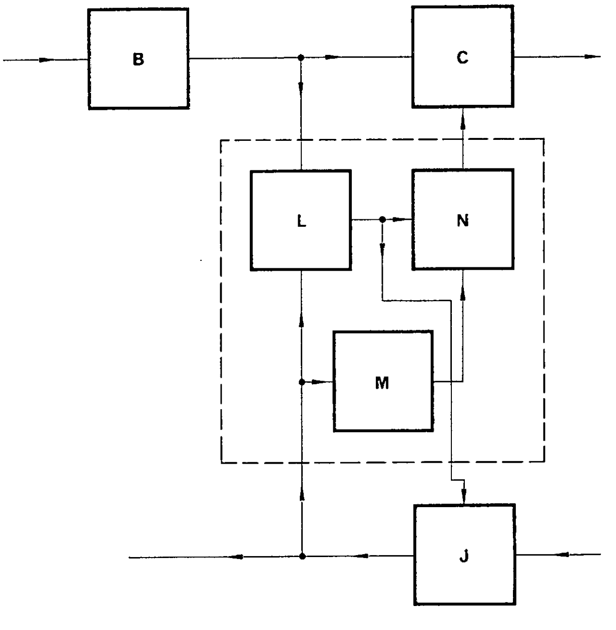
2.2.3 Tests between Lincompex terminals, one of which was equipped with the new echo-suppression system and the other of which was equipped with a conventional echo suppressor, showed the terminals to be fully compatible.

2.2.4 Typical test data on echo suppression follow in Table I.

TABLE I

Echo-suppression operate time

Final build-up level of received signal	Echo-suppression operate time
6 dB above threshold	3·5 ms
3 dB above threshold	11·0 ms



Lincompex Units

B: Amplitude assessor
C: Frequency-modulated oscillator
J: Frequency discriminator

Additional Units

L: Level comparator
M: Threshold detector
N: Inhibit circuit

FIGURE 1

Schematic diagram of echo-suppression — Japanese system

3. Doc. 3/57 (U.S.S.R.)*

3.1 *General*

Fig. 2 indicates schematically the signal comparator and associated elements of the Lincompex terminal, for one of possible variants of the system.

Operation of the system is as follows:

3.1.1 The signal comparator comprises units P, Q and R. The potential at point c is proportional to the difference in levels between the transmit and receive sides.

3.1.2 Under condition of no signal in either path, an output from R clamps the frequency of oscillator C to the upper end of its range, and the distant-end expander is held closed.

3.1.3 When signals exist in the receive path only, operation is as in § 3.1.2.

3.1.4 When signals exist in the transmit path only, the potential at point e changes. When a pre-set threshold level (ΔU) at d is exceeded, the output from R is removed and the oscillator C operates normally.

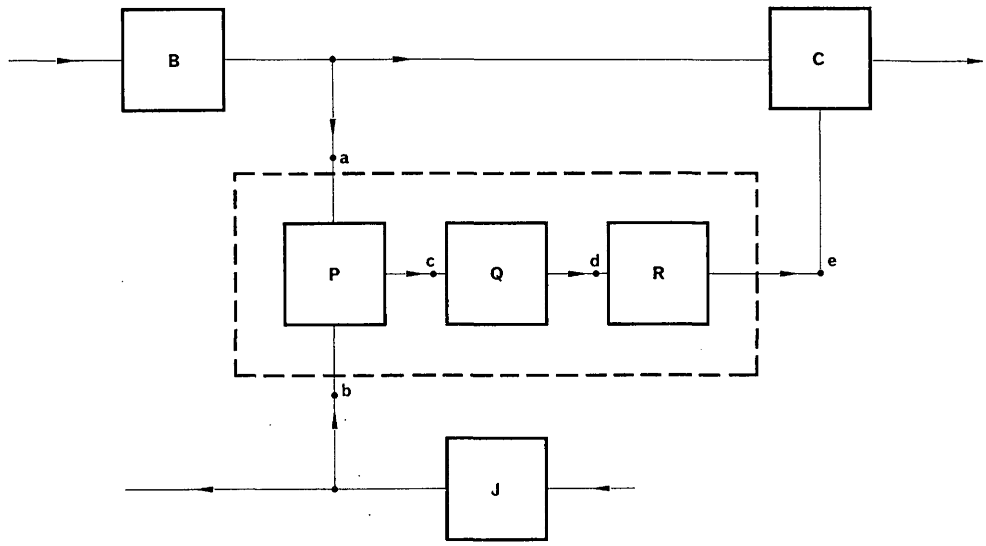
3.1.5 When signals exist in both paths the level differential will determine which path has priority.

3.2 *Test results*

Field trials over long-distance HF radiotelephone trunk circuits, show a high degree of efficiency in echo and singing suppression. The new system is demonstrably fully compatible with Lincompex terminals equipped with functionally independent echo suppressors.

Experience shows use of the new-type echo-suppressor system to improve the radio-circuit performance and to enhance equipment reliability. The operate time (τ) and release time (T) of the echo suppressor are 4 ms and 200 ms respectively.

* See [Kloeck, 1970] and [Bukhviner *et al.*, 1971].



Lincompex units

B: Amplitude assessors
C: Frequency-modulated oscillator
J: Frequency discriminator

Additional units

P: Subtraction stage
Q: Integrator
R: Threshold stage

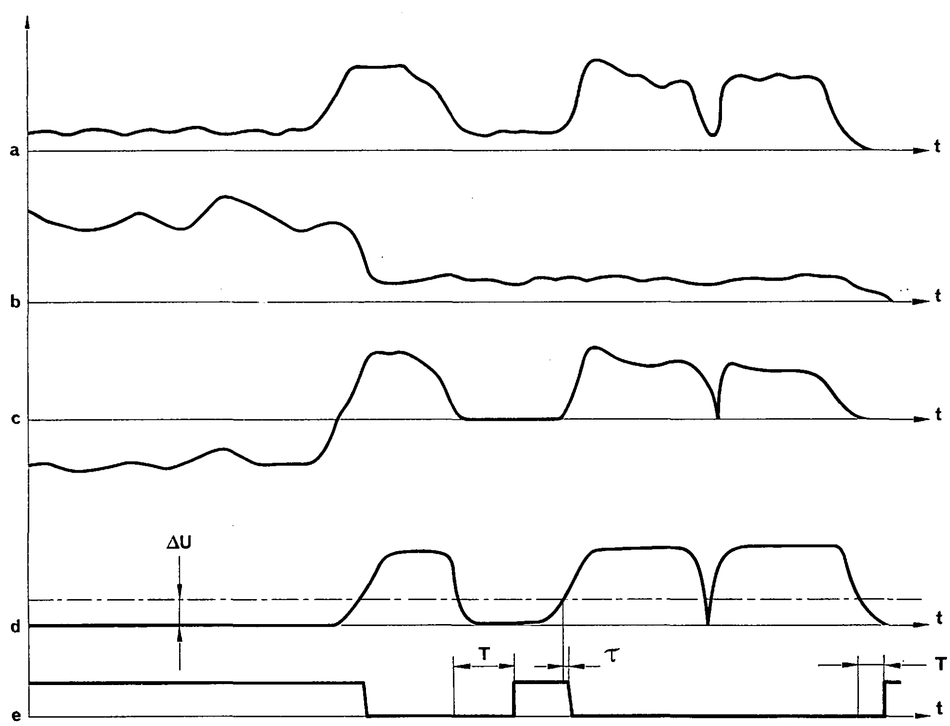


FIGURE 2

Schematic and timing diagram of echo-suppression — U.S.S.R. system

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REPORT 355-1*

USE OF DIVERSITY ON INTERNATIONAL HF RADIOTELEPHONE CIRCUITS

(Question 13-1/3)

(1966 – 1970)

1. Introduction

This Report discusses some diversity techniques for the HF radiotelephone service, including wide-spaced diversity, in-band diversity, and time diversity.

2. Wide-spaced diversity for voice operation

In addition to the absence of correlation in the fast phase-interference fading of radio-frequency signals at receiving stations separated by a number of miles, there is some lack of correlation in the slower fading. To investigate the latter, interstation tests were made, over a telephony link from Amsterdam, operating at 18 MHz in class of emission A3A, with receivers at two sites in New Jersey about 135 km (85 miles) apart.

The antenna outputs were recorded over the operating hours of a period of ten months, using equipment having a time constant of 40 s. Analysis of the charts showed:

— signal strength differences up to 10 or 20 dB and lasting for an hour or more were not uncommon, despite the fact that there was a strong correlation between the general (hourly median) levels at the two sites, both during normal and magnetically disturbed days;

— as was to be expected, the interstation diversity would not have helped appreciably against sudden ionospheric disturbances;

— in general, on days when the overseas transmission was disturbed, the interstation improvements, in decibels, on the average did not differ greatly from that obtained on other days;

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* Adopted unanimously.

— the distribution of the simultaneous differences, in decibels, between the antenna outputs, approximated closely to the normal;

— the standard deviation of this distribution (for an analysed period of about three months) was 8·5 dB. The correlation between the two outputs was about 0·85;

— the average difference (for this period) was 0 dB;

— the average of the signal improvement, in decibels, useful half of the time, was 7 dB. During two-thirds of the time that one branch signal was depressed more than 20 dB from the median, the average improvement was greater than 8 dB; and for 15% of this time, greater than 23 dB.

To utilize the potential signal-to-noise improvement, an automatic selecting arrangement and the necessary additional wire lines would have to be used. The amount of lost circuit time resulting otherwise from poor radio transmission which would be reclaimed by the interstation diversity would depend upon the value, relative to the median value, of the signal strength representing the commercial limit. The latter, in turn, depends largely upon the noise. To the degree that the effective noise input to the receiver is constant, as it tends to be if set noise, or to a lesser extent cosmic noise, is controlling, the distributions of signal-to-noise ratio would tend to have the same variances as those of the signals. On this basis, and assuming an ideal selecting and utilizing system, the fraction of lost circuit time reclaimed on the 18 MHz Amsterdam circuit would have been roughly one-third.

The method is also effective in the case of co-channel interference from a distant undesired station. During the tests a marked diversity effect between Amsterdam signals and those of a co-channel interfering telegraph station in Europe was observed. The telegraph signal was present in the Amsterdam channel sometimes for hours, and during these periods, its intensity relative to the Amsterdam signal was observed to vary over wide ranges. There were also large differences at times between the outputs of the antennae at the two receiving sites on these telegraph signals, and still larger differences at the outputs of the receivers whose gains were controlled by the Amsterdam signals. This "compounded" diversity effect was so great at times that the interference might render one receiver uncommercial and at the same time be hardly audible on the other. This effect may become increasingly important in problems in the future when radio reception may be increasingly limited by unwanted signals other than radio noise (see Report 414).

In addition to the foregoing tests, a comparison of several thousand paired measurements of the signal-to-noise ratio at the two sites, using similar receiving antennae on a London circuit, was made. The estimated average diversity improvement, useful half of the time, which an ideal selecting system would have yielded was 5·5 dB. Data for several operating frequencies were lumped together in arriving at this result. The 5·5 dB value can be compared with the 7 dB figure given above for the Amsterdam tests at 18 MHz and based upon signal recordings alone rather than recordings of the signal-to-noise ratio.

Subsequently, an experimental comparator to select the better receiver branch was used. Briefly, this comparator measures the received noise and interference during outgoing speech (under the control of the VODAS), and selects the output of the quieter receiver. The time-constants are such that the switch does not operate on isolated noise impulse peaks. The noise outputs of both the accepted and rejected branches were recorded on a dual pen recorder which was equipped also with an event recording pen to provide a continuous record of the switch position. An example of noise distributions for the accepted branch, and the rejected branch, as derived from recordings covering portions of three days, is shown in Fig. 1. This short sample is, of course, inadequate to represent results over a much longer time.

No effort was made to determine the correlation of the slower fading as a function of the separation of the receiver sites. In addition to separation, topographical differences of a kind which would affect the directional response of the antennae differently would influence the results.

The improvement afforded by wide-spaced diversity may justify its use on some important systems.

3. Time diversity of voice operation

The new time-diversity system for radiotelephone transmissions described below is suitable for push-to-talk type operation, broadcast relay, and other similar services but, since the system introduces a time delay of up to a second, it is not suitable for normal telephone service where almost instantaneous replies are required. The system relies upon the fact that there is appreciable frequency redundancy in speech waves, so that if one frequency segment is lost the other segments will normally carry the intelligence.

The equipment used at the transmitting site separates the speech wave into a number of small frequency bands; for example, the centre frequencies of the filters may be at 360, 570, 900, 1430, 2270, 3600 Hz. The output of the first filter is fed directly to the transmitter, the second filter to a time delay of one-half second, a third filter fed to a time delay of one second, the fourth filter is fed directly to the transmitter, etc. as shown in Fig. 2.

The output of the receiver is fed to similar equipment, but in this case the frequency segments that are not delayed at the transmitter are delayed a full second at the receiver and the frequency segments that are delayed one-half second are delayed an additional one-half second at the receiver and finally the segments that are delayed a full second at the transmitter base are fed undelayed to the combiner network at the receiver. Thus, a natural sounding wave delayed one second results.

The system has three desirable effects:

— if a fade lasts for less than a second, the bulk of the highly redundant speech wave will be received;

— there is a 6 to 7 dB measured reduction in peak level for a constant average level. The reason for this improvement is that the peaks of the voice wave form are reduced relative to the average level. The energy is more evenly distributed because of the time delays;

— the technique provides privacy in that the reception of the signal requires decoding equipment. However, if time delays of 1·5 to 2 s are used, the privacy effect is for all practical purposes eliminated. Experiments with this system indicate that to achieve the reduction in peak-to-average levels a time delay of at least 0·1 s is required. The amount of time delay required for achieving diversity gain is, of course, a function of the fading rate and it would appear that a delay of at least 1 s is desirable if one wishes to achieve a substantial reduction in the effects of fading.

4. Audio-frequency band-splitting combiner for space diversity

In this system a combiner splits each of the two receiver audio-frequency bands into three segments. Each segment is processed through two band-pass filters, a comparator and two amplifiers.

The output signals from the band-pass filters are applied to the amplifiers and also to the comparator circuit. The comparator converts the a.c. input signals into two d.c. voltages of opposite polarity. These voltages are compared on a continuous basis to determine which is the stronger signal.

The comparison output drives a differential control amplifier. The type of variable-gain action obtained prevents any thumps, clicks and transients of the signal applied to the two filters for that segment. However, should the signal at Filter 1 fade by 2 dB or more, compared with the signal at Filter 2, the selected output signal (signal at Filter 2) will be at least 20 dB greater than the weaker signal (signal at Filter 1).

The outputs from the three segments are combined in linear addition to reproduce the audio spectrum. The audio output response is improved over the non-diversity case for any amount of signal fading.

4.1 Doc. III/22 (Federal Republic of Germany), 1966–1969, describes tests carried out over a New York–Frankfurt radiotelephone circuit. In this test, the audio-frequency outputs of two space-diversity receivers were separated by splitting them into five bands 550 Hz wide, by means of the filter units of an ordinary privacy equipment. A switching device selected, from each of the five pairs of corresponding frequency bands, the branch with the greater amplitude. The combined diversity telephone signal was then compared with the by-passed non-diversity outputs from the two receivers. Special care was taken to eliminate the influence of differing characteristics of the two receivers and extension circuits, the selection devices and the tape recorders.

The results of the tests may be summed up as follows:

— for "barely acceptable commercial quality" with dual-diversity reception and the selection of five partial bands, the method reduces the fading probability, or the proportion of fading time in the service period (fading depth $\geqslant 10$ dB below the median value) to about 20% of the value without selection;

— extension to multiple-diversity reception and sub-division into a larger number of partial bands than used in the tests would not appreciably increase efficiency;

— the method leads to a substantial increase in speech fidelity, but to no perceptible increase in intelligibility. It is supposed therefore that the improvement in logatome clarity, which is near the perceptibility threshold, cannot be more than a few per cent;

— the higher the quality of transmission, for instance, as characterized by the articulation index [Fletcher, 1953], the smaller the improvement that can be obtained. It would therefore seem better to use methods which effectively increase the signal-to-noise ratio to momentary speech values (Lincompex, or constant net loss operation).

References

Fletcher, H. [1953] *Speech and hearing*. D. van Nostrand Company, Inc., New York, London.

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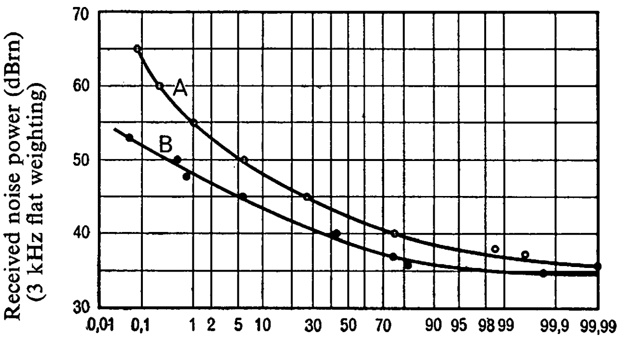
Kahn, L.R. [1962] A time-diversity technique for speech transmission over rapidly fading channels (Echoplex). IRE International Convention Record, Part 8.



Percentage of the time that the noise is
equal to or greater than the ordinate

FIGURE 1

Wide-spaced diversity, 16 430 kHz, 11 to 13 June, 1962.
Receiving stations at Manahawkin and Netcong, N. J.

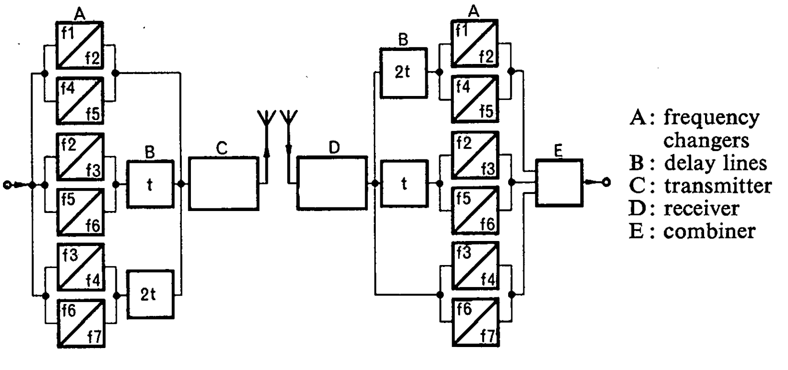


FIGURE 2

Simplified block diagram of Echoplex

REPORT 434-1*

TRANSMISSION CHARACTERISTICS OF HF RADIOTELEPHONE CIRCUITS

(Question 13-1/3)

(1970 - 1974)

1. In view of the difficulty of connecting HF radiotelephone circuits to international automatic exchanges using C.C.I.T.T. signalling code No. 4 or No. 5, the French P.T.T. Administration, convinced of the advantages of semi-automatic operating, developed and brought into use in 1966 semi-automatic dialling devices which are based on the following principles:

A circuit is specially assigned for traffic between OUTGOING country A and INCOMING country B. The information given by the operator in country A—seizing, numerical, clear-forward—is converted into voice-frequency signals by a device placed in the radioterminal centre. The signals are transmitted in this form to the other terminal, where a receiving device restores the outgoing signals and performs the seizing, dialling etc. at the automatic switching equipment in country B, just as a subscriber in that country would do. The operator at A is thus "remote-connected" to the switching system in country B.

The transmitting and receiving devices required can be accommodated in the network connection cabinets at both terminals without any adaptation of these equipments.

This system has proved entirely satisfactory and its use is limited only by the quality of the channel used for the call. It is being introduced on a wide scale by the French Administration.

2. Recommendation 455-1, in answer to Question 13-1/3, describes an improved transmission system for HF radiotelephone circuits (Lincompex). In Doc. 3/2 (United Kingdom), 1970–1974, tests are reported that show that even with Lincompex, satisfactory operation of C.C.I.T.T. signalling system No. 5 is difficult over long-distance HF radio paths, although it might be possible over short paths not subject to selective fading. Interface equipment which would reduce the effects of selective fading and of interference might be designed.

Tests with the signalling system developed by the French Administration described in § 1 have given much more satisfactory results. Tests were carried out with this system and Lincompex through a fading simulator and, later, over a radio link from London to Johannesburg with a return cable circuit. Five-digit test numbers were sent repetitively over the circuit, the sample size being at least 300 calls. In the fading simulator tests, near-end noise was introduced to give specific non-fading signal-to-noise ratios. With a 20 dB signal-to-noise ratio the average success rate was 99·5 per cent for both selective and non-selective fading conditions. When the signal-to-noise ratio was reduced to 15 dB success rates of 96 per cent for selective fading and 97·5 per cent for non-selective fading were obtained. The London–Johannesburg circuit tests showed a success rate of over 98 per cent.

3. Doc. 3/14 (Netherlands), 1970–1974, describes another semi-automatic signalling system which is successfully used over Lincompex HF radio circuits. The operator is connected to a distant exchange via a radio circuit which functions in a similar manner to a d.c. circuit.

Two states, "current" and "no-current" are required to mark the conditions in the transmission of signalling information. The *no-current* state is transmitted as an FSK signal consisting of 100 baud reversals on a centre frequency of 2500 Hz by using a shift of 200 Hz ($f_1 = 2400$ Hz and $f_2 = 2600$ Hz). The *current* state is marked by the absence of signal.

* Adopted unanimously.

Some examples of signalling conditions on the radio circuit are:

No traffic: a "no-current" state is established and is indicated on the radio circuit by the transmission of a FSK signal.

Seizing: which establishes a "current" state and is indicated over the radio circuit by the removal of the FSK signal.

Dialling: a sequence of elements (60 ms) of "no-current" state and elements (40 ms) of "current" state.

Speech period: a "current" state (no FSK signal).

Clear: a "no-current" state (restore FSK signal).

The received signal is fed to an impulse demodulator. A guard circuit is inserted which protects against false operation on speech currents. During idle time, the presence of the control tone and the FSK signal shows that a radio circuit has been established.

The use of the two frequencies 2400 and 2600 Hz permits the application of frequency diversity techniques in the signalling receiver. The modulation rate of 100 bauds in the FSK signal differs sufficiently from the syllabic rhythm of 5 to 15 Hz in speech.

When, during the transmission of signalling information, the level of the Lincompex control tone in the guard circuit drops by more than 30 dB, the process of setting up a circuit is stopped and a "number engaged" tone is transmitted back to the operator.

4. Tests described above suggest that the use of a frequency-modulated sub-carrier could provide an answer to the problem of using C.C.I.T.T. signalling system No. 5 over HF radio circuits. Studies are continuing along these lines.

SECTION 3C: RADIOTELEGRAPHY AND FACSIMILE

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 106-1

VOICE-FREQUENCY TELEGRAPHY ON RADIO CIRCUITS

(1953 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that, when voice-frequency equipment is used on radio circuits at frequencies lower than about 30 MHz, the quality of these circuits will, in general, be insufficient if no means of diversity reception is provided;

(b) that, in the presence of fading, space, polarization or frequency diversity gives comparable improvements in the quality of reception of telegraph signals transmitted over radio channels;

(c) that, for adequate frequency diversity, it appears necessary that the frequencies which are used in combination to obtain this diversity should differ by at least 400 Hz;

(d) that space or polarization diversity needs only half the bandwidth and less power for each telegraph channel, as compared with frequency diversity, but usually requires more equipment;

UNANIMOUSLY RECOMMENDS

1. that, when voice-frequency telegraph systems are used on radio circuits at frequencies lower than about 30 MHz, diversity reception should be used on the individual voice-frequency channels;

2. that, whenever practicable, space or, possibly, polarization diversity should be used in preference to frequency diversity;

3. that, for frequency diversity, the channel frequencies used in combination should have a separation of at least 400 Hz so that adequate diversity effects may be obtained.

RECOMMENDATION 246-3

FREQUENCY-SHIFT KEYING*

(Question 8/3)

(1951 – 1953 – 1956 – 1959 – 1966 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that frequency-shift keying is employed in radiotelegraphy in the fixed service;

(b) that it is desirable to adapt the frequency-shift used to the modulation rate;

(c) that it is desirable to standardize the main operating characteristics of systems employing frequency-shift keying;

(d) that various technical factors influence the choice of operating characteristics in such systems, in particular:

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* For the use of frequency-shift keying in the maritime mobile service, see Appendix 20B (Mar), § (c) of the Radio Regulations.

— economy of bandwidth and the consequent need to control the shape of the transmitted signals,

— signal distortion due to propagation conditions,

— instability of the characteristics of certain transmitter and receiver elements (such as oscillators, filters or discriminators), this instability being one of the reasons for the relatively large shift still employed in some existing types of equipment;

(e) that for synchronous transmissions using limiter-discriminator detection, a modulation index of about 0·8 is desirable for obtaining low bit error rates (see Recommendation 436-1 and Report 198) and that for asynchronous (start-stop) transmissions, a modulation index between 1 and 2 is more appropriate;

(f) that for synchronous transmissions using filter-assessor detection, a sufficiently high value of frequency-shift is desirable to take advantage of frequency diversity effects;

(g) that difficulties can arise from the use of terms "mark" and "space" on teletype circuits and also that the C.C.I.T., at its VIIth Plenary Assembly (1953), issued Recommendation I.4 introducing new terms; these terms have been published by the I.T.U. in the "List of Definitions of Essential Telecommunication Terms", Part I, General Terms, Telephony, Telegraphy, June 1957;

UNANIMOUSLY RECOMMENDS

1. that for frequency-shift systems working on two conditions only (i.e. single channel or time division multiplex systems) and operating between about 3 MHz and 30 MHz, the value of the frequency-shift employed should be the lowest compatible with the maximum modulation rate regularly used, the propagation conditions and the equipment stability;

2. that for services where the transmitting equipment and the receiving equipment are of sufficient high stability* and selectivity, the following values of frequency-shift are preferred for new systems:

Maximum modulation rate		Frequency-shift (Hz)
Synchronous (baud)	Asynchronous (baud)	
—	50	70
100	50 and 75	85
200	100	170
—	200	340

3. that for systems using filter-assessor detection (see Report 345-1) or where the achievement of the necessary stability or receiver selectivity is impractical, the preferred values of frequency-shift are 200 Hz, 340 Hz, 400 Hz** and, for modulation rates above 250 baud, 500 Hz. The values of 140 Hz, 280 Hz and 560 Hz may be used provisionally, but 560 Hz should not be adopted for new systems. The value of the frequency-shift should, if possible, be maintained within ± 3% of its nominal value and, in any case, within ± 10%;

* In the absence of a Recommendation on the stability required for narrow-band frequency-shift keying a provisional value of 12 Hz may be used for the maximum permissible overall frequency error, including modulator, demodulator and translating stages at both ends of the circuit.

** The value 170 Hz is used in the maritime mobile service (see Appendix 20B (Mar), §(c) of the Radio Regulations).

4.* that the following equivalence among the various terms indicating circuit condition be adopted:

(This table is in accordance with C.C.I.T.T. Recommendations U.1 and V.1.)

Frequency of emission	Circuits using teleprinter or punched tape equipment							Circuits using Morse code
	International Telegraph Alphabet No. 2				Emitted 7-unit signal (2)	Data	Telex	
Higher frequency	Space	Start	No perforation	A (1)	B	0	Free line condition	Mark
Lower frequency	Mark	Stop	Perforation	Z (1)	Y	1	Idle circuit condition	Space

(1) on a wire circuit
(2) on a radio channel

RECOMMENDATION 342-2

AUTOMATIC ERROR-CORRECTING SYSTEM FOR TELEGRAPH SIGNALS TRANSMITTED OVER RADIO CIRCUITS

(Study Programme 18A/1)**

(1951 – 1953 – 1956 – 1959 – 1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that it is essential to be able to interconnect terminal start-stop apparatus employing the International Telegraph Alphabet No. 2 by means of radiotelegraph circuits;

(b) that radiotelegraph circuits are required to operate under varying conditions of radio propagation, atmospheric noise and interference, which introduce varying degrees of distortion which may at times exceed the margin of the receiving apparatus;

(c) that, in consequence, the transmission of 5-unit code signals over radio circuits is liable to errors and that such errors are not automatically detectable by the receiving apparatus;

(d) that an effective means of reducing the number of wrongly printed characters is the use of codes, permitting the correction of errors by detecting the errors and automatically causing repetition;

(e) that the method using synchronous transmission and automatic repetition (ARQ), is now well proven;

(f) that it is desirable to permit the correct phase to be established automatically on setting up a circuit;

(g) that certain circumstances can occur which result in a loss of the correct phase relationship between a received signal and the receiving apparatus;

(h) that it is desirable to permit the correct phase relationship to be re-established automatically after such a loss, without causing errors;

(j) that, to avoid mis-routing traffic, it is essential to prevent phasing to a signal which has been unintentionally inverted;

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* When modification of equipment is necessary, it is recognized that it may take some time before the recommendations of these paragraphs can be implemented on circuits between different Administrations.

** This Study Programme replaces Study Programme 5A/III.

(k) that there is sometimes a need to subdivide one or more channels, to provide a number of sub-channels at a proportionately reduced character rate;

(l) that the method of automatically achieving the correct phase relationship between the received signal and the sub-channelling apparatus should be an integral part of the phasing process;

(m) that compatibility with existing equipment, designed in accordance with Recommendation 242, Los Angeles, 1959, is a requirement;

UNANIMOUSLY RECOMMENDS

1. that, when the direct use of a 5-unit code on a radio circuit gives an intolerable error rate and there is a return circuit, a 7-unit ARQ system be employed;

2. when automatic phasing of such a system is required, the 7-unit system, described in Annex I, should be adopted as a preferred system;

3. that equipment, designed in accordance with § 2, should be provided with switching, to permit operation with equipment designed in accordance with Recommendation 242, Los Angeles, 1959.

Note. — Methods in accordance with this Recommendation are described in Doc. III/17, Geneva, 1962.

ANNEX I

1. Table of conversion

TABLE I

Table of code conversion

	International code No. 2	International code No. 3
A	ZZAAA	AAZZAZA
B	ZAAZZ	AAZZAAZ
C	AZZZA	ZAAZZAA
D	ZAAZA	AAZZZAA
E	ZAAAA	AZZZAAA
F	ZAZZA	AAZAAZZ
G	AZAZZ	ZZAAAAZ
H	AAZAZ	ZAZAAZA
I	AZZAA	ZZZAAAA
J	ZZAZA	AZAAAZZ
K	ZZZZA	AAAZAZZ
L	AZAAZ	ZZAAAZA
M	AAZZZ	ZAZAAAZ
N	AAZZA	ZAZAZAA
O	AAAZZ	ZAAAZZA
P	AZZAZ	ZAAZAZA
Q	ZZZAZ	AAAZZAZ
R	AZAZA	ZZAAZAA
S	ZAZAA	AZAZAZA
T	AAAAZ	ZAAAZAZ
U	ZZZAA	AZZAAZA
V	AZZZZ	ZAAZAAZ
W	ZZAAZ	AZAAZAZ
X	ZAZZZ	AAZAZZA
Y	ZAZAZ	AAZAZAZ
Z	ZAAAZ	AZZAAAZ
Carriage return	AAAZA	ZAAAAZZ
Line feed	AZAAA	ZAZZAAA
Figures	ZZAZZ	AZAAZZA
Letters	ZZZZZ	AAAZZZA
Space	AAZAA	ZZAZAAA
Unperforated tape	AAAAA	AAAAZZZ
Signal repetition		AZZAZAA
Signal α		AZAZAAZ
Signal β		AZAZZAA

2. Repetition cycles

2.1 Four characters for normal circuits, which are not subject to excessive propagation time. The cycle should comprise one "signal repetition" and three stored characters.

2.2 Eight characters on circuits for which the four-character repetition cycle is inadequate. The cycle should comprise one "signal repetition", three signals β and four stored characters, or one "signal repetition" and seven stored characters.

3. Channel arrangement

3.1 *Channel A*

3.1.1 For equipment employing a four-character repetition cycle: one character inverted followed by three characters erect. (See Fig. 1*(a)*).

3.1.2 For equipment employing an eight-character repetition cycle: one character inverted followed by seven characters erect. (See Fig. 2*(a)*).

3.2 *Channel B*

3.2.1 For equipment employing a four-character repetition cycle: one character erect followed by three characters inverted. (See Fig. 1*(b)*).

3.2.2 For equipment employing an eight-character repetition cycle: one character erect followed by seven characters inverted. (See Fig. 2*(b)*).

3.3 *Channel C*

As for Channel B (see Figs. 1*(c)* and 2*(c)*).

3.4 *Channel D*

As for Channel A (see Figs. 1*(d)* and 2*(d)*).

3.5 *Order of transmission*

3.5.1 Characters of Channels A and B are transmitted consecutively. (See Figs. 1*(e)* and 2*(e)*).

3.5.2 Elements of Channel C are interleaved with those of Channel A. (See Figs. 1*(g)* and 2*(g)*).

3.5.3 Elements of Channel D are interleaved with those of Channel B. (See Figs. 1*(g)* and 2*(g)*).

3.5.4 In the aggregate signal, A elements precede those of C, and B elements precede those of D. (See Figs. 1*(g)* and 2*(g)*).

3.5.5 The first erect character on A, transmitted after the inverted character on A, is followed by the erect character on B. (See Figs. 1*(e)* and 2*(e)*).

3.5.6 The erect character on C is followed by the inverted character on D. (See Figs. 1*(f)* and 2*(f)*).

3.5.7 The inverted character on A is element-interleaved with the erect character on C. (See Figs. 1*(g)* and 2*(g)*).

4. Sub-channel arrangement

4.1 The character transmission rate of the fundamental sub-channel should be a quarter of the standard character rate.

4.2 Sub-channels should be numbered 1, 2, 3 and 4 consecutively.

4.3 Where a four-character repetition cycle is used, sub-channel 1 should be that sub-channel which has opposite keying polarity to the other three sub-channels of the same main channel. (See Figs. 3*(a)-(d)*).

Where an eight-character repetition cycle is used, sub-channel 1 should be that sub-channel which has alternately erect and inverted keying polarity. (See Figs. 3*(e)-(h)*).

4.4 When sub-channels of half-character rate, or three-quarter-character rate are required, combinations of the fundamental sub-channels should be arranged as shown in Table II.

TABLE II

Proportion of full-channel character rate	Combination of fundamental sub-channels
(1) quarter (2) quarter (3) half	No. 1 No. 3 Nos. 2 and 4
(1) half (2) half	Nos. 1 and 3 Nos. 2 and 4
(1) quarter (2) three-quarters	No. 1 Nos. 2, 3 and 4

5. Designation of aggregate signal

To assist in identifying the signal condition when applying the aggregate telegraph signal to modulate the radio channel, the following designation for the aggregate signal should be used:

TABLE III

Seven-unit code condition	Aggregate signal condition	
	Erect character	Inverted character
A	B	Y
Z	Y	B

6. Diagrams

As a result of the characteristics specified in §§ 2, 3 and 4 of this Annex, the transmission of characters will be as shown in Figs. 1, 2 and 3.

7. Automatic phasing

7.1 Automatic phasing should normally be used. It should be initiated either:

7.1.1 after a waiting period during which cycling due to the receipt of errors has occurred continuously on both channels of a 2-channel system, or on at least two main channels of a 4-channel system;

7.1.2 after equal counts of A and Z elements have been made over at least two consecutive system cycles whilst continuous cycling due to the receipt of errors is occurring on all main channels;

7.2 when the slave station is phasing, it should transmit in each channel, in place of the "signal repetition", a 7-element signal in which all 7 elements are of the same polarity, all other characters in the repetition cycle being transmitted unchanged*.

* Existing systems without this facility need not be modified because compatibility is assured.

8. C.C.I.T.T. Recommendation S.12 recommends that the interval between the beginning of successive start elements of the signals transmitted into the landline network be 145 5/6 ms. Therefore, the duration of the transmission cycle on the radio circuit and also the modulation rate must be chosen correspondingly, if connection to the network is required.

Practical values for the modulation rate in bauds and the duration of the transmission cycle, which enable synchronization to be effected by using a single oscillator for three cases, are shown in Table IV.

TABLE IV

Transmission cycle (ms)	Modulation rate (bauds)	
	2-channel operation	4-channel operation
145 5/6	96	192
This is the preferred standard. See C.C.I.T.T. Recommendations S.12 and S.13		
163 1/3	85 5/7	171 3/7
140	100	200

The transmission cycle of 145 5/6 ms is the preferred standard for connection to 50-baud networks.

The transmission cycle of 163 1/3 ms is suitable for connecting to 45-baud networks.

The transmission cycle of 140 ms is suitable for radio circuits without direct connection to a landline network.

The tolerance on the frequency of the master oscillator, controlling the timing of each terminal equipment, should be $\pm 1 \times 10^{-6}$.

9. C.C.I.T.T. Recommendation U.20 gives the signalling conditions to be used when telex communication is to be established by means of such radio circuits:

9.1 for circuits on switched telegraph networks, the conditions of C.C.I.T.T. Recommendation U.20 should apply;

9.2 for point-to-point circuits, Administrations may adopt, at the terminal equipment under their jurisdiction, their own method of stopping and starting the motors of the receiving machines, based on C.C.I.T.T. Recommendation S.7;

9.3 signal β should normally be transmitted to indicate the idle circuit condition. However, for signalling purposes, the signals α and β may be employed.

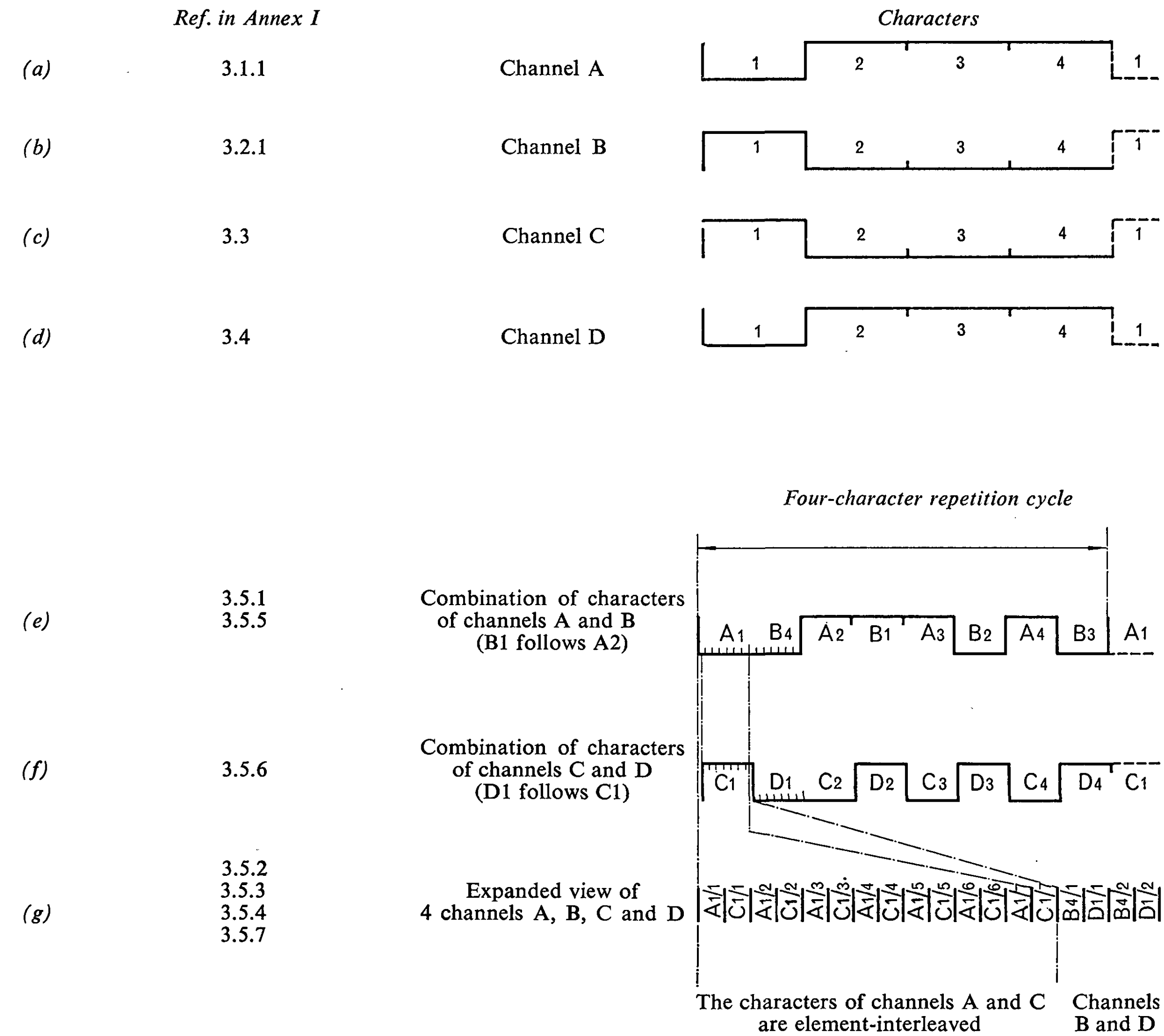


FIGURE 1

Channel arrangement for a four-character repetition cycle

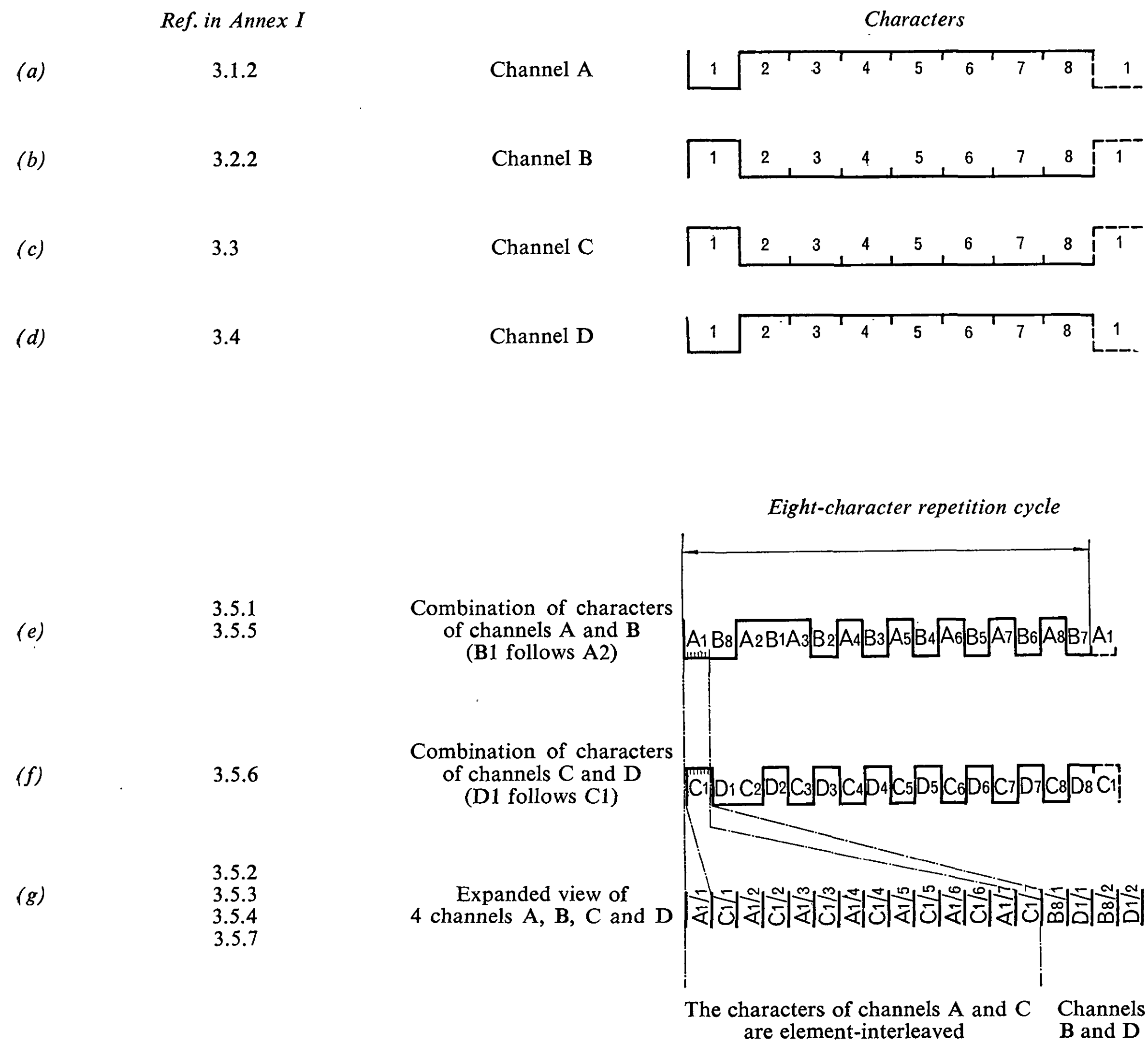


FIGURE 2

Channel arrangement for an eight-character repetition cycle

Ref. in Annex I

(a)	3.1.1, 4.2, 4.3
(b)	3.2.1, 4.2, 4.3
(c)	3.3, 4.2, 4.3
(d)	3.4, 4.2, 4.3
(e)	3.1.2, 4.2, 4.3
(f)	3.2.2, 4.2, 4.3
(g)	3.3, 4.2, 4.3
(h)	3.4, 4.2, 4.3

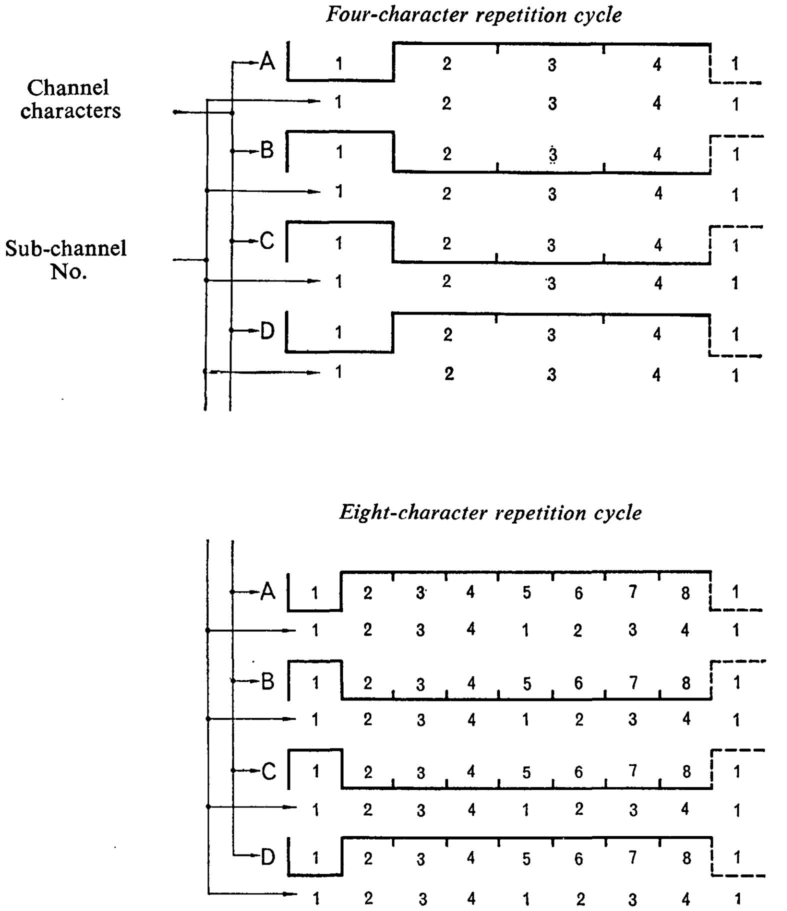


FIGURE 3

Sub-channelling arrangements for a four- and an eight-character repetition cycle

ANNEX II

TERMS RELATED TO ARQ-SYSTEMS*

Part 1

1. Signal repetition RQ-signal Signal Roman one	— the seven unit combination (AZZAZAA) which is used to request a repetition (RQ-signal) or to precede a re-transmission (BQ-signal);
2. Repetition cycle	— the sequence of characters, the number of which is determined by the *loop time-delay of the system*, to provide automatic repetition of information;
3. RQ-cycle Request cycle	— the *repetition cycle* transmitted by ARQ-apparatus at the detection of a mutilation;
4. BQ-cycle Response cycle	— the *repetition cycle* transmitted by ARQ-apparatus at a request for repetition;

* The twenty-three terms and definitions in Part 1 of this list have been studied by a joint Working Party of Study Groups III and XIV during the Xth Plenary Assembly of the C.C.I.R., Geneva, 1963, as a provisional contribution (see § 2 of the Annex to Resolution 21-1 (1966) to the "List of Definitions of Essential Telecommunication Terms" (Part II to be published later).
The other terms and definitions contained in Part 2 of this list, which are of more general application, are given as information pending examination by the C.C.I.T.T.

5.	Non-print cycle	— the interval at the ARQ-receiver, initiated by the detection of a mutilation or a *signal repetition*, that has the same duration as a *repetition cycle* and during which all signals received are prevented from being printed;
6.	Gated RQ	— a procedure in which a check is made for the presence of a signal repetition during a *non-print cycle;*
7.	Tested RQ	— a procedure in which a check is made for the presence of a *signal repetition* and a check is made for the ratio A/Z on all characters received after the *signal repetition* within the *non-print cycle;*
8.	Tested repetition cycle	— a *non-print cycle* in which a check is made for the presence of a *signal repetition* and for the correct ratio A/Z of all the characters received;
9.	Cycling	— the condition that a repetition procedure is in progress;
10.	Marking pattern	— a specific pattern of polarity inversions applied to characters in an *aggregate signal;*
11.	Marked cycle System cycle	— a cycle consisting of a specific character *marking pattern*, that is continuously repeated and has the duration of a *repetition cycle;*
12.	System phase Marked cycle phase	— the condition in which the *marking pattern* of the local timing coincides with the *marked cycle* of the received signal;
13.	Phasing Phase hunting	— the condition in which a station is hunting for *character phase* or *system phase;*
14.	Manual phasing	— *phasing* by manual action only;
15.	Semi-automatic phasing	— *phasing* completed automatically after manual initiation;
16.	Automatic phasing	— *phasing*, initiated and completed automatically after automatic detection of "out-of-phase";
17.	Master station	— the station, the transmitting equipment of which is directly driven by a master oscillator but the receiver timing of which is normally synchronized to the incoming signal;
18.	Slave station	— the station, the receiver and transmitter timing of which are both synchronized to the received signal;
19.	End-to-end time delay	— the delay between the output terminals of an ARQ-transmitter and the input terminals of the ARQ-receiver at the other end (this is the sum of radio and line circuit delays in one direction of a route);
20.	Loop time-delay of a route	— the sum of the end-to-end delays in the send and return directions of a route;
21.	Master station delay	— the period between the beginning of reception of a *signal repetition* at the ARQ-input terminals at the *master station* and the beginning of transmission of the replying *signal repetition* at that station. *Note.* — This comprises the "scanning" and equipment delays and a further delay which, when added to the *loop time-delay of the system*, produces an integral multiple of the *character cycle* duration;

22. Slave station delay — the period between the beginning of reception of a *signal repetition* at the ARQ-input terminals at the *slave station* and the beginning of transmission of the replying *signal repetition* at that station.

Note. — This comprises "scanning" and equipment delays and a "pre-set" delay between the receiver and the transmitter;

23. Loop time-delay of a system (as seen from the master station) — the sum of the *loop time-delay of the route* and the *slave station delay*, measured under working conditions.

Part 2

(a) Aggregate signal — the synchronous signal produced by combining the channel signals;

(b) Balanced aggregate signal — an aggregate signal containing equal numbers of elements of each polarity;

(c) Character cycle — the period in which each channel of a time-division multiplex transmission has completed one character in the synchronous path;

(d) Element synchronism — in synchronous systems:
the condition in which an element of the local timing coincides completely with an element of the received signal;

(e) Synchronizing — the action of adjustment of element synchronism;

(f) Phase relationship — in synchronous systems:
the relative phase of receiving apparatus and incoming signals, or receiving and sending apparatus;

(g) Character phase — the condition in which a *character cycle* of the local timing coincides completely with a character cycle of the received signal.

Note. — Under these conditions, a character of the aggregate signal transmitted on a particular channel is received on the correct channel.

(h) Sub-channel — a teleprinter channel which is allocated a quarter rate of a normal channel, or multiples thereof;

(j) Sub-channel phase — the condition in which a character transmitted on a particular sub-channel is received on the correct sub-channel;

(k) Transposition — Add to definition 33.25 of the I.T.U. "List of Definitions..." (Part I):

"Transpositions may be regarded as of first or higher order according to the number of interchanges occurring within a character."

RECOMMENDATION 343-1

FACSIMILE TRANSMISSION OF METEOROLOGICAL CHARTS OVER RADIO CIRCUITS

(1956 – 1959 – 1963 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that increasing use is being made of facsimile telegraphy for the transmission of meteorological charts for reception on direct-recording apparatus;

(b) that it is desirable to standardize certain characteristics of the radio circuits for this purpose;

UNANIMOUSLY RECOMMENDS

1. that, when frequency modulation of the sub-carrier is employed for the facsimile transmission of meteorological charts over radio circuits, the following characteristics should be used:

centre frequency	1900 Hz
frequency corresponding to black	1500 Hz
frequency corresponding to white	2300 Hz;

2. that, when direct frequency modulation is employed on radio circuits, the following characteristics should be used:

2.1 *HF (decametric) circuits*

centre frequency (corresponding to the assigned frequency)	f_0,
frequency corresponding to black	f_0 – 400 Hz,
frequency corresponding to white	f_0 +400 Hz;

2.2 *LF (kilometric) circuits*

centre frequency (corresponding to the assigned frequency)	f_0,
frequency corresponding to black	f_0 – 150 Hz,
frequency corresponding to white	f_0 +150 Hz;

3. that this Recommendation should be considered as an answer to Question 232, the study of which is hereby terminated.

RECOMMENDATION 344-2

STANDARDIZATION OF PHOTOTELEGRAPH SYSTEMS FOR USE ON COMBINED RADIO AND METALLIC CIRCUITS

(1948 – 1953 – 1956 – 1959 – 1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that to facilitate interworking, it is desirable to standardize the characteristics of systems employed for phototelegraph transmission over long-distance HF (decametric) circuits;

(b) that it is desirable to standardize certain characteristics of these systems in such a way as to make them equally suitable for transmission over metallic circuits;

(c) that the transmission system using direct amplitude modulation is generally unsatisfactory over HF (decametric) radio circuits, because of the intolerable fading ratio usually encountered;

(d) that the system of sub-carrier frequency modulation has proved satisfactory, but requires standardization in respect of the centre frequency and shift frequencies, taking into account the values of the picture-modulation frequencies to be transmitted;

(e) that, when a direct frequency-modulation system is employed, the terminal equipment normally used for a sub-carrier modulation system should be usable without serious modifications;

(f) that, taking into account the degree of distortion that is tolerable, the effect of multipath echoes on long-distance HF (decametric) radio circuits normally limits the maximum admissible picture-modulation frequency to approximately 600 Hz;

(g) that Recommendations M.88, T.1, T.11, T.12, T.15 and T.20 of the C.C.I.T.T. give standards for phototelegraph systems;

UNANIMOUSLY RECOMMENDS

1. that over the radio path:

1.1 the preferred method of transmission of half-tone pictures is by sub-carrier frequency modulation, of a single-sideband or independent-sideband emission with reduced carrier. The following characteristics should therefore be used:

centre frequency	1900 Hz,
frequency corresponding to white	1500 Hz,
frequency corresponding to black	2300 Hz;

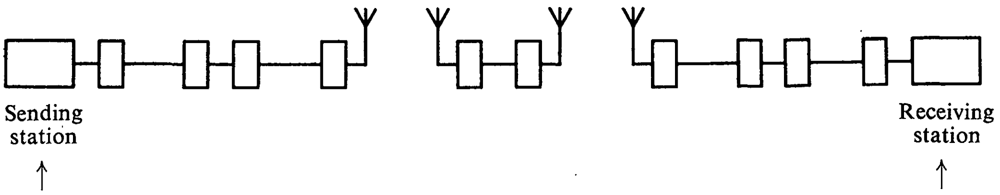
(The frequency 1500 Hz is also used for the phasing signal);

1.2 when a direct frequency-modulation system is employed, the following characteristics should be used:

centre frequency (corresponding to the assigned frequency)	f_0,
frequency corresponding to white	f_0 – 400 Hz,
frequency corresponding to black	f_0 +400 Hz;

(The frequency f_0 – 400 Hz is also used for the phasing signal);

1.3 that the frequency tolerances on each of the various sections of a combined radio and metallic circuit should be no greater than those proposed by the C.C.I.T.T. (see Annex V to Doc. III/3, 1963–1966) as shown in Fig. 1, which gives the composition of a very long circuit of this type:



Frequency tolerances (Hz) for short-term (1 s)

8 2 2 8 2 8 2 2

Frequency tolerances (Hz) for long-term (15 min)

16 2 2 16 2 16 2 2

FIGURE 1

If it is assumed that these deviations are distributed at random and if we take the standard deviation, we shall obtain the values 15 and 28 Hz respectively, which are not harmful for satisfactory reception, since C.C.I.T.T. Recommendation T. 1 admits a maximum deviation of 32 Hz;

2. that, for the present, the following alternative characteristics should be used:

	a	*b*
index of cooperation	352	264
speed of rotation of drum in r.p.m.	60	90/45

In due course, characteristic *b* will become obsolete;

3. that frequency modulation or amplitude modulation may be used in the metallic portions of the combined circuit. When conversion from amplitude modulation to frequency modulation (or vice versa) is required, the conversion should be such that the deviation of the frequency-modulated carrier varies linearly with the amplitude of the amplitude-modulated carrier.

The standards for both amplitude-modulated and frequency-modulated transmissions will be found in C.C.I.T.T. Recommendations T. 1, T. 11 and T. 15.

Each Administration will decide, when the question arises, on the location of modulation converters. They may be placed either at the terminal phototelegraph station or at the control station associated with the radio station, to facilitate speech on the circuit used for phototelegraphy, if the radio channel will carry speech.

Note. — The provisions of § 2 do not imply the imposition of such standards on private users who use their own equipment for the transmission of pictures over private circuits.

RECOMMENDATION 345

TELEGRAPH DISTORTION

(1953 – 1956 – 1959 – 1963)

The C.C.I.R.,

CONSIDERING

that the definitions applying to telegraph distortion and to the mutilation of telegraphic signals, which appear in Section 33, Part I, of the List of Definitions of Essential Telecommunication Terms, published by the International Telecommunication Union, give an answer to Question 18, which required a general definition of telegraph distortion capable of being usefully applied to the cause of radiotelegraphy;

UNANIMOUSLY RECOMMENDS

that the following definitions, contained in Section 33 of the above-mentioned List of Definitions of Essential Telecommunication Terms, should be applied to radiotelegraphy:

Perfect modulation (or restitution) (Definition 33.01 of the List)

Modulation (or restitution) such that all the significant intervals are associated with correct significant conditions and conform accurately to their theoretical durations.

Incorrect modulation (or restitution)
Defective modulation (or restitution) } (Definition 33.03 of the List)

Modulation (or restitution) containing one or more elements, the significant condition of which differs from that corresponding to the kind prescribed by the code.

Telegraph distortion (of a modulation or a restitution) (Definition 33.04 of the List)

(a) A modulation (or restitution) suffers from telegraph distortion, when the significant intervals have not all exactly their theoretical durations.

(b) A modulation (or restitution) is affected by telegraph distortion, when significant instants do not coincide with the corresponding theoretical instants.

Transmitter distortion (Definition 33.059 of the 1st Supplement to the List)

A signal transmitted by an apparatus (or a signal at the output of a local line with its termination) is affected by telegraph distortion, when the significant intervals of this signal have not exactly their theoretical durations.

Degree of individual distortion of a particular significant instant (of a modulation or of a restitution) (Definition 33.06 of the List)

Ratio to the unit interval of the displacement, expressed algebraically, of this significant instant from an ideal instant.

This displacement is considered positive when the significant instant occurs after the ideal instant.

The degree of individual distortion is usually expressed as a percentage.

Degree of isochronous distortion (Definition 33.07 of the 1st Supplement to the List)

(a) Ratio to the unit interval of the maximum measured difference, irrespective of sign, between the actual and the theoretical intervals separating any two significant instants of modulation (or of restitution), these instants being not necessarily consecutive.

(b) Algebraical difference between the highest and lowest value of individual distortion affecting the significant instants of an isochronous modulation. (The difference is independent of the choice of the reference ideal instant.)

The degree of distortion (of an isochronous modulation or restitution) is usually expressed as a percentage.

Note. — The result of the measurement should be completed by an indication of the period, usually limited, of the observation.

For a prolonged modulation (or restitution), it will be appropriate to consider the probability that an assigned value of the degree of distortion will be exceeded.

Degree of start-stop distortion (Definition 33.08 of the 1st Supplement to the List)

(a) Ratio to the unit interval of the maximum measured difference, irrespective of sign, between the actual and theoretical intervals separating any significant instant of modulation (or of restitution) from the significant instant of the start element immediately preceding it.

(b) The highest absolute value of individual distortion affecting the significant instants of a start-stop modulation.

The degree of distortion of a start-stop modulation (or restitution) is usually expressed as a percentage.

Note 1. — See Note to Definition 33.07.

Note 2. — Distinction can be made between the degree of *late* (or positive) distortion and the degree of *early* (or negative) distortion.

Degree of gross start-stop distortion (Definition 33.09 of the List)

Degree of distortion determined when the unit interval and the theoretical intervals assumed are exactly those appropriate to the standardized modulation rate.

Note. — See Note to Definition 33.07.

Degree of synchronous start-stop distortion (i.e. at the actual mean modulation rate) (Definition 33.10 of the List)

Degree of distortion determined when the unit interval and the theoretical intervals assumed are those appropriate to the actual mean rate of modulation (or of restitution).

Note 1. — See Note to Definition 33.07.

Note 2. — For the determination of the actual mean modulation rate, account is only taken of those significant instants of modulation (or restitution), which correspond to a change of condition in the same sense as that occurring at the beginning of the start element.

Characteristic distortion (Definition 33.15 of the List)

Distortion caused by transients which, as a result of the modulation, are present in the transmission channel and depend on its transmission qualities.

Fortuitous distortion (Definition 33.16 of the List)

Distortion resulting from causes generally subject to random laws (accidental irregularities in the operation of the apparatus and of the moving parts, disturbances affecting the transmission channel, etc.).

Bias distortion, asymmetrical distortion (Definition 33.17 of the List)

Distortion affecting a two-condition (or binary) modulation (or restitution), in which all the significant intervals corresponding to one of the two significant conditions have longer or shorter durations than the corresponding theoretical durations.

Character error rate of a telegraph communication (Definition 33.19 of the 1st Supplement to the List)

Ratio of the number of alphabetic signals of a message incorrectly received (after automatic translation, where applicable), to the number of alphabetic signals of the message, the keying being correct.

Note 1. — A telegraph communication may have a different error rate for the two directions of transmission.

Note 2. — The notion of character error rate could be applied to any operation taking place in a telegraph communication (e.g. keying, translation, etc.).

Note 3. — The statement of the error rate will be accompanied by that of the time interval, generally limited, during which the observation was made. For a communication established for a sufficiently long time, the probability of exceeding an assigned value of error rate could be considered.

Note 4. — Faulty translation, resulting from a previous error in functional control (such as shift, line feed, synchronism, etc.), is not counted in calculating a character error rate; in such a case, the error in the functional control signal is alone counted and is counted only once.

Element error rate (Doc. 203, Geneva, 1963)*

The ratio of the number of unit elements incorrectly received to the total number of unit elements sent.

Efficiency factor in time (of a telegraph communication with automatic repetition for the correction of errors) (Definition 33.23 of the List).

Ratio of the time necessary to transmit a text automatically without repetition, at a specified modulation rate, to the time actually taken to receive the same text with a given error rate.

Note 1. — The whole of the apparatus comprising the communication is assumed to be in the normal conditions of adjustment and operation.

Note 2. — A telegraph communication may have a different efficiency factor in time for the two directions of transmission.

Note 3. — The actual conditions in which the measurement is made should be specified, in particular the duration of the measurement.

Mutilation (Definition 33.24 of the List)

A transmission defect in which a signal element becomes changed from one significant condition to another.

Transposition (Definition 33.25 of the List) (See also Annex II, Part 2, definition *k* of Recommendation 342-2)

A transmission defect in which, during one character period, one or more signal elements are changed from one significant condition to the other, and an equal number of elements are changed in the opposite sense.

RECOMMENDATION 346-1

FOUR-FREQUENCY DIPLEX SYSTEMS

(Question 8/3)

(1956 – 1959 – 1963 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that there are in use, in the fixed radiotelegraph services operating between 2 MHz and 27 MHz, four-frequency diplex (or twinplex) systems, in which each of four frequencies is used to transmit one of the four possible combinations of signals corresponding to two telegraph channels, it being understood that either one, or both of the two telegraph channels may be sub-channelled by time-division methods and that the use of such systems may be extended;

* *Note by the C.C.I.R. Secretariat.* — This term is now defined in the 2nd supplement to the List (Definition 52.28): The ratio of the number of elements incorrectly received to the total number of elements sent.

(b) that it is desirable to standardize the main characteristics of four-frequency diplex systems;

(c) that it may sometimes be necessary to employ the same radio transmitter to work with more than one receiving station;

(d) that circuit interruptions should be reduced to a minimum, by avoiding frequent changes of the spacing between adjacent frequencies and of the correspondence between the frequencies and the significant conditions of the channels;

(e) that various technical factors influence the choice of operating characteristics in such systems, in particular:

— the economy of bandwidth and the consequent need to control the shape of the transmitted signals;

— that a relatively wide spacing between adjacent frequencies may be necessary for high telegraph speeds;

— the signal distortion due to propagation conditions;

— the instability of the characteristics of certain receiver and transmitter elements such as oscillators, filters or discriminators;

(f) that many existing four-frequency diplex systems each use one of four values of spacing between adjacent frequencies with corresponding telegraph speeds;

(g) that it is desirable to use only one coding system, the simpler the better;

UNANIMOUSLY RECOMMENDS

1. that the following preferred values should be adopted for the spacing between adjacent frequencies:

Spacing between adjacent frequencies (Hz)	Nominal telegraph speed of each channel (bauds)
1000	over 300
500(1)	200 to 300
400(1)	100 to 200
200(1)	200(2)

(1) Lower telegraph speeds may be used with these spacings at present.
(2) Synchronous operation with phase-locked channels.

2. that the following system of coding be adopted*:

Frequency of emission	Channel 1			Channel 2		
	Tele-printer	ARQ aggregate	Morse	Tele-printer	ARQ aggregate	Morse
f_4 (highest frequency)	A	B	Mark	A	B	Mark
f_3	A	B	Mark	Z	Y	Space
f_2	Z	Y	Space	A	B	Mark
f_1 (lowest frequency)	Z	Y	Space	Z	Y	Space

* When modification to equipment is required, it is recognized that it may take some time before the systems of coding indicated in this paragraph can be implemented on circuits between different Administrations.

where f_1, f_2, f_3, f_4 designate the frequencies of the emissions, the spacings between adjacent frequencies $(f_4 - f_3)$ $(f_3 - f_2)$ $(f_2 - f_1)$ being equal,

A represents the start signal of the teleprinter,

Z represents the stop signal of the teleprinter;

3. that the value of the frequency separation between adjacent frequencies employed should be the lowest of the preferred values compatible with the maximum telegraph speeds regularly used, the propagation conditions and the equipment stability;

4. that, when the two channels are not synchronized, it is desirable to limit the maximum rate of change of frequency to minimize the bandwidth of the emission.

RECOMMENDATION 347

CLASSIFICATION OF MULTI-CHANNEL RADIOTELEGRAPH SYSTEMS FOR LONG-RANGE CIRCUITS OPERATING AT FREQUENCIES BELOW ABOUT 30 MHz AND THE DESIGNATION OF THE CHANNELS IN THESE SYSTEMS

(1956 – 1959 – 1963)

The C.C.I.R.,

CONSIDERING

(a) that there exists a large number of long-range multi-channel radiotelegraph systems using frequencies below about 30 MHz and that it is desirable to classify them in categories;

(b) that the lack of uniformity in the arrangement and designation of the channels in these systems, may give rise to certain difficulties when one transmitting station has to work with several receiving stations;

(c) that the increasing use of multi-channel telegraph systems makes it desirable to adopt a uniform designation of channels in such systems;

UNANIMOUSLY RECOMMENDS

1. that the systems should be classified and the different categories designated by letters, as follows:

1.1 *Time-division multiplex systems:* capital letter T (for example, synchronous systems, such as Baudot, RCA and TOR multiplex and double-current cable code);

1.2 *Frequency-division multiplex systems*

1.2.1 Systems with *constant* frequency arrangements of significant conditions: capital letter U (for example: voice-frequency multiplex with frequency-shift);

1.2.2 Systems with *variable* frequency arrangements of significant conditions: capital letter V (for example: four-frequency diplex);

1.3 *Multi-channel systems using a combination of these processes*

1.3.1 Frequency-division systems, with constant frequency arrangement, combined with a time-division multiplex system 1.3.2 Four-frequency diplex system, combined with a time-division multiplex system	combination of the above-mentioned letters (always beginning with the frequency-division letters U or V);

2. when a multi-channel telegraph signal is applied to a multi-channel telephone transmitter, the designation of the telephone channel should come first in the sequence and should be in accordance with Recommendation 348-2;

3. when a multi-channel telegraph signal is applied to an independent-sideband transmitter used solely for telegraphy, the designation of the sideband should come first in the sequence. The letter H should denote the upper sideband, and the letter L the lower sideband;

4. that in time-division systems, the telegraph channels should be designated by capital letters A, B, C, D, etc.; for sub-division, the sub-channels should be designated by A1, A2, A3, A4, B1, B2, B3, B4, etc.;

5. that in frequency-division systems, the telegraph channels should be designated by figures;

6. that in a combination of multi-channel processes, the telegraph channels should be designated by a letter and figure sequence.

For example;

when using a frequency-division system with constant frequency arrangement of significant conditions (letter U), and modulating the 3rd channel of this latter system with a time-division multiplex (letter T), channel B of this latter system would be indicated by U3TB;

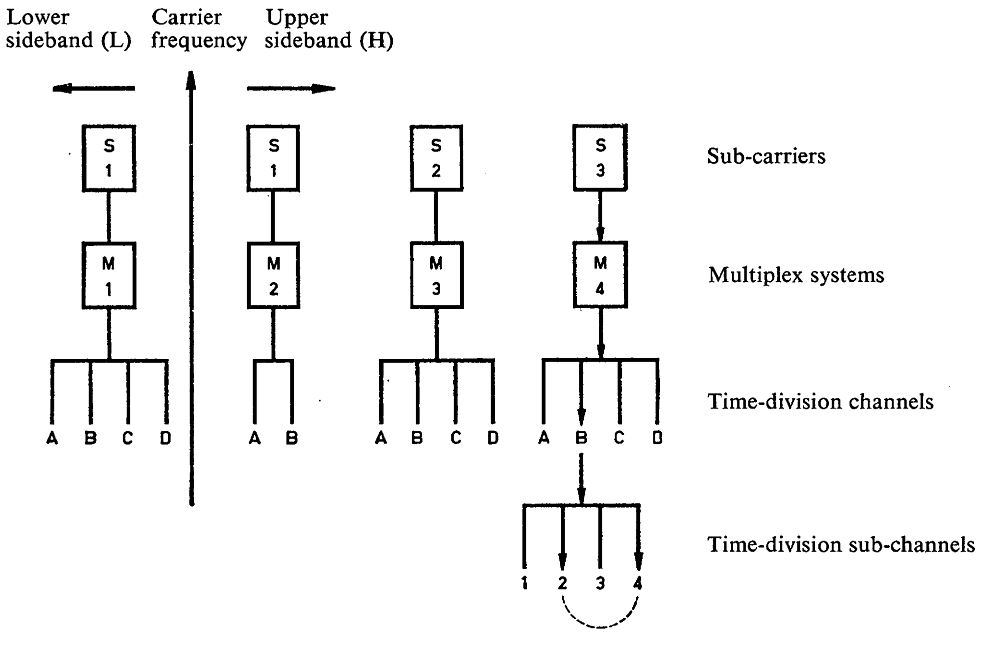
where channel B of the time-division system is sub-divided and sub-channel 2 is in use, the designation would be U3TB2;

if the above-mentioned system is applied to channel B of an independent-sideband telephone transmitter, the corresponding designation would be BU3TB or BU3TB2;

if the above-mentioned system is applied to the upper sideband of an independent-sideband multi-channel transmitter used solely for telegraphy, the corresponding designation would be HU3TB or HU3TB2;

where additional information is required, the multiplex system may be identified by a number inserted between the letters T and B, and where two sub-channels (quarter-channels) are linked together to form a half-speed sub-channel (half-channel), each quarter-speed sub-channel component may be designated by the use of numbers separated by an oblique stroke. The full designation HU3T4B2/4 would be applicable to the arrangement shown diagrammatically by the arrows on the right of the figure below;

in established communication networks, where the sub-carrier, multiplex system, channel and sub-channel arrangements are mutually known to the station management at each end of the circuit, it shall be permissible to shorten the full designation HU3T4B2/4 above, beginning at the first letter or number which is of major significance for identification purposes. For example, in the given instance 4B2/4 will identify the specific area illustrated by the arrows to the right of the figure below.



Multi-channel independent-sideband radiotelegraph transmitter

Note. — Sub-carriers are numbered sequentially in both upper and lower sidebands, starting with the number 1, adjacent to the carrier (radiated or suppressed).

RECOMMENDATION 436-1

ARRANGEMENT OF VOICE-FREQUENCY TELEGRAPH CHANNELS WORKING AT A MODULATION RATE OF ABOUT 100 BAUDS OVER HF RADIO CIRCUITS

(Study Programme 17A-1/3)

(1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that lack of standardization in the arrangement of channels for voice-frequency multi-channel telegraph systems working over HF radio circuits can give rise to difficulties when setting up such systems;

(b) that it is necessary to use the radio-frequency spectrum to the best advantage in the interests of both spectrum economy and circuit efficiency;

(c) that frequency-shift systems are in use on many routes;

(d) that the frequency-exchange method of operation is in use on long routes suffering from severe multipath distortion;

(e) that on such systems, radiotelegraph channels which operate synchronously at a modulation rate of 96 bauds and employ automatic error correction are being increasingly used;

UNANIMOUSLY RECOMMENDS

1. that the channel arrangement shown in Table I be preferred for voice-frequency multi-channel frequency-shift systems operating at a modulation rate of approximately 100 bauds over HF radio circuits;

2. that for frequency-exchange systems, the central frequencies of Table I should be used, and should be paired in the manner found to be best suited to the propagation conditions of the route. (A typical arrangement would take alternate pairs giving 340 Hz between tones.)

Note. — Theoretical work in Japan indicates an optimum frequency-shift of 0·8 B (Hz), where B is the modulation rate in bauds. This would lead to a required minimum bandwidth (at the –3 dB points) of B (Hz). Laboratory experiments and measurements on the synchronous ARQ circuit Frankfurt–Osaka support these conclusions.

TABLE I*

Central frequencies of voice-frequency-shift telegraph channels with a channel separation of 170 Hz and a modulation index of about 0·8

(Frequency-shift: ± 42·5 Hz or ± 40 Hz)

Channel position	Central frequency (Hz)	Channel position	Central frequency (Hz)
1	425	8	1615
2	595	9	1785
3	765	10	1955
4	935	11	2125
5	1105	12	2295
6	1275	13	2465
7	1445	14	2635
		15	2805

RECOMMENDATION 456

DATA TRANSMISSION AT 1200/600 BIT/S OVER HF CIRCUITS WHEN USING MULTI-CHANNEL VOICE-FREQUENCY TELEGRAPH SYSTEMS AND FREQUENCY-SHIFT KEYING

(1970)

The C.C.I.R.,

CONSIDERING

(a) that the effects of the random variations and disturbances in the HF propagation medium, in particular the effects of multipath distortion, in general preclude the use of serial transmission of binary data at rates of 1200 or 600 bit/s;

(b) that voice-frequency multi-channel frequency-shift systems that operate synchronously at a modulation rate of approximately 100 bauds are in widespread use over HF circuits;

(c) that such systems in effect provide an aggregate capacity of up to 1500 bit/s;

(d) that such systems, therefore, are suitable, and in fact are being used for data transmission at the standard data rates of 1200 and 600 bit/s;

* See C.C.I.T.T. Recommendation R.70 bis.

(e) that the presence of multiplexer and demultiplexer or of land lines in the complete circuit may introduce envelope delay distortion, this distortion being most severe for the lowest and highest channels of a multi-channel voice-frequency frequency-shift system;

UNANIMOUSLY RECOMMENDS

1. that for data transmission at binary data rates of 1200 or 600 bit/s using frequency-division multiplex frequency-shift systems, the system described in the Annex be preferred;

Note. — By agreement between Administrations, the use of systems with a different number of channels and other channel spacings and modulation rates, for data transmission at 1200/600 bit/s, is allowed.

2. that channel spacing and central frequencies of the channels of the frequency-shift system should be in accordance with Table I of Recommendation 436-1;

3. that channels 3 to 14 inclusive of Table I of Recommendation 436-1 should be used for the transmission of the data.

ANNEX

1. Description of system

To avoid excessive multipath distortion, which would result when higher speed binary data streams are directly transmitted in serial form, the incoming-bit stream is converted into a number of relatively low-speed streams, which are transmitted simultaneously in parallel and recombined into a single serial data output at the receiving terminal.

In this way, the modulation rate of the channels transmitted over the HF circuit can be kept to an acceptable value.

A block diagram of the 1200 bit/s system is shown in Fig. 1.

2. Serial-to-parallel converter, transmission at 1200 bit/s

At the transmit side, the 1200 bit/s incoming-data stream is fed to a 12-bit shift register. At 12-bit intervals (i.e. at 10 ms intervals) the content of this register is transferred in parallel to a 12-bit storage register, the output of which is connected to 12 parallel channels of the multi-channel frequency-shift system.

Bit synchronization for the shift register may be:

2.1 extracted from the transitions of the data stream, provided the data stream is not expected to have excessive intervals during which no transitions occur (i.e. steady "1", or steady "0" condition);

2.2 obtained from a bit synchronizing signal from the data source, if available;

2.3 generated by an internal clock, in which case a synchronizing output is fed back to the data source.

The parallel transfer pulses are obtained from the bit synchronizing signal through a digital division process. If required, this frame synchronizing information may be transmitted over an additional channel of the frequency-shift system.

3. Channel arrangement, transmission at 1200 bit/s

The 12 channels of the frequency-shift system used for the transmission of the data information, each operating at a modulation rate of 100 bauds, shall be channels 3 to 14 inclusive of Table I of Recommendation 436-1; with channel 3 corresponding to the first (in time) bit of each 12-bit sequence, channel 4 to the second bit of this sequence, and so forth. The frequency spectrum occupied by these channels is that portion of the voice-frequency band which is least affected by envelope delay distortion caused by multiplexer and demultiplexer filters or by land lines which may be incorporated between the terminal sites and the HF transmitting and/or receiving sites.

4. Parallel-to-serial converter, transmission at 1200 bit/s

The parallel-to-serial converter at the receiving terminal shall be designed to perform the following functions:

4.1 to provide delay equalization for the 12 individual channels of the frequency-shift system;

4.2 to provide frame synchronization and bit synchronization by means of extracting synchronization information from the data channels (or from the additional frame synchronizing channel, if this is used);

4.3 to sample the outputs of the 12 data channels, store the sampled data in a 12-bit storage register, transfer the stored data to a 12-bit shift register once per frame interval (10 ms) and read out the data in serial form.

A bit synchronizing output terminal shall be provided for synchronization of associated data equipment which may require a separate synchronizing signal.

5. Data transmission at 600 bit/s

For data transmission at 600 bit/s the following modes of operation are optional:

5.1 the use of 6 instead of 12 channels of the frequency-shift system;

5.2 the use of 12 channels of the frequency-shift system with dualling of channels to provide in-band frequency diversity;

5.3 the use of 12 channels of the frequency-shift system and reducing the channel modulation rate from 100 bauds to 50 bauds;

5.4 the use of 12 channels of the frequency-shift system and applying binary coding techniques to provide error correction, error detection or combined error correction/detection.

The option of § 5.1 enables two independent data streams at 600 bit/s to be transmitted in a single 3 kHz voice band. The options of §§ 5.2 and 5.3 provide improved performance (i.e., lower error rate) with little or no additional equipment required, but at the cost of increased bandwidth. Where lowest error rate is required, the use of redundant coding (which may include time-diversity methods) of the option of § 5.4 is preferred.

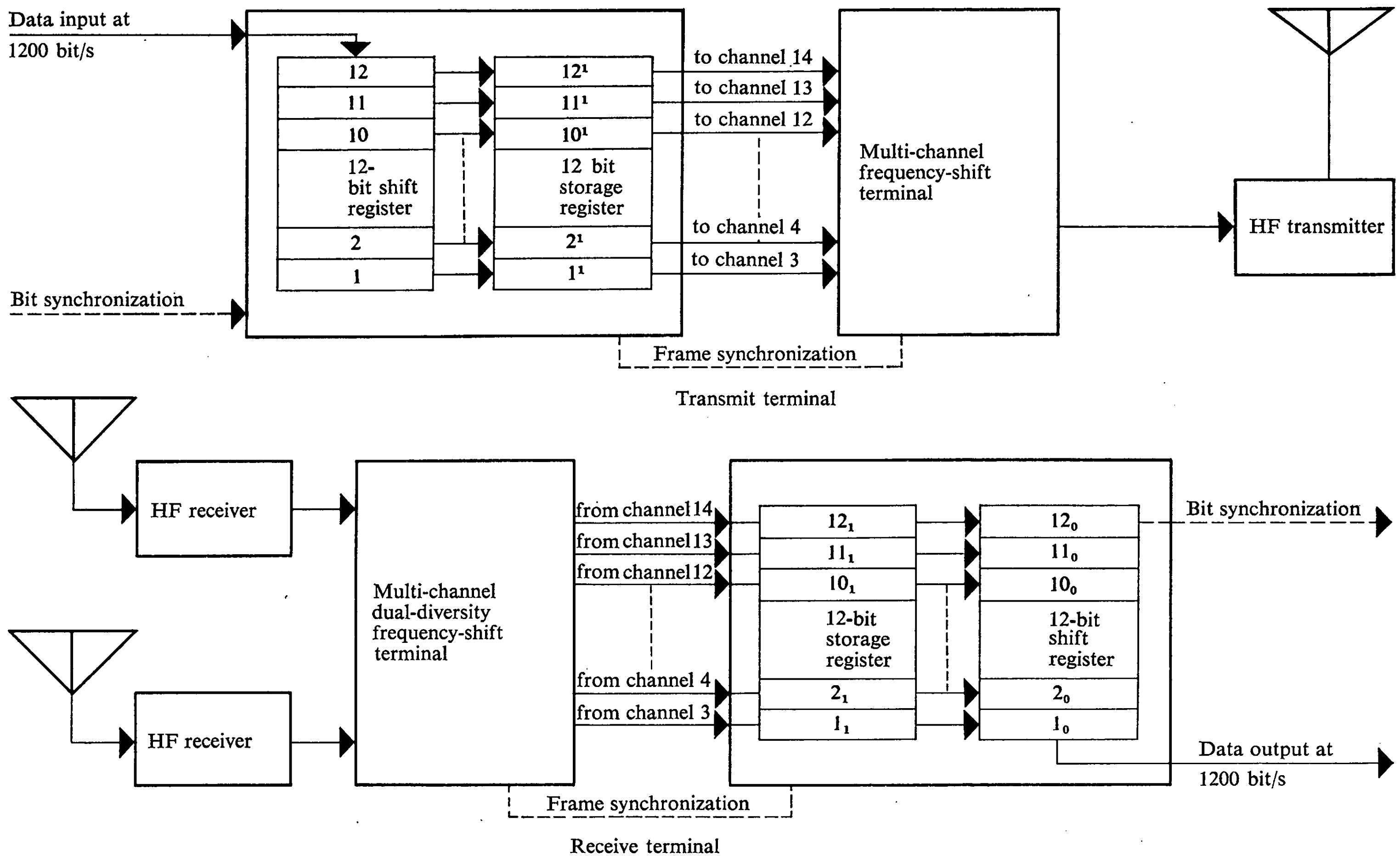


FIGURE 1

Data transmission system operating at 1200 bit/s

3C: *Reports*

REPORT 19-1*

VOICE-FREQUENCY TELEGRAPHY OVER HF RADIO CIRCUITS

(Study Programme 17A-1/3)

(1953 – 1966)

In principle, the voice-frequency telegraph systems described in C.C.I.T.T. Recommendations R.35, R.35 bis, R.36, R.37, R.38A and R.38B are capable of being used over HF radio circuits, but the following considerations need to be borne in mind:

1. Specifications of performance in C.C.I.R. Recommendations do not normally follow the practice adopted by the C.C.I.T.T.

2. The ratio between the frequency spacing and the nominal modulation rate of the channels is greater in the C.C.I.T.T. Recommendations than that which is currently used for FDM-FSK systems in operation over HF radio circuits. The systems listed by the C.C.I.T.T. would consequently be slightly less resistant to noise, but slightly more resistant to the effects of multipath propagation than the narrower channels proposed by the C.C.I.R. Furthermore, the number of channels that can be used in a given bandwidth will be less.

3. Since the C.C.I.T.T. systems do not normally have to contend with fading, there may be insufficient protection by the receiving filters against inter-channel interference when the fading is frequency-selective. Also the range of levels over which the channel receiver should operate would need to be increased by at least 10 dB.

4. Systems of use over HF radio circuits should incorporate features which permit diversity reception.

Although it might appear convenient to have unified standards for line and radio systems, the divergent requirements referred to above will make this uneconomic. The characteristics of radio transmission lead to the operation of point-to-point channels with synchronous operation, and, ideally, regeneration at the radio receiving station. This is in contrast to the requirement, in landline systems, to be able to connect channels in tandem without regeneration and to transmit start-stop signals with acceptable quality.

REPORT 42-2*

USE OF RADIO CIRCUITS IN ASSOCIATION WITH 50-BAUD 5-UNIT START-STOP TELEGRAPH SYSTEMS

(Study Programme 17A-1/3)

(1953 – 1956 – 1963 – 1966 – 1970)

The principal factors determining the error rate in radiotelegraphy transmission arise from the fact that:

— radio propagation is essentially variable,

— unwanted signals caused by noise or interference appear at the receiving end.

* Adopted unanimously.

1. As a result of variations in propagation, a complex signal is supplied to the receiver, consisting of superimposed signals from several transmission paths with differential delays of up to several milliseconds (see Report 203). As a result, the telegraph signal appearing at the output of the demodulator suffers random distortion, the limiting value of which is practically independent of the signal-to-noise ratio.

Start-stop systems are particularly vulnerable to this form of distortion, because of the risk of a loss of synchronization produced by mutilation of a start or stop element (see Report 195, Fig. 4).

2. Various Administrations have, for several years, had in service, on certain HF circuits, equipment with a channel spacing of 120 Hz, the central frequencies and frequency-shifts of which are given in Table I.

TABLE I*

Central frequencies of voice-frequency, frequency-shift telegraph channels with a channel separation of 120 Hz and a modulation index of about 1·4

(Frequency-shift: ± 35 Hz or ± 30 Hz)

Channel positions	Central frequency (Hz)	Channel positions	Central frequency (Hz)
1	420	11	1620
2	540	12	1740
3	660	13	1860
4	780	14	1980
5	900	15	2100
6	1020	16	2220
7	1140	17	2340
8	1260	18	2460
9	1380	19	2580
10	1500	20	2700

REPORT 195**

BANDWIDTH AND SIGNAL-TO-NOISE RATIOS IN COMPLETE SYSTEMS

Prediction of the performance of telegraph systems in terms of bandwidth and signal-to-noise ratio

(Study Programme 1A-2/3)

(1959 – 1963)

1. Study Programme 1A-2/3 sets out some questions, the answer to which would form a basis for the evaluation of the performance of complete systems. The questions include terms like "excellent service", the interpretation of which depends greatly on the type of traffic the system is intended to carry and the grade of service. This Report will not discuss such questions in detail, but rather attempt to give a basis for a more objective method of performance specification in the light of recent work on communication systems.

Theoretical studies of the mechanisms of detection of telegraph signals in the presence of noise, having a Gaussian distribution [Kotelnikov, 1947; Law, 1957], have made it possible to define the performance of a system, in terms of element error rate, as a function of the signal-to-noise ratio just prior to the detector. The word "detector" is used here in a very general sense and the detector might be a limiter-discriminator. It is convenient to use a quantity called the "normalized signal-to-noise ratio",

* See C.C.I.T.T. Recommendation R.70 bis.

** Adopted unanimously.

R, which is defined as the quotient of the average of the specific energies of the mark and the space signals, and the noise power per unit bandwidth. For systems which use two equally probable signals of equal energy, this ratio is equal to the signal-to-noise power ratio per baud per unit bandwidth, or the ratio of the signal power to the noise power per unit bandwidth, divided by the number of bauds. Direct comparison between receivers, even when working at different speeds is, therefore, possible.

In these studies, it was also found possible to specify the performance of a telegraph receiver by a single parameter. This parameter has been called the "demodulation factor" and it is the amount (in dB) by which the signal-to-noise ratio (normalized), applied to the receiver under test, exceeds that applied to an idealized receiver of the same type for the same element error rate. For the purpose of this work, we have to distinguish between coherent and non-coherent receivers. The coherent receiver has *a priori* knowledge of the phase of the elementary waveform. The mark- and space-elements are assumed to be equally probable.

1.1 *Coherent reception. No fading*

Assume that $x_1(t)$ and $x_2(t)$ are the two signal waveforms, that τ is the unit interval (duration of one element), and that N is the noise power per Hz. Then if:

$$y^2 = \frac{1}{4N}\int_0^{\tau} [x_1(t) - x_2(t)]^2 \, dt,$$

the element error rate P_e is given by:

$$P_e = \frac{1}{\sqrt{\pi}}\int_y^{\infty} \exp\left(-z^2\right) dz = \tfrac{1}{2}\operatorname{erfc}(y) = \tfrac{1}{2} - \tfrac{1}{2}\operatorname{erf}(y).$$

In terms of the "normalized signal-to-noise ratio", R, this error-rate can be expressed in the form:

$$P_e = \tfrac{1}{2}\operatorname{erfc}(\alpha R)^{\frac{1}{2}};$$

— for phase-reversal modulation $\alpha_1 = 1$;

— for frequency-shift keying with two orthogonal signals $\alpha_2 = \frac{1}{2}$;

— for amplitude keying (on-off signals) too, $\alpha_3 = \frac{1}{2}$.

For large values of R, the complementary error function can be well approximated by an exponential curve:

$$P_e \approx \frac{1}{2\sqrt{\pi\alpha R}} \exp\left(-\alpha R\right)$$

1.2 *Non-coherent reception. No fading*

For non-coherent reception of a steady signal, the error rate is of the form:

$$P_e = \tfrac{1}{2}\exp\left(-\alpha R\right)$$

Again:

— for differentially coherent reception [Lawton, 1959] of phase-reversal modulation $\alpha_1 = 1$;

— for matched filter reception and envelope detection [Reiger, 1953] of frequency-shift keying $\alpha_2 = \frac{1}{2}$ (for narrow-band FSK with shifts of the order $(0{\cdot}8/\tau)$, the effect of correlation leads to better results);

— for amplitude keying, we get approximately [Reiger, 1953] $\alpha_3 = \frac{1}{2}$.

1.3 *Coherent diversity reception. Flat fading*

It is assumed that the fading is of Rayleigh type, that the fadings in different branches are uncorrelated (but that they are the same for mark and space signals), that the mean signal-on energies of all branches are equal, and that the fading is so slow, relative to the speed of signalling, that the signal power may be regarded as constant during any one signal element. The outputs of the diversity branches are assumed to be weighted, according to the signal energy and combined (maximal ratio combination).

For Rayleigh fading and one receiver, we get the following error rate:

$$P_{e1} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R/(\alpha R + 1)}$$

For dual diversity:

$$P_{e2} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R\left(\alpha R + \frac{3}{2}\right)^2 \Big/ (\alpha R + 1)^3}$$

For triple diversity:

$$P_{e3} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R\left(\alpha^2 R^2 + \frac{5}{2}\alpha R + \frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{2!}\right)\Big/ (\alpha R + 1)^5}$$

For quadruple diversity:

$$P_{e4} = \frac{1}{2} - \frac{1}{2}\sqrt{\alpha R\left(\alpha^3 R^3 + \frac{7}{2}\alpha^2 R^2 + \frac{7}{2}\cdot\frac{5}{2}\cdot\frac{1}{2!}\alpha R + \frac{7}{2}\cdot\frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{3!}\right)\Big/ (\alpha R + 1)^7}$$

For large values of R, these results are closely approximated by:

$P_{e1} = 1/4\alpha R$; $P_{e2} = 3P_{e1}^2 = 3/(4\alpha R)^2$; $P_{e3} = 10\, P_{e1}^3 = 10/(4\alpha R)^3$; $P_{e4} = 35\, P_{e1}^4 = 35/(4\alpha R)^4$

respectively.

In the definition of the normalized signal-to-noise ratio R, the average signal energy and signal power per branch should now be substituted for signal energy and signal power respectively.

The basic curves, for idealized coherent reception of frequency-shift signals in fading ($\alpha = \frac{1}{2}$), are given in Fig. 1 for single, double, triple and quadruple diversity systems.

1.4 *Non-coherent reception. Flat fading*

The equations for the error rate for non-coherent reception, under the circumstances otherwise specified in § 1.3 (maximum ratio combining), are:

$P_{e1} = \dfrac{1}{2(1 + \alpha R)}$, Rayleigh fading, one receiver;

$P_{e2} = \dfrac{1}{2(1 + \alpha R)^2}$, dual diversity;

$P_{e3} = \dfrac{1}{2(1 + \alpha R)^3}$, triple diversity;

$P_{e4} = \dfrac{1}{2(1 + \alpha R)^4}$, quadruple diversity.

The basic curves for this case are given in Fig. 2, again for the reception of frequency-shift signals in fading ($\alpha = \frac{1}{2}$).

1.5 *Coherent reception. Independent fading*

1.6 *Non-coherent reception. Independent fading*

If it may be assumed that the frequencies corresponding to the two significant conditions of modulation are sufficiently widely separated for the fading in the two branches to be independent, then independent reception in the two branches is possible.

If, furthermore, the same assumptions are made as in §§ 1.3 and 1.4, the resulting error rates may be derived directly from the above. Then, going from flat fading to independent fading is equivalent to doubling the order of diversity, while having the power in each diversity branch [Barrow, 1962].

2. Demodulation factor

If the performance curve of an actual receiver for coherent reception is of the complementary error function type, then a constant factor indicates the extent by which a practical receiver falls short of the ideal, and it is the same for all types of diversity.

Also, if the performance curve of an actual receiver for non-coherent reception is of the exponential type, the demodulation factor will be a constant.

Equipment for measuring the demodulation factor of a receiver in the laboratory, under simulated fading conditions, has been described elsewhere [Law *et al.*, 1957]. Alternatively, a measure of the demodulation factor may be obtained by calculation from the performance of the receiver under non-fading conditions, as in the Annex.

In this Report we have only discussed maximum-ratio combining. In the literature [Brennan, 1959], one can find a comparison of this type of diversity with equal-gain and selection diversity. The loss for equal-gain combining is apparently of the order of 1 dB.

The performance of a circuit is usually expressed in terms of character error rates. Calculations from the probability functions involved give a simple conversion from an element error rate to a character error rate for various types of telegraph code, thus providing a simple relationship between the signal-to-noise ratio and the number of errors on the printed copy. The particular case for random arrival of element errors represents a useful limiting condition which is approached closely when the error rate is low.

Relationships between element and character error rates are shown in Figs. 3 and 4.

In Fig. 3, curve 1 represents the upper limit of the character error rate for a synchronous seven-unit code, when the element errors are mutually independent. It should be noted here, that the character error rate is defined as being the number of characters subject to error at the output of the detector and thus an error in "letter shift" or "figure shift" is counted only once and similarly for other errors, such as those occurring in "carriage return" or "line feed". However, if the fading characteristics give rise to groups of errors, then the curve showing the relationship between element and character error rates becomes asymptotic to curve 2 which was calculated on the assumption that the signal level remains constant during a character. For element error rates lower than 1×10^{-3}, the curve 1 is appropriate.

In Fig. 4, the upper limits are shown as follows:

— curve 1: for a five-unit synchronous code: $P_c \approx 5P_e$;

— curve 2: for a seven-unit code: $P_c \approx 7P_e$;

— curve 3: for a five-unit start-stop system with tape printing and allowing for errors due to loss of synchronism, in addition to the simple character errors: $P_c \approx 17P_e$;

— curve 4: for a five-unit start-stop system with page printing i.e., including an additional allowance for multiple errors due to carriage return and line-feed failures. Again, as for the previous curves, errors in "letter shift" or "figure shift" are only counted once: $P_c \approx 34 P_e$.

An example is given below to demonstrate the way in which the curves may be used. It is stressed that this example shows the method employed in making one of the steps in the calculations necessary to plan circuits for a specified grade of service, but that the demodulation factor of the receiver must be known as a result of measurement.

First, we take the general case for reception of a steady signal.

Let R_o = the pre-detection signal-to-noise ratio (dB);

R_n = the normalized signal-to-noise ratio, corresponding to R (dB); $R_n = 10 \log_{10} R$;

S = the modulation rate in bauds (elements/s);

B = the pre-detection bandwidth (Hz) of the receiver in question;

D = the demodulation factor of the receiver for the modulation rate specified, in decibels;

then

$$R_o = R_n + 10 \log_{10} (S/B) + D \qquad (1)$$

Example

A coherent receiver, having a pre-detection bandwidth of 1000 Hz, is used for 50 bauds, 5-unit synchronous working, using triple diversity. The measured demodulation factor of the receiver, for this signalling speed and bandwidth, is 10 dB. A character error rate of 1×10^{-4} is permissible; what must be the pre-detector signal-to-noise ratio?

From Fig. 4, the corresponding element error rate is 2×10^{-5}. From Fig. 1, an ideal receiver using triple diversity produces an element error rate of 2×10^{-5} for $R_n = 16$ dB.

Using equation 1, we find:

$$R_o = R_n + 10 \log_{10} (S/B) + D$$

and inserting the known values we have

$$R_o = 16 - 13 + 10 = 13 \text{ dB}.$$

This is the required signal-to-noise ratio per branch. The signal-to-noise ratio after combining will be 3 R_o or 18 dB.

3. Conclusion

Extension of this work, to cover noise other than thermal noise, may result in the need for more parameters to describe fully system performance, but it seems clear that:

— the performance of telegraph circuits should be related to stated character error rates, and for the engineering planning of circuits and design of equipment it is preferable to have these expressed in corresponding element error rates;

— the approach indicated in this Report forms a useful starting point in the development of an objective method determining the performance of telegraph systems.

ANNEX

In the absence of a fading simulator, it is possible to derive an approximate value of the element error rate under fading conditions from the results of tests under steady conditions. These steady-state tests will give the error rate as a distribution function $g(R)$, of the normalized signal-to-noise ratio R.

If, for coherent reception, $g(R)$ can be expressed in the following form:

$$g(R) = \tfrac{1}{2}\,\text{erfc}\,(bR/2)^{\frac{1}{2}}$$

then the demodulation factor is constant, $10 \log_{10} b$, independent of the order of diversity employed.

In practice, this will not generally be the case and then the demodulation factor will be a function of both R and q (the order of diversity). However, by an extension of the work in [Law, 1957], it can be shown that, in general, the element error rate with q diversity branches will be:

$$P_{eq} = [(q-1)!\,N^q]^{-1} \int_0^\infty y^{q-1} \exp\left(-\,y/R\right) g\,(y)\,\mathrm{d}y.$$

For large signal-to-noise ratios, or small error rates, the following approximation for the demodulation factor D_q, with q diversity branches, and flat fading, can be found:

$$(D_q)^q = [2^q \,.\, q!/(2q-1)!] \int_0^\infty y^{q-1} g\,(y)\,\mathrm{d}y.$$

Measured distribution functions under steady-state conditions can be expressed in the following form:

$$g\,(R) = \sum a_k \,.\, \exp\left(-\,b_k R\right)$$

Then for large values of R:

$$(D_q)^q = [2^q \,.\, q!\,(q-1)!/(2q-1)!] \sum (a_k/b_k{}^q)$$

For other forms of the function $g(R)$, similar calculations can be performed.

For non-coherent reception, the reasoning is completely analogous. Again, the answer is simple, if the error rate under steady conditions can be expressed as a single exponential form.

For the more complicated error performance given by a sum of exponentials, as above, the demodulation factor is given in this case by:

$$(D_q)^q = \sum (a_k/2)\;(2b_k)^q$$

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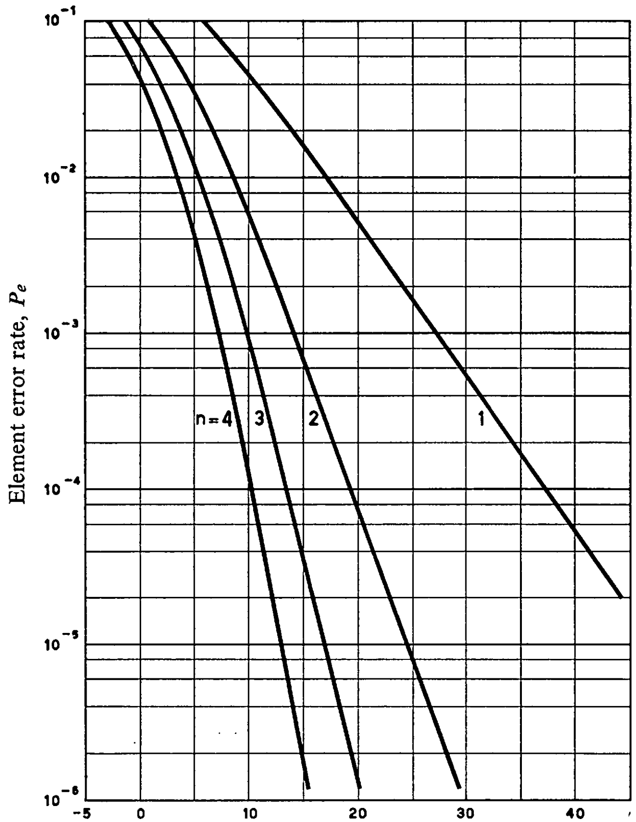

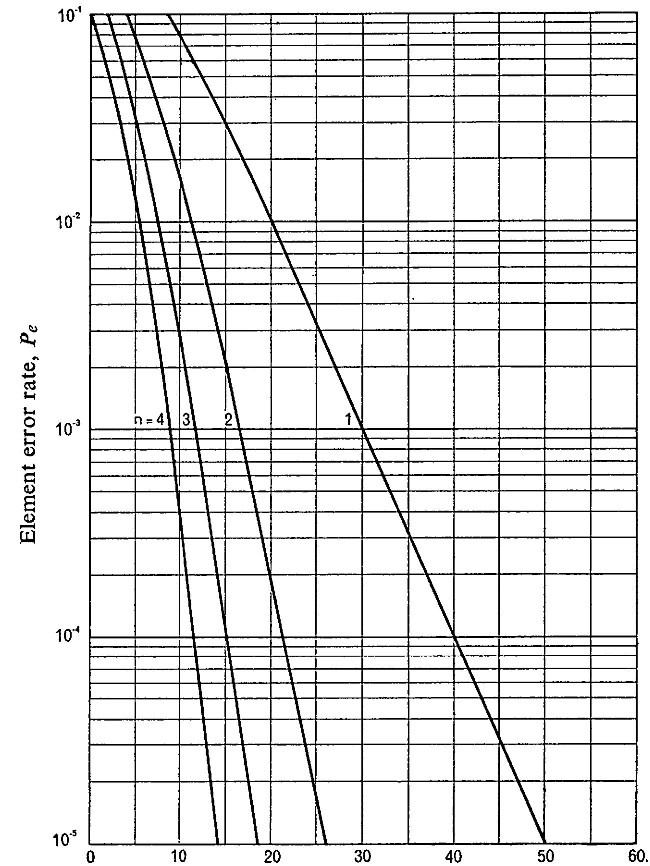

Normalized signal-to-noise ratio per diversity branch (dB)
$R_n = 10 \log R$ (n = number of diversity branches)

FIGURE 1
Coherent reception

FIGURE 2
Non-coherent reception

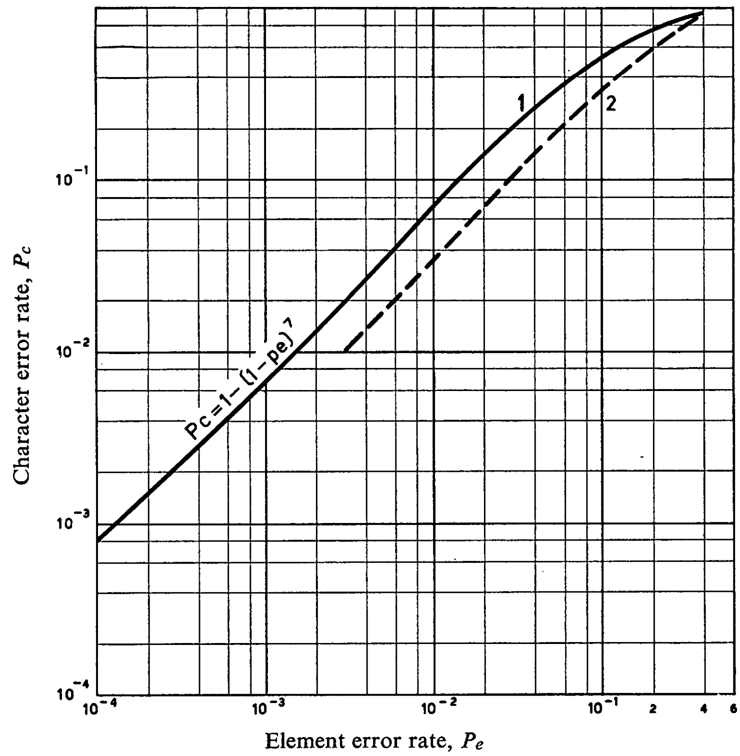

FIGURE 3

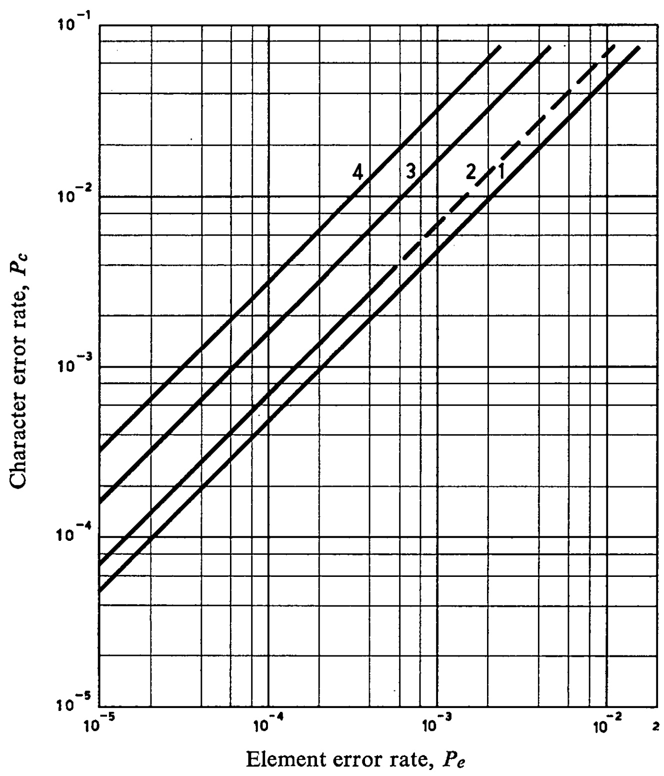

FIGURE 4

Curve 1: 5-unit synchronous code,
2: 7-unit synchronous code,
3: 5-unit start-stop, tape printing,
4: 5-unit start-stop, page printing.

REPORT 197-3*

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

(Study Programme 1A-2/3)

(1963 – 1966 – 1970 – 1974)

1. Urgent need for information

The attention of Administrations is drawn to the urgent need for the information requested in Study Programme 1A-2/3, for several classes of emission. As requested in the Annex to Study Programme 1A-2/3, the establishment of minimum protection ratios for additional classes of emission under stable conditions should be given priority. It is realized that no Administration will be able to give all the answers, but partial answers are very welcome. This information will permit an improvement in the calculation of the probability of harmful interference between assignments and the consideration of the possibility of sharing.

Study Group 3 also needs the information to complete Recommendations 240-2 and 339-3 to bring them up to date.

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

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

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

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

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

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

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

For telegraph channels on which the errors occur in bursts, a two state Markov process gives a suitable model for calculations [Van Duuren, 1966]. In one state the probability of error is 0·5, in the other state the channel is error free. Moreover a third decision can be taken into account, when it is not sufficiently sure whether a mark or a space was received. This suggests that the use of such a third decision may materially reduce the appearance of undetected errors at the output of an ARQ channel.

* Adopted unanimously.

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

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

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

4. Error rates on long distance HF communications

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

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

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

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

5. Diversity reception and mutual signal correlation ratio

Experiments carried out in the U.S.S.R. have shown that the signal correlation ratio R (300 m distance between the antennae) depends on the path distance and on the relation f_{op}/MUF, where f_{op} is the operating frequency [C.C.I.R., 1966–1969].

According to these experiments, the effectiveness of diversity reception decreases greatly when $R > 0{\cdot}6$. For path lengths up to 1500 km the probability of $R > 0{\cdot}6$ comes to 18% and for path lengths from 1500 to 3000 km this probability reaches 31%.

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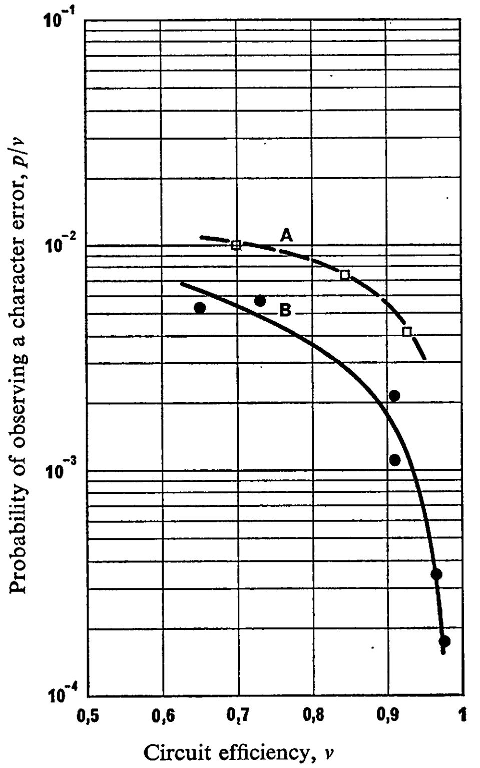

FIGURE 1

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

Curve A: without diversity
B: with dual diversity

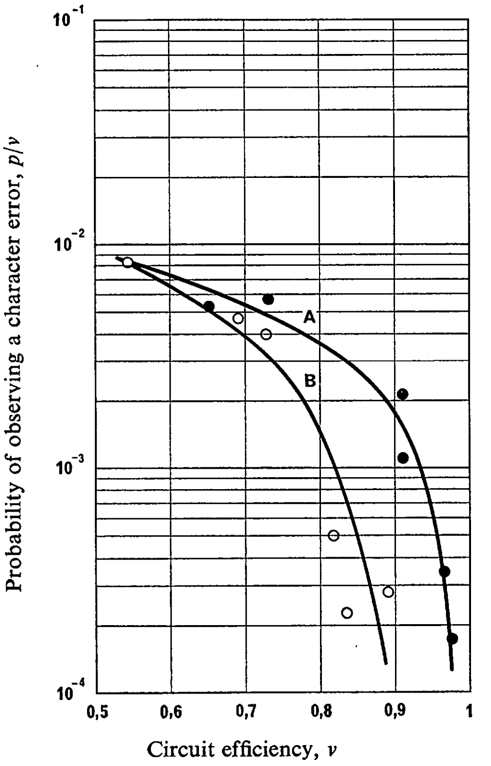

FIGURE 2

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

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

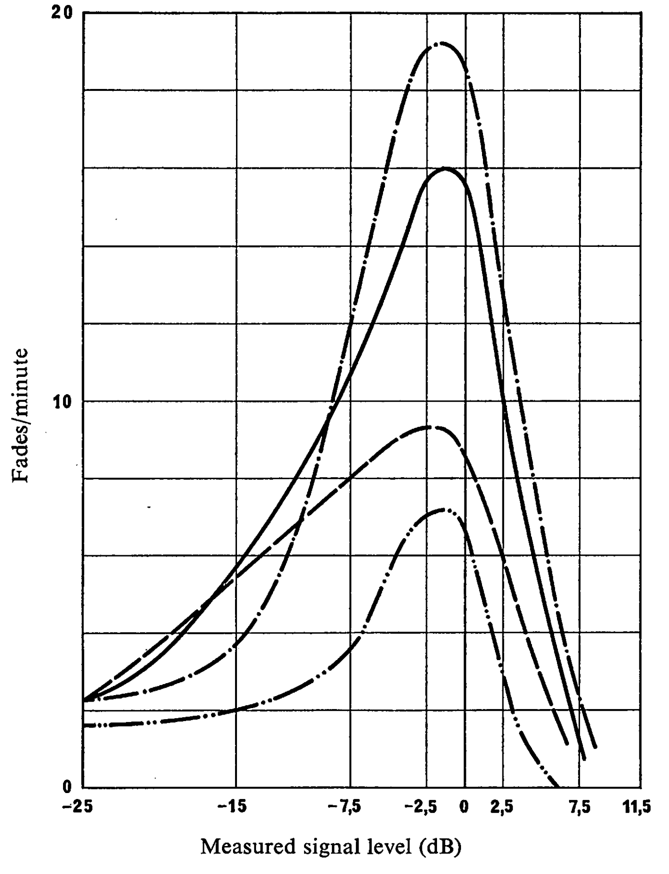

FIGURE 3

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

—·—·— New York

— — — Seoul

——— Buenos Aires

—··—··— Ankara/Cairo for September, 1961

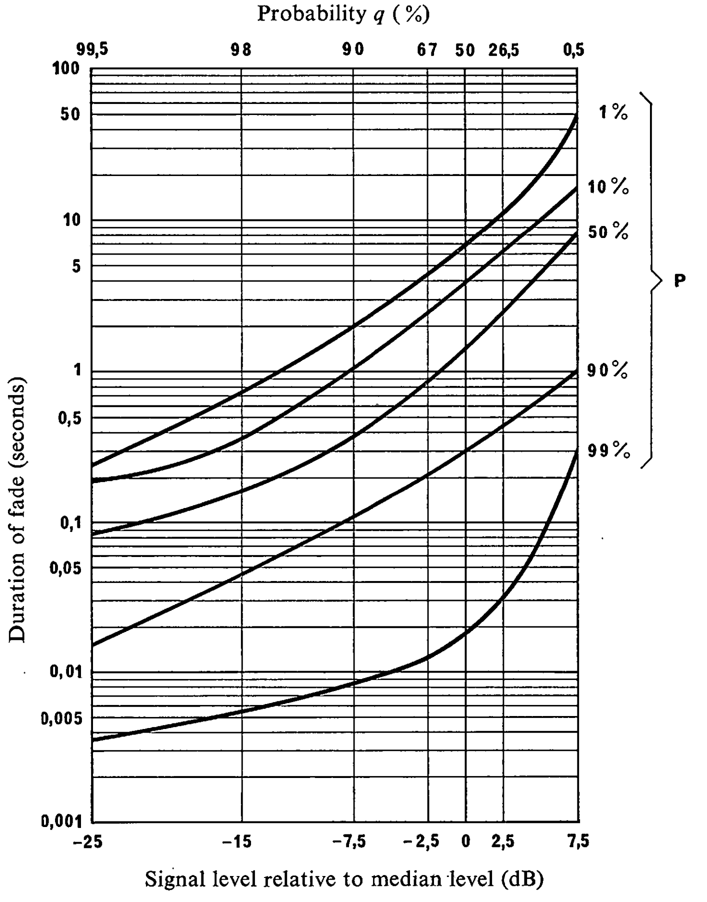

FIGURE 4

Duration of fades as a function of the level of the test signal

Circuit: New York — Frankfurt-on-Main; 14 September, 1961; 1100 h Central European Time; frequency 13·79 MHz.

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

REPORT 198*

VOICE-FREQUENCY (CARRIER) TELEGRAPHY ON RADIO CIRCUITS

(Study Programme 17A-1/3)

(1963)

Theoretical work in Japan (Doc. III/23, Geneva, 1962) indicates an optimum frequency-shift of 0·8 B (Hz), where B is the number of bauds. This would lead to a required minimum bandwidth (at –3 dB points) of B (Hz). Laboratory experiments and measurements on the synchronous ARQ circuit Frankfurt-Osaka, support these conclusions.

It is to be noted, that this shift is preferably to be used on circuits near MUF and that otherwise a larger shift may be beneficial. For asynchronous circuits, some theoretical results indicate B to 2 B as best shift [Akima, Voss]. Further experiments, on circuits of different lengths, in different directions and in different seasons, are desirable before a definite conclusion can be reached.

REPORT 200-1*

TELEGRAPH DISTORTION, ERROR RATE

(1963 – 1966)

1. Distribution of telegraph distortion

The study of the relationship between telegraph distortion and error rate has received further consideration. The statistical distribution of distortion can be of value for assessing the quality of a radiotelegraph circuit (see Report 351-2).

2. Isochronous telegraph distortion

2.1 The measurement of isochronous telegraph distortion can be applied meaningfully at several points in a radiotelegraph system.

2.2 In making measurements of isochronous distortion of the separate components of the system, the following C.C.I.T.T. Recommendations should be taken into consideration:

Recommendation R.4 — Methods for the separate measurements of the degrees of various types of telegraph distortion.

Recommendation R.5 — Observation conditions recommended for routine measurements of distortion on international circuits.

Recommendation R.74 — Choice of type of distortion measuring apparatus.

2.3 The measurement of the variation in restitution delay is important in determining the fortuitous distortion contributed by the transmission medium.

2.4 Bias distortion is one component of the distortion produced by equipment and its measurement is useful in determining equipment performance.

3. Statistical measurements of error rate on the Warsaw-New York circuit did not indicate any direct relationship between error rate and the level of the received signal.

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* Adopted unanimously.

REPORT 201-2*

REMOTE CONTROL SIGNALS FOR FACSIMILE TRANSMISSIONS

(1963 – 1966 – 1970)

1. Introduction

With the rapidly increasing use of facsimile transmissions for various purposes, using continuous web (chart type) recorders, it has become desirable for the C.C.I.T.T. to set up standards for the remote control signals to be employed for the connection, starting, phasing, speed control, stopping, etc. of a facsimile transmission.

2. Remote control signals for the meteorological facsimile service

The World Meteorological Organization, in collaboration with the C.C.I.T.T., has established a set of standards, including control signals for use over the leased weather network (see C.C.I.R. Recommendation 343-1).

3. Remote control signals for the subscribers' facsimile service

The C.C.I.T.T. proposals for the remote control of subscribers' apparatus for the transmission of business documents are given in C.C.I.T.T. Recommendation T.4 (White Book, Vol. VII).

4. Conclusions

These documents make known to the C.C.I.R. proposals for the standardization of remote control signals. The C.C.I.R. will study them to determine whether these signals are acceptable and applicable on radio circuits.

REPORT 345-1*

PERFORMANCE OF TELEGRAPH SYSTEMS ON HF RADIO CIRCUITS

(Study Programme 17A-1/3)

(1966 – 1970)

1. Introduction

This Report summarizes the results of an extensive series of tests in which different systems of voice-frequency radiotelegraphy are compared, both in the laboratory and on a real circuit. The systems treated in the laboratory are two-tone and narrow-band frequency-shift modulation; results have already been published [Ridout and Wheeler, 1963], but a summary of the major conclusions is given in § 2. Tests were also carried out on a differential phase-modulation system, but the results are excluded from this Report.

The results of a practical comparison, on a real circuit, of two-tone and narrow-band frequency-shift are given in § 3.

* Adopted unanimously.

2. Laboratory measurements

2.1 *Description of systems*

It will be convenient to refer to the various systems by means of code designations defined as follows:

2.1.1 *System A* is a frequency exchange or two-tone system using the method of detection described by Allnatt, Jones and Law [1957]. Each channel can be regarded as comprising a pair of amplitude-modulation channels with complementary keying, separate detection and additive combination of the detected signals to produce a frequency-diversity improvement. For modulation at 100 bauds the modular spacing of the frequencies is 170 Hz. The two frequencies used for a channel may be separated by a multiple of this, being interleaved with the frequencies of other channels. The separation is chosen according to the most likely multipath propagation time difference, the optimum in hertz being equal to half the inverse of this time difference in seconds.

2.1.2 *System B1* is a frequency-shift system with a channel spacing of 170 Hz [Lyons, 1960]. The normal modulation rate of each channel is 100 bauds and the frequency-shift is 80 Hz. The channel receiver comprises the conventional limiter and discriminator arrangement. When diversity reception is used, the demodulated signals produced by each branch channel receiver are weighted according to the amplitude of the input signal to each branch.

2.1.3 *System B2* is a frequency-shift system of the same basic form but with a channel spacing of 340 Hz and frequency-shift of 170 Hz. The channels can accept a modulation rate of up to 200 bauds.

2.1.4 *Reference system*

To facilitate comparison between the systems, there is included with each set of performance curves one representing the hypothetical system mentioned in C.C.I.R. Report 195, which is based on the use of coherent detection of a non-fading signal.

2.2 *Method of testing*

The performance of each system has been measured in terms of mean element error rate versus normalized signal-to-noise ratio under various conditions of fading signal with added uniform-spectrum random noise. The transmission path was provided by a fading simulator [Law *et al.*, 1957] with facilities for simulating equal-activity two-path propagation (with selected path-time difference) and dual space-diversity reception.

2.3 *Test results*

Since the application of dual space-diversity reception is quite usual for telegraphy, the performance curves for that mode only are given here in Figs. 1 to 3.

In considering these curves, it should be borne in mind that, in system *A* (two-tone) the spacing of the significant frequencies was 510 Hz (i.e. three times the modular spacing); hence its optimum performance occurs when two-path propagation is present, with equal activity in both paths and a propagation time difference of about 1 ms.

2.4 *Discussion of results*

The results will be discussed in the light of possible working requirements, first in terms of the normalized signal-to-noise ratio required for a given error rate in the case of unprotected transmission, and then in terms of a given time-efficiency factor when an error-correction (ARQ) system is used.

2.4.1 *Unprotected transmission*

Different classes of user will tolerate various limits for accuracy, but it will be assumed in these comparisons that an acceptable mean error rate is 1 in 10^4 elements corresponding to 1 in 2000 characters for synchronous 5-unit code transmission.

In the absence of multipath propagation it would not, of course, be necessary to limit the modulation rate to one or two hundred bauds, but it will be of interest to compare the systems in this condition. However, on long-distance circuits, multipath propagation with effective path-time differences in the range 1 to 2 ms is often encountered and must be taken into account. Under these test conditions systems *B* could not produce the required performance. System *A* would require a normalized signal-to-noise ratio ranging from 17 to 24 dB according to the actual path-time difference and relative activity of the paths.

2.4.2 *Protected transmission*

When automatic error detecting and correcting systems are used on radio channels, the radio signal element error rate may be permitted to rise considerably above 1 in 10^4 before the undetected error rate approaches 1 in 2000 characters printed; no data is available on the exact relationship between detected and undetected errors for each transmission system under fading conditions, but it is estimated that the increase could be by a factor approaching 10^2. Thus an element error rate of 1 in 10^2 can be taken to define the upper limit of consideration. With similar conditions in each direction of transmission and assuming that errors occur randomly and without correlation between the two directions, this corresponds to a time-efficiency factor of 60-70%, i.e. about one-third of the circuit time is taken up by automatic retransmission for correction of errors. An element error rate of 1 in 10^3 will still produce an efficiency factor of approximately 97% with a negligible undetected character error rate. Hence the range of practical interest in element error-rate of transmission systems can be confined between the limits 1 in 10^2 to 1 in 10^3. This leads to the conclusion that, a system having a residual error liability which would make it undesirable for unprotected use can still be used with an ARQ system if it possesses other desirable features.

To illustrate the comparative performance of the systems in ARQ operation, curves of time-efficiency factor versus normalized signal-to-noise ratio, with space-diversity reception, have been derived from the element error-rate curves and are shown in Fig. 4. It has been assumed that the fading rate may be up to 20 per minute. With flat fading there are slight differences between systems *A* and *B1* but for the sake of clarity only a single curve is shown; system *B2* has been omitted since its performance at 100 bauds is not better overall than that of *B1* and its performance at 200 bauds with a path-time difference of 2 ms would produce an inferior efficiency. From these curves it is concluded that the order of merit would be *A*, *B1* and *B2* and, if fading conditions ranging between the extremes considered are assumed, that *B1* needs approximately 3 dB better normalized signal-to-noise ratio than *A* to maintain 90% efficiency.

2.4.3 *Bandwidth utilization*

It is, however, unusual to encounter radio circuits engineered to such close limits that a difference in performance of 3 dB would be easily discernible in practice: furthermore, bandwidth requirements of the systems have not so far been considered. For a given number of channels, system *A* will require almost exactly twice the bandwidth of system *B*.

Assuming that the best use is to be made of a conventional 3 kHz bandwidth, Table I shows the number of 100 baud channels which may reasonably be provided by each system and the aggregate signal-to-noise power required to produce various values of time-efficiency factor.

TABLE I

Performance of a practical fully-occupied nominal 3 kHz telephony channel

Type of system	Number of 100-baud channels	Aggregate signal-to-noise power ratio in a 3 kHz bandwidth, to give stated efficiency (dB)		
		50%	70%	90%
A	8	2 to 3	3·5 to 5·5	6·5 to 9
B1	16	6 to 7	8·5 to 10	12 to 14

2.5 *Characteristics of system B*

It will be observed from Figs. 2 and 3 that the system *B1* performance tends to approach a specific minimum value for each condition rather than progress to zero with uniform slope as does system *A*. Further work in the United Kingdom [Groves and Ridout, 1966] has thrown fresh light on this phenomenon, known as "bottoming", observed on real communication channels using frequency modulation. It is there shown that when two approximately equal signal components reach the receiver by direct and delayed paths they may combine with any relative phase. When the components are in phase opposition then large and rapid phase alternations can occur, sufficient in some cases to displace transitions by more than the differential multi-path delay.

This phenomenon is not by itself, however, sufficient to account for the residual element error rate experienced. Restriction by the channel filters of the higher order sidebands produced in the frequency-modulation process inevitably causes some amplitude modulation which has a fundamental frequency twice that of the frequency modulation. This has the effect of prolonging the period over which the resultant signal phaser is undergoing rapid changes of phase. As an example the frequency displacement due to this rapid change can be as high as 100 Hz over a period of 10 ms, sufficient to cause a reversal of polarity on a channel having a deviation of 40 Hz.

Analysis of this phenomenon confirmed by measurements over the fading simulator of § 2.2 has shown the residual element error rate on such a system to be:

— proportional to the square of the path-time difference of a two equal mode propagation path,

— a function of the deviation,

— an inverse function of the bandwidth of the channel filter,

— sensibly independent of the fading rate,

— not greatly reduced by space-diversity operation as simulated by two paths subject to uncorrelated fading,

— largely made up of groups of errors of the same polarity.

Other work in Japan [Aritake and Takeuchi, 1961] has given results almost the same as those stated above. In this, mathematical analysis and operational observations were made on the system *B* operated between Tokyo and San Francisco.

Both of them showed that:

— multipath distortion is frequently observed on HF radio circuits even at times of favourable propagation conditions and when the received signal is strong;

— when the bandwidth of the channel filter is not wide enough to pass the essential sidebands, the waveform of the demodulated signal is severely distorted, causing intolerable errors.

In conclusion, it has been suggested that the following methods should be used to reduce error rate:

— to operate at a higher frequency, near the MUF, despite the fact that the receiving signal is not as strong as at the optimum frequency;

— to use the optimum modulation index (m = total frequency-shift in Hz/modulation rate in bauds) which concentrates the distribution of higher level essential sidebands close to the centre frequency (usually $m \approx 0{\cdot}8$ is recommended) for the transmission of the signal waveform;

— for high-speed transmission (more than 100 bauds), to divide the incoming signal into lower speed signals (maximum of 100 bauds) for transmission over the radio path, by using a serial-to-parallel converter at the transmitting end and to recombine them into a single high-speed signal using a parallel-to-serial converter at the receiving end.

2.6 *Further tests under conditions of multipath distortion*

Results obtained from tests on two channels of system *B1*, used in frequency diversity, that were provided with signals from a fading simulator, seem to indicate that system *B1* will produce a performance comparable to system *A*, as regards both channel capacity and signal-to-noise power ratio, at least over the range of error rates of practical significance when used on protected circuits. The artificial fading used during the tests was selective fading, produced by the interference of five equally active paths, differing in propagation time from one to the other by approximately equal amounts such that an overall difference of 2 ms was achieved. The two diversity branches of the receiver were provided with signals having uncorrelated fading patterns.

3. Comparison between systems A and B1 operating over a real circuit

A series of directly comparative tests was carried out over periods aggregating to four weeks on a 7200 km route between Singapore and Nairobi.

3.1 *Test arrangements*

The telegraph system between Singapore and Nairobi normally uses a six-channel two-tone equipment carrying a number of 96-baud ARQ aggregate signals of the Singapore to London circuit which are relayed at Nairobi. At Singapore the two lowest frequency channels of the two-tone system utilizing frequencies of 765, 935, 1105 and 1275 Hz were suppressed and four frequency-modulation channels (deviation 80 Hz) were injected into the composite signal on these frequencies.

One of the Singapore/London circuits, which is usually busy throughout the twenty-four hours, was selected for the tests and arranged to key both a two-tone (the component frequencies being spaced at 340 Hz) and a frequency-modulation channel so that the same information was radiated within a 3 kHz bandwidth on the two systems.

Adjacent channels on both the two-tone and FM-VFT systems were activated with different live traffic or reversal signals to simulate normal working conditions. Tone levels were adjusted so that equal peak powers were radiated by all tones as observed on a spectrum analyser.

At the Nairobi receiving station, the composite group of signals was received on a dual-path single-sideband receiver and fed to both the dual-diversity two-tone and FM-VFT channel equipment.

Synchronous electronic regenerators were used to eliminate the distortion from channels on both systems. Outputs from the regenerators which correct all distortion up to 48% were connected to electromechanical ARQ equipment modified to detect all incorrect 3/4 ratios of the 7-unit ARQ signals. Counters were employed to register the number of errors detected, and hourly readings were recorded.

The regenerators and ARQ equipment used for the two channels being tested were interchanged every twenty-four hours so that, should any hidden fault have developed in the equipment which could not be detected by normal means, it would have affected both channels equally. The output from the regenerator connected to the normal channel was also used to key the onward circuit to London.

In this manner, every effort to ensure a valid comparison of the two systems was made, and, in conjunction with reports from receiving station logs, radio condition reports, and distortion recorder charts, doubtful information which could have been caused by interference (QRM) was eliminated.

3.2 *Test results*

Each test run was taken over either seven or eight consecutive days and nights and the "errors detected" figures were examined. As the scatter of these hourly average figures would have given the graphs a saw-tooth shape, a running three-hour average figure was used for the error graphs.

The most useful criterion for the communicator is the percentage efficiency of the circuit, and as these error figures refer to only one direction of a normal ARQ circuit it is not possible to give an accurate assessment from the test results. However, by the use of a curve [Croisdale, 1958] reproduced here as Fig. 7, it is possible to estimate the effect the detected errors would have had on the percentage efficiency of the circuit if the return path had been error-free. Any detected errors on the return path, i.e. Nairobi to Singapore, would have lowered the efficiency graphs, but the effect would apply equally to either system (see Fig. 6). On these figures, the efficiency expected from the receiving station logs is shown in shadow-graph form; the actual efficiency of the whole Singapore-Nairobi-London ARQ circuit for the period covered is also given.

3.3 *Discussion of results*

It will be seen from Fig. 5 that, in general, the two-tone system results were always better than the frequency-modulation system results, even though the channels were of equal radiated power.* During the hours of "good propagation conditions" the errors per hour on either system were very few. However, as conditions deteriorated errors increased on both systems, but were more frequent on the frequency-modulation system than on the two-tone system.

It is of interest to note that as the efficiency of the circuits decreases, the difference between the two systems generally increases.

4. Conclusions

These tests demonstrate that under difficult radio propagation conditions the two-tone system provides channels which have a higher efficiency factor than individual channels of an FM-VFT system when equal power per channel is used.

However, if the major traffic load is to be carried during the hours when radio propagation conditions are not unusually difficult then the larger number of channels given by the FM-VFT system, within a 3 kHz bandwidth, is a great asset.

It should be noted that if the lower limit of Telex circuit-efficiency, adopted in C.C.I.T.T. Recommendation U.23 were used, i.e. automatic "clearing" of these circuits whenever the efficiency falls below 80%, then a situation could arise where for appreciable periods no Telex operation would be possible if an FM-VFT system were employed, whereas satisfactory operation would be obtained by the use of the two-tone system.

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* If the maximum number of channels were to be used in each case, a frequency-modulation channel would be 3 dB lower than a two-tone channel for the same aggregate peak envelope power.

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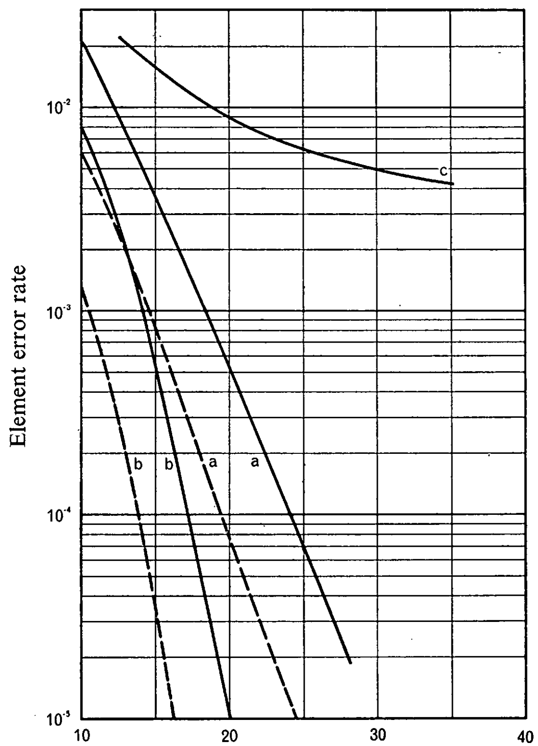

FIGURE 1

System A. Dual space-diversity reception

- - - - - Reference system a: flat fading and also a path-time difference of about 2 ms

——— System *A* b: path-time difference 1 ms

c: path-time difference 4 ms

Modulation rate: 100 bauds; fading rate: 40 per min

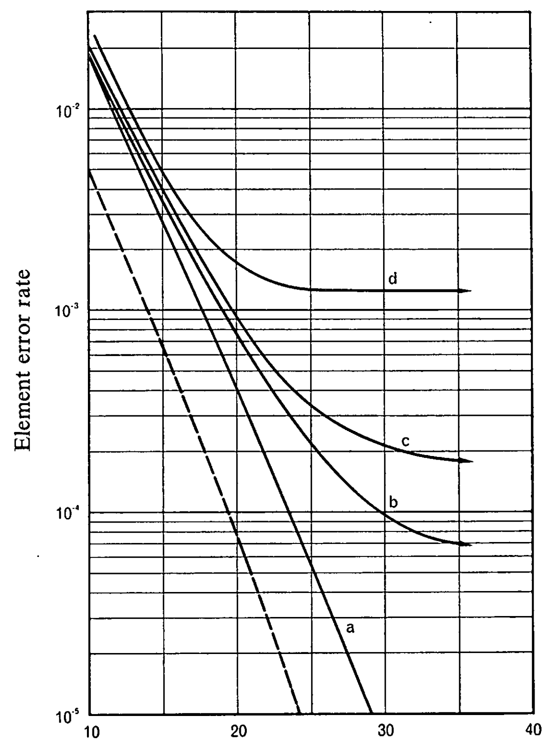

FIGURE 2

System B1. Dual space-diversity reception

- - - - - Reference system a: flat fading

——— System *B1* b: path-time difference 0·5 ms

c: path-time difference 1 ms

d: path-time difference 2 ms

Modulation rate: 100 bauds; fading rate: 40 per min

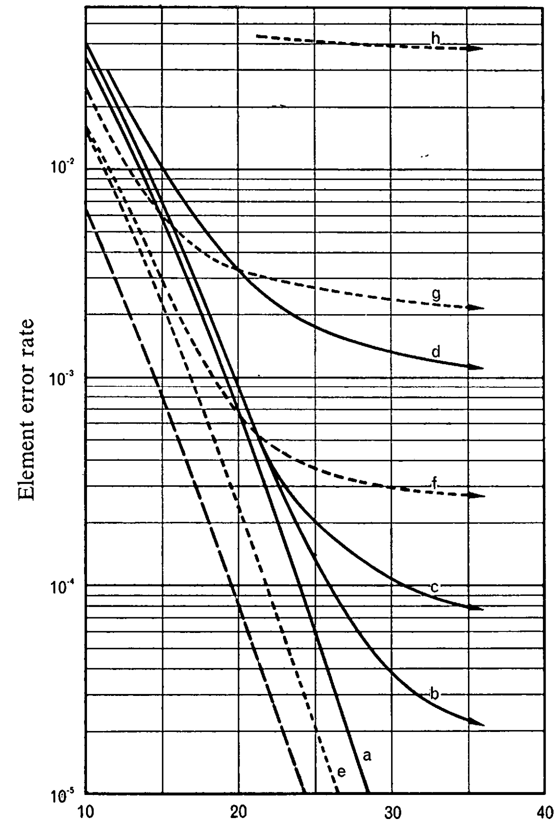

FIGURE 3

System B2. Dual space-diversity reception

- - - - - Reference system

——— System *B2*: modulation rate 100 bauds

------- System *B2*: modulation rate 200 bauds

a: flat fading
b: path-time difference 0·5 ms
c: path-time difference 1 ms
d: path-time difference 2 ms
e: flat fading
f: path-time difference 0·5 ms
g: path-time difference 1 ms
h: path-time difference 2 ms

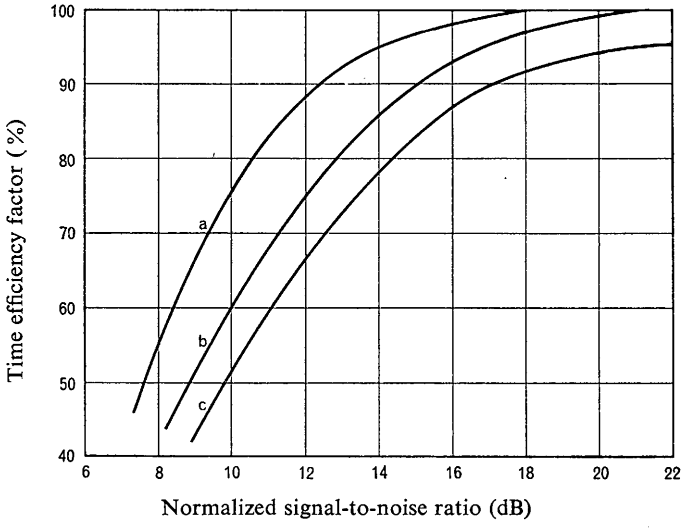

FIGURE 4

Time efficiency factor

a: System *A*. Path-time difference 1 ms (optimum for frequency spacing)
b: System *A*. Flat fading and path-time difference 2 ms
System *B1*. Flat fading
c: System *B1*. Path-time difference 2 ms (in this case no frequency-diversity improvement is realized with a spacing of 510 Hz)

Modulation rate: 100 bauds

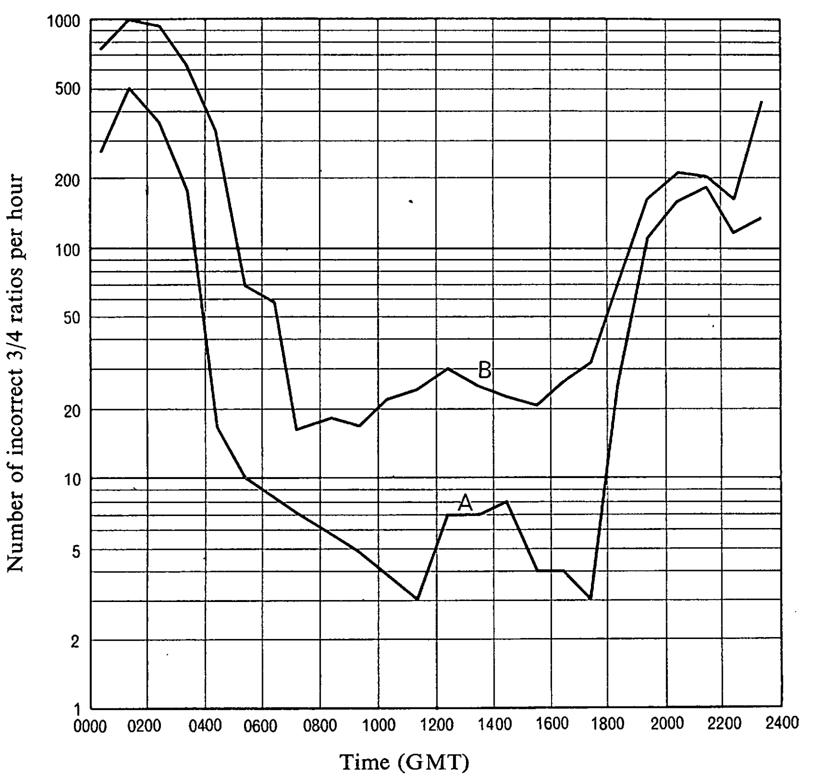

FIGURE 5

Typical performance curves

Average number of errors per day over three hours on the Singapore-Nairobi telegraph system during the period 26 March—1 April, 1963

A: System *A* (two-tone) B: System *B1* (FM)

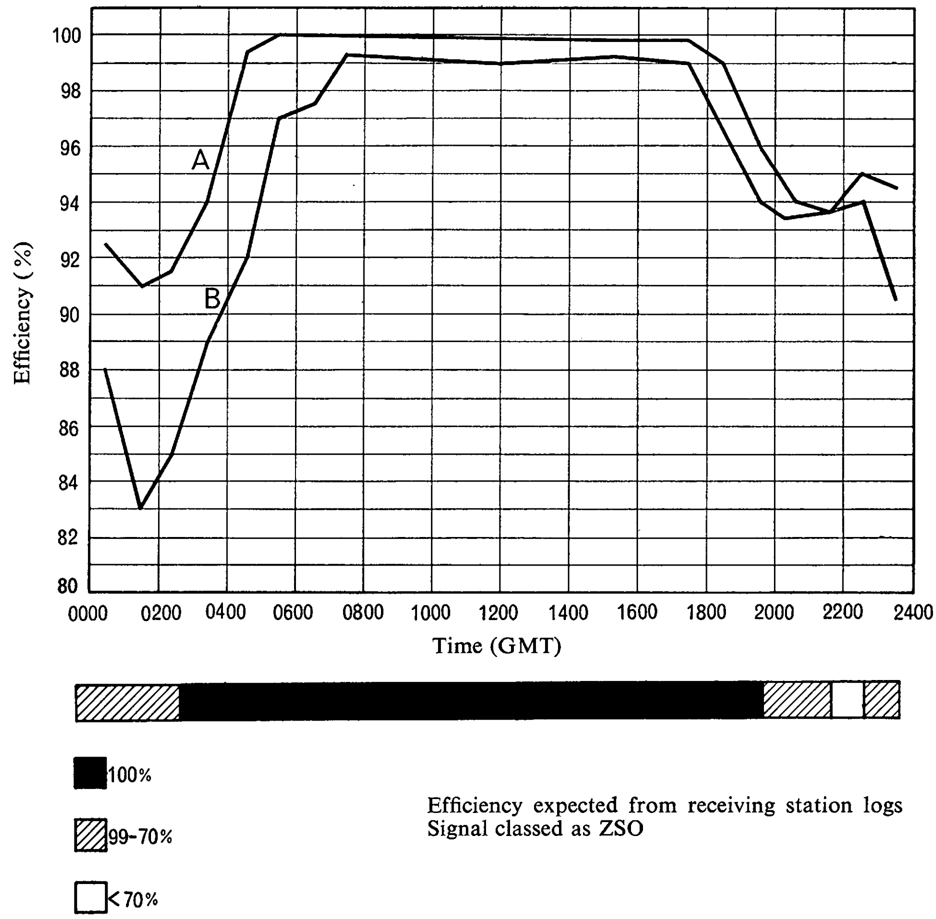

FIGURE 6

Estimated performance of error-corrected (in one direction only) systems (based on Fig. 5)

Measurements of average daily efficiency factor of the overall Singapore-London circuit for the period 26 March — 1 April, 1963 (average daily efficiency of overall Singapore-London circuit for this period 90 %).

A: System *A* (two-tone) B: System *B1* (FM)

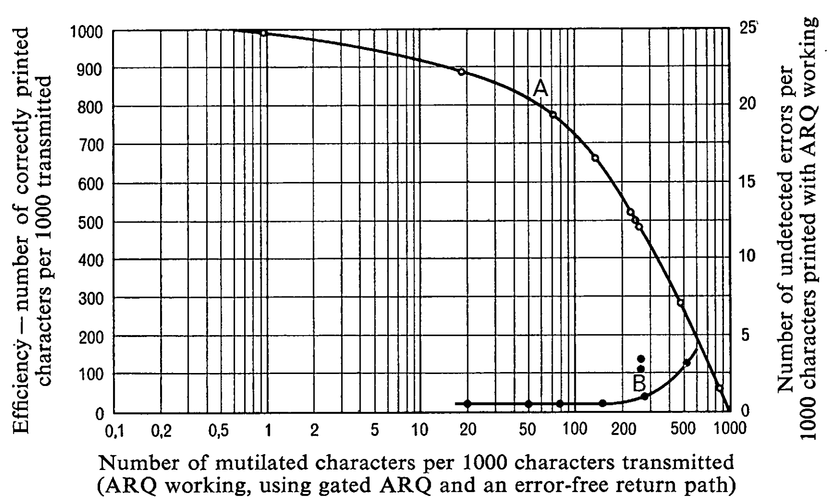

FIGURE 7

A: Efficiency of ARQ B: ARQ undetected errors

REPORT 346*

PERFORMANCE OF SYSTEMS USING PHASE-SHIFT KEYING OVER HF RADIO CIRCUITS

(Study Programme 17A-1/3)

(1966)

1. Introduction

This Report summarizes the results of a field test, in which the performance of two types of telegraph system using phase-shift keying, both employing four-phase modulation, are compared with a narrow-band system using frequency-shift modulation.**

2. Description of systems

It will be convenient to refer to the various systems by means of code designations defined as follows:

2.1 *System B1* is a frequency-shift system with a channel spacing of 170 Hz [Lyons, 1960]. The modulation rate of each channel is 75 bauds and the frequency-shift is 85 Hz.

2.2 *System C1* is a time-differential phase-shift keyed system (TD-PSK) according to the principles described in [Doeltz *et al.*, 1957; Mosier and Clabaugh, 1955], in which two information bits are phase multiplexed on each of twenty tones. All tones are keyed isochronously at a rate of 75 bauds, thus providing an aggregate data capacity of 3000 bit/s. Each receiving channel comprises two gated, very high-Q, mechanical resonators. These are connected alternately to the signal path during successive element periods, so that the incoming signal is integrated during one period and stored for reference use during the next. Phase comparison between the oscillations in the two resonators near the end of each element period effectively demodulates the signal. Each resonator is quenched at the end of its storage period, immediately prior to being reconnected to the signal input. The gating period of the signal (before integration) is somewhat less than the duration of the signal element length so as to reduce the effects of distortion occurring at the signal transition due to multipath propagation. Synchronization is obtained by means of a transmitted pilot tone.

2.3 *System C2* is a frequency-differential phase-shift keyed system (FD-PSK) according to the principles described in [De Haas, 1965; Walker, 1965], in which three information bits are phase coded on each of forty tone pairs (channels). All channels are keyed isochronously at a rate of 25 bauds, thus providing an aggregate data capacity of 3000 bit/s. In addition, twenty-two unmodulated reference tones are transmitted, spaced at regular intervals throughout the baseband, so that there are two information channels between adjacent reference tones. At the receiver, all tones are translated to a common processing frequency, the reference tones are extracted by means of narrow-band filters and phase-demodulation is effected by cross-correlating each signal tone with a phase reference obtained by linear addition of appropriate fractions of the two references which bracket the signal tone. A delay line in the information tones path provides compensation for the delay in the narrow-band reference extraction filters. By virtue of the long transmitted symbol compared to the prevailing multipath delay, spread-inter-symbol interference is minimized. Synchronization is obtained through the use of two unused channel positions and by comparison of the phase of the beat frequencies between successive reference tones with the receiver time base.

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* Adopted unanimously.

** Results of laboratory tests comparing one type of system using phase-shift keying with a two-tone system and a narrow-band system using frequency-shift modulation are given in [Ridout and Wheeler, 1963].

3. Comparison of systems B1, C1 and C2

The tests were conducted over an available commercial radio circuit from Pretoria, South Africa to Riverhead, Long Island, United States of America, a great circle distance of approximately 12700 km. The emission of the transmitters was a reduced-carrier, independent single-sideband (ISSB) signal, with a maximum of 12 kHz bandwidth consisting of four independent 3 kHz baseband slots. Both transmitter and receivers were frequency stabilized by means of synthesizers, providing frequency stability of 1 part in 10^8 per day. At the receiving terminal at Riverhead, the test signals were received in space diversity by two rhombic antennae, feeding the stabilized receiving system consisting of two receivers and two converters.

3.1 *Test arrangements*

Whenever possible, two systems were run simultaneously in the two 3 kHz slots on either side of the carrier ("dual mode"), with periodic sideband switching to average out any systematic channel inequalities. However, conditions of unequal QRM in the two slots often precluded this mode of operation. Under such conditions, the three systems were tested on a sequential basis, each system having an "on" period of fifteen minutes, with five-minute silent periods between successive test periods to evaluate channel noise and QRM.

To evaluate the performance of each system on an equal energy per bit basis, the available transmitter power was maintained constant while the voice-frequency output level of each data system (drive) was set in accordance with the values computed to provide equal energy per bit. In these computations, the total composite signal powers of the PSK systems (including pilot tone and reference tone powers) were used as the basis for determining the energy per bit values.

Collateral data on the characteristics of the propagation medium were continuously monitored visually by means of two spectrum analysers and audibly by means of a loud-speaker. In addition, pen recordings were made of the a.g.c. voltages of the HF receivers. By comparing the a.g.c. level during the test run with the levels during the preceding and following five-minute off periods, a measure of received signal-plus-noise to noise ratio was available.

Manually set-up word generators were used to supply the modems at the transmitting terminal with a 52-bit binary sequence, and to detect errors at the receiving terminal. Sixteen bits of this pattern were used for sequence synchronization purposes. Bit timing for the word generators was derived from the timing clocks of the modem(s) under test.

The test circuit was operated during two 30-day test periods, which included the month of April, 1964, and the period from 15 June to 14 July, 1964.

The accumulation of test data was hampered by all the usual difficulties of HF communications. In general, data runs could be attempted for only about 16 hours out of each 24-hour period. During the hours of 0100 to 0900 GMT the circuit was not usable because of extreme QRM or lack of signal strength.

The amount of QRM experienced throughout the entire test period was a particular difficulty. Some QRM was experienced at nearly all times of the day. At times, it was possible to sidestep this type of interference by moving the radio-frequency carrier by 500 to 1000 Hz in an attempt to move away from the interfering signal.

Finally, test data time was limited by circuit outages experienced during frequency changeovers. This problem was minimized whenever possible by frequency dualling when extra transmitters were available.

3.2 *Test results*

Fig. 1 presents the cumulative performance curves for the three systems, representing some 100 hours of recorded data and including periods of significant QRM and severe atmospheric noise.

Fig. 2 gives scatter-diagrams showing the comparative results of parallel runs between TD-PSK/FSK and FD-PSK/FSK. These results exclude data known to contain significant QRM or known to contain moderate to severe static (exceeding 100 static bursts per run). The diagonal in a scatter diagram is the locus of points of equal performance and divides the diagram in two fields. The result of each parallel run is plotted as a point in the diagram, with ordinates corresponding to measured bit error rate of each system.

3.3 *Discussion of results*

The FSK system was not operated at the optimum keying speed consistent with its channel characteristics (Recommendation 436-1, New Delhi, 1970). (Theoretical considerations and experimental results show that under conditions of constant energy per bit, this represents a penalty in the performance of the FSK system of approximately 0·5 dB; that is, at optimum modulation index, the FSK system would have required 0·5 dB less signal-to-noise ratio for a given error rate. In addition, the aggregate data capacity of the FSK system used should be considered to be 1600 bit/s in a 3 kHz channel.

The results presented in Figs. 1 and 2 show that both PSK systems performed about as effectively as the particular FSK system tested. The "goodness" criterion for the type of curves of Fig. 1 is quite evident as long as the curves do not cross over. A cross-over may result from the type of time distribution of error rates, and the inclusion of sequential runs, where the amount of data, especially at the lower error rates, may not be sufficient to ensure averaging out of differences in channel conditions.

The apparent randomness of the scatter diagrams of Fig. 2 is typical of HF communications. Similar results can be obtained when comparing individual channels of a single multi-channel system.

Observed values of multipath spread were in general between 1 and 2 ms, with occasional values of up to 3 or 4 ms. The tests were conducted during a year of low sunspot activity, and larger values may therefore be expected for this circuit under conditions of higher sunspot activity. The observed values, however, are not abnormally low for many circuits, although values in excess of 4 ms may be encountered during 1% to 2% of the time (Report 203).

4. Use of bit-synchronous systems on protected circuits

Present-day practice tends to identify a channel of a multi-channel voice-frequency telegraph system with a given number of ARQ channels; for example, it is common practice to send two-channel ARQ (96 bauds) over each channel of a narrow-band (170 Hz spacing) FSK system. The fact that the channel rates of PSK systems are often not directly compatible with the ARQ rate, and the need for isochronous keying of all channels in unison, have been cited as a disadvantage of these systems. However, PSK systems, as in the examples, have capacities which are multiples of 300 bit/s, e.g. by using six-channel ARQ operation (288 bauds) on channel blocks of 300 bit/s capacity, the loss in efficiency of the PSK systems would be not more than 4%. Furthermore, the synchronous character of the PSK systems, coupled with an intelligent use of the "spare" bits, may well prove to be of considerable value in automatic phasing of the ARQ systems in multi-channel point-to-point operation. For the introduction of PSK systems on ARQ circuits, operational procedures have still to be developed.

5. Conclusions

The limited duration of the tests preclude definite conclusions with respect to the relative performance of PSK and FSK systems for ionospheric transmissions. However, the tests demonstrated that, under conditions reasonably typical for systems of the fixed service, the four-phase PSK systems compared to a conventional two-level FSK system were capable of providing increased bandwidth efficiency without penalty in error rate, or total power, for the same amount of information transmitted.

6. General remarks

The tests discussed in this Report refer only to a limited number of systems. Other techniques may be able to achieve equal or better results.

Members of the C.C.I.R. are urged to submit results of tests of any such systems.

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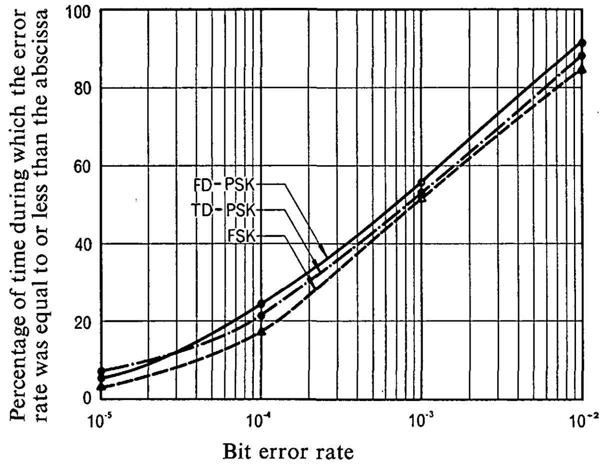

FIGURE 1

Cumulative performance curves

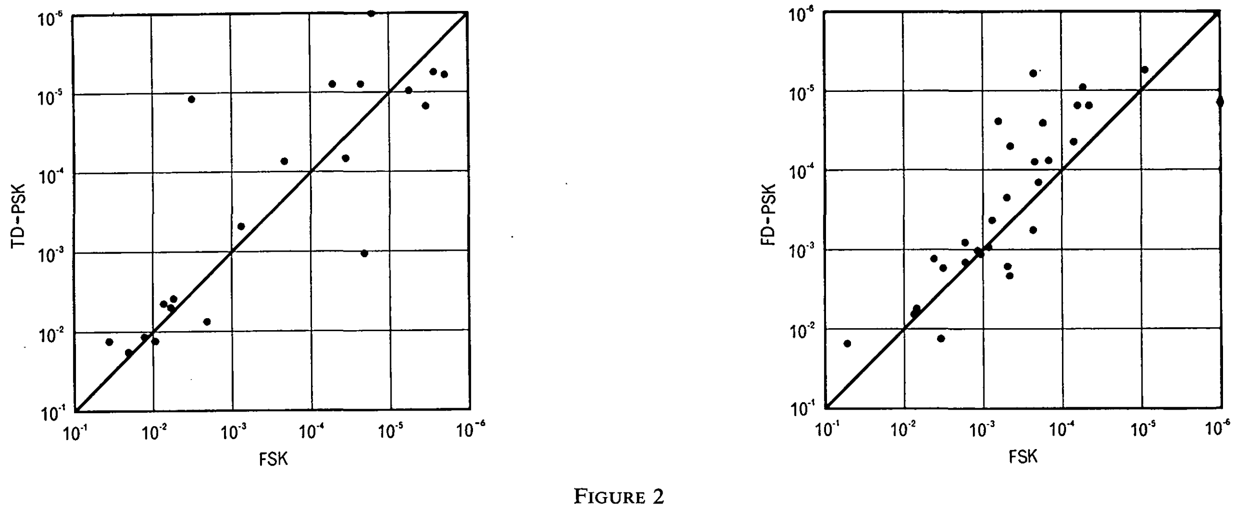

FIGURE 2

Scatter diagrams of error rates for parallel runs

REPORT 347*

VOICE-FREQUENCY TELEGRAPHY OVER RADIO CIRCUITS

(Study Programme 17A-1/3)

(1966)

On certain radio circuits with special characteristics (e.g. North-South links, such as Paris–Abidjan), several Administrations have since 1965 used automatic 96-baud error-correction devices associated with voice-frequency, multi-channel, frequency-shift telegraph systems with a channel spacing of 120 Hz and a frequency shift of ±35 Hz as in the Table of Report 42-2. The systems used were arranged for radio circuits.

Circuits thus set up are used in particular for transmission of cyphered messages and they have been working satisfactorily since they came into operation. Measurements conducted by the French Administration using error correction over such a circuit during a period totalling more than 50 hours showed that values of efficiency factor were achieved in accordance with the attached curve.

This method of operation may suit quite a large number of links (e.g. Europe-West Africa links) and bearing in mind the constant search for the most rational use of the radio spectrum, it is concluded that as much information as possible should be obtained on the performance of circuits of this type, in particular concerning the undetected error rate.

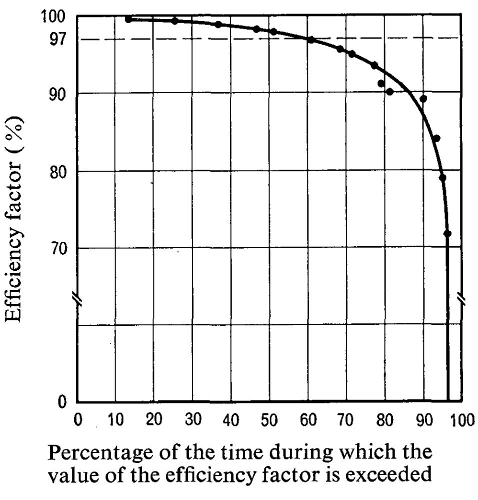

FIGURE 1

Distribution of efficiency factor in a 100-baud ARQ system with a 120 Hz central frequency spacing

* Adopted unanimously.

REPORT 348-2*

SINGLE-CHANNEL SIMPLEX ARQ TELEGRAPH SYSTEM

(Study Programme 1A-2/3)

(1966 – 1974)

1. Study Programme 1A-2/3 points out that regard should be given to new techniques and systems for application to the fixed services.

2. Large areas of the world do not yet have the facility of being connected to the international telegraph network, although they have a potential need for the exchange of messages by telegraph.

2.1 The amount of traffic to be dealt with will initially be small and the distances to be bridged will usually be great. A HF radio system might therefore best be suited to link an isolated station to one of the offices of the world-wide telegraph network.

2.2 A suitable HF radio system could be a synchronous telegraph system making use of the well-known principle of automatic error correction, by which the quality of the radio circuit is improved to a grade comparable with that of landline connections.

2.3 To participate in the telex network, the direction of traffic flow should be instantly reversible.

2.4 The location of such isolated stations often does not permit the simultaneous use of the radio transmitter and radio receiver.

2.5 It may be useful to employ the same frequency in both directions of a circuit.

2.6 The power consumption of the equipment should be kept to a minimum.

2.7 The system should not be unduly complex.

3. A telegraph system that is quite useful for the practical realization of these facilities is the one for the maritime mobile-services, described in Recommendation 476-1.

REPORT 349-1*

SINGLE-CHANNEL RADIOTELEGRAPH SYSTEMS EMPLOYING FORWARD ERROR CORRECTION

(Study Programme 18A/1)**

(1966 – 1970)

1. Introduction

Contributions by Administrations to the XIth Plenary Assembly, Oslo, 1966, provided a basis for a preliminary report on the question of protection of single-channel radiotelegraph channels by means of methods of forward error correcting. The experimental results reported in Docs. III/113 (XIII/82) and XIII/120, 1963–1966, are summarized in this Report, as well as the pertinent Docs. III/107 and III/117, 1963–1966 and Doc. III/9 (United States of America), 1966–1969. More detailed tests, utilizing laboratory simulation, were reported in Docs. III/81 and III/91, 1966–1969, and are also summarized.

* Adopted unanimously.

** This Study Programme replaces Study Programme 5A/III.

2. Summary and discussion of reported results

2.1 Docs. XIII/82 (United Kingdom) and XIII/120 (Norway), 1963–1966, both report on trials conducted with a system described by Keller [1963]. This system uses a ten-unit self-checking code, a synchronous mode of transmission and is capable of correcting all single errors in the text and of detecting all double errors as well as most multiple errors introduced by the transmission path.

The ten-unit code consists of the 5 elements of the International Telegraph Alphabet No. 2 followed by 5 parity check elements. The 5 parity elements are either an erect or an inverse repetition of the information elements, depending on whether the Z count in the information elements is odd or even. Errors which are detected, but cannot be corrected, are indicated by the printing of "error" symbols, usually combination 31 or 32.

Transmission over the radio circuit is at modulation rates of 62·3, 68·5 or 102 bauds for teleprinter circuits operating at modulation rates of 45·45, 50 and 75 bauds respectively. At the lower modulation rates, the system is capable of extension over the inland telegraph network using conventional 50-baud voice-frequency channels.

No special phasing signals are required, as the system is capable of fully automatic phasing during periods of traffic as well as during periods of idling.

The system reported in Docs. XIII/82 and XIII/120 is currently in commercial service. Results obtained from field trials with this system are summarized in Table I.

In addition to these results, Doc. XIII/82 also reports that over the period of 7 August 1965 to 27 November 1965 a total number of 1099 data tapes, each containing between 1500 and 1800 characters, were transmitted from ships at sea to an office in London. Of these, 889 were accepted without need for later re-transmission (i.e. contained no errors).

It is further reported that tests between ship and shore stations with plain language messages, and ship-borne reception of broadcast services (e.g. press transmissions) were considered satisfactory, provided some measure of diversity in reception is used.

A further development of the system described above consists of element interleaving of blocks of 10 characters, providing 10 element (145 ms) error-burst correction capability.

2.2 Doc. III/107 (Netherlands), 1963–1966, proposes a single-channel error indicating system, operating at a modulation rate of 100 bauds, having to some extent capability for error correction. The system uses a constant-ratio, seven-unit error detecting code, described in Doc. III/82, 1963–1966, but transmits each character twice with four other characters (equivalent to 280 ms) between the repetitions. If the reception of the first transmission of a character passes the constant-ratio check, it is accepted and passed to the printer through a delay circuit. If not accepted, the reception of the repeated transmission of the character is checked, and if accepted is passed directly to the printer. If neither reception is found acceptable, a special "space" symbol is printed.

Furthermore, a third decision can be taken into account when it is not sufficiently sure whether a mark or space was received (zero-position marker). When this condition occurs, it also results in the printing of the special "space" symbol.

Transmission over the radio circuit is at a modulation rate of 100 bauds for teleprinter circuits operating at a modulation rate of 50 bauds.

Before starting the transmission of information, and in the idle time between successive messages or message blocks, the transmitting station emits idle-time signals which are also used for phasing.

This system may be viewed in either of two ways:

- as a time-diversity system with additional error detection capability. In this case, error performance (including detected but uncorrected errors) appears to be similar to the performance obtained by straight time-diversity such as reported by Lyons [1964], provided that the separation of error bursts is not less than 420 ms. The additional four bits used in the system proposed in Doc. III/107 are used both for diversity selection and for error detection;
- as a time-spread forward error-correcting system. As such, the system is capable of correcting all single errors and most multiple errors, including error bursts of up to 280 ms, provided that the period between the occurrence of errors is at least 420 ms. It is further capable of detecting most uncorrectable errors.

Systems performance measurements, utilizing laboratory simulation, have been made (see § 3.2).

2.3 The time-diversity system reported by Lyons [1964, 1965a and b] provides a burst error-correction capability for bursts up to 1·5 s, as well as having the capability of correcting most single and other multiple errors. It is particularly suitable for the reduction of errors due to time-variant distortion effects commonly experienced on HF radio circuits, such as impulsive or burst noise, sporadic interference and certain cases of selective fading due to multipath propagation.

The system utilizes two adjacent channels of a multi-channel voice-frequency frequency-shift system, each operating at a modulation rate of up to 100 bauds. One of the two channels transmits the information without delay (hereafter called the normal channel), while the other channel transmits the same information, but delayed in time by approximately 1·5 s (hereafter called the delayed channel). In addition, a parity bit is inserted after each nine information bits in the input bit stream. The information rate (bit/s) on the system is then equal to 0·9 times the modulation rate of either of the voice-frequency telegraph channels. The system is independent of input format and can be used equally well with character type transmission as with random digital input data.

Upon reception, both the normal and the delayed channel are examined for bit distortion (margin assessment) and, based on this assessment, either the normal or the delayed channel is selected as the primary channel. If, however, a parity error is found in a block in the primary channel, only that block is then taken from the other channel, provided it has no parity error.

Results obtained from a field trial of several weeks duration over a long-haul HF circuit using dual space diversity at the receiving end showed that for character error rates of approximately 1×10^{-2} on the normal channel without time diversity, the corresponding error rate of the time diversity system (measured simultaneously) was approximately 1×10^{-5}.

2.4 Doc. III/117 (United States of America), 1963–1966, refers to four general types of forward error-correcting codes suitable for use on HF radio circuits. It further reports results from two field tests:

2.4.1 a system using a (15,10) block code (i.e. 10 information bits and 5 check bits per block), interleaved to provide 2 s burst error correction capability. This system was tested at teletype speeds over an HF link [Fritchman and Leonard, 1965], and provided an improvement in the bit error rate of about one order of magnitude when the uncorrected channel error rate was 1×10^{-2}, and two orders of magnitude when it was 1×10^{-3};

2.4.2 a system using an adaptive convolutional code (Gallager code) with maximum burst error-correction capability of 6 s. A specific feature of this system is that the error-free interval, required for burst correction (guard space), is equal to the actual length of the burst plus about 20 bits, rather than equal to a fixed interval determined by its maximum burst correction capability.

A test is reported whereby this system was compared with the use of frequency diversity. Analyzed in terms of blocks of about 3300 telegraph characters, it was found that, with the coding, over 90% of the blocks were error free, as compared with about 15% of the blocks when using diversity [Kohlenberg and Berner, 1966].

3. Systems performance measurements utilizing laboratory simultation

3.1 Doc. III/81 (United Kingdom), 1966–1969, presents a comparison between typical forward error correcting systems tested under simulated propagation conditions in band 7 (HF) [Law *et al.*, 1957]. The systems all accepted and delivered 50-baud start-stop teleprinter signals but used synchronous transmission in the radio path, the modulation rate of which is indicated in § 3.1.1 individually.

3.1.1 The systems tested were as follows:

System A, as described in § 2.1, with no element interleaving. Synchronous modulation rate 68·5 bauds.

System B, as system *A* but with blocks of 10 characters element-interleaved. Synchronous modulation rate 68·5 bauds.

System C. A half-rate, recurrent code similar to [Hagelbarger, 1959], but with two additional check elements per character to detect uncorrected errors and substitute error symbols, and internal dispersion giving 12 element (145 ms) error-burst correction. Synchronous modulation rate 83 bauds.

System D, as described in § 2.2 without third-decision detector (zero position marker). Synchronous modulation rate 100 bauds.

System D′, as system *D*, but with third-decision detector. Synchronous modulation rate 100 bauds.

System E. A half-rate diffuse convolutional code with threshold decoding giving 32 element (350 ms) error-burst correction [Electronics, 1965; Kohlenberg and Forney]. Synchronous modulation rate 90 bauds.

Reference system. Uncoded except for the addition of one element per character for character synchronization. Synchronous modulation rate 42·3 bauds.

3.1.2 *Test conditions*

3.1.2.1 *Modulation F1*, phase continuous, 170 Hz total frequency-shift.

3.1.2.2 *Demodulation*. Two alternative methods of demodulation were employed:

— filter-assessor with filter bandwidths of 140 Hz (3 dB);

— limiter-discriminator with predetection filter bandwidth of 180 Hz (3 dB), except for system *D′*, which had a built-in limiter-discriminator with a predetection filter bandwidth of 500 Hz (3 dB).

3.1.2.3 *Digital test signal*. Repetitive pattern consisting of all the characters of International Telegraph Alphabet No. 2, except combination 32 (all space).

3.1.2.4 *Simulated propagation conditions.* Measurements were made with flat, Rayleigh distributed random fading and with selective fading produced by equal activity, independently-fading, two-path propagation having a path-time difference of 2 ms. Tests were made with quasi-random fading rates of 10 and 40 fades per minute. Additive Gaussian noise was used and the signal-to-noise ratio was normalized [Report 195, § 1], but with respect to the nominal data transfer rate (50 bauds) instead of to the modulation rate in order to provide a more objective evaluation of the advantages of forward error correcting coding systems.

3.1.2.5 *Character error count.* Incorrectly printed characters (i.e. undetected character errors) and printed error symbols were counted as character errors.

3.1.2.6 *Test results.* Figs. 1 to 4 represent the results of the tests for dual space diversity and for single aerial reception. System D' was not tested with diversity reception.

3.2 Doc. III/91 (Netherlands), 1966–1969, presents performance measurements for two forward error-correcting systems under simulated propagation conditions in band 7 (HF) [Law *et al.*, 1957]. Both systems accepted and delivered 50-baud start-stop teleprinter signals and used synchronous transmission in the radio path.

3.2.1 *The systems tested* were as described in § 2.2, one system with and the other without third-decision detector. Synchronous modulation rate for both was 100 bauds.

3.2.2 *Test conditions*

3.2.2.1 *Modulation F1*, phase continuous, 200 Hz total frequency-shift.

3.2.2.2 *Demodulation* limiter-discriminator with predetection filter bandwidth of 500 Hz (3 dB). The third-decision detector, when used, was adjusted to 33 % of peak detector output.

3.2.2.3 *Digital test signal.* The test signal consisted of repetitive transmission of signal *R* of Report 348-2.

3.2.2.4 *Simulated propagation conditions.* Measurements were made with flat, Rayleigh distributed random fading and with selective fading produced by equal amplitude, independently phase-varying, five-path propagation with time delays of 0·5 ms between successive paths. Tests were made with quasi-random fading rates of 10, 30 and 40 fades per minute. Additive Gaussian noise was used and the signal-to-noise ratio was normalized [Report 195, § 1] to the modulation rate (100 bauds). Figs. 5 to 8 in this Report have been adjusted to a normalized S/N ratio with respect to the information transfer rate (50 bauds) to achieve conformity with § 3.1.

3.2.2.5 *Character error count.* Incorrectly printed characters (i.e. undetected character errors) and printed error symbols were counted as residual character errors (E_R). Undetected character errors were also counted separately (E_u).

3.2.2.6 *Test results.* Figs. 5 to 8 represent the results of the tests for single antenna reception.

3.3 *Discussion of results*

3.3.1 Selective fading characteristics corresponding to equal activity, independently fading, two-path propagation with a path-time difference of 2 ms and a fading rate of 10 fades/minute were chosen in the tests of § 3.1 as being representative of very unfavourable propagation conditions, and thus provide a lower bound on the performance that might be expected from the various systems tested.

The condition of flat, Rayleigh-distributed random fading with a fading rate of 10 fades/minute represents rather favourable propagation conditions, but cannot be taken as an upper bound as all the forward error-correcting systems gave a better performance with a fading rate of 40 fades/minute. This may be taken as an indication that a longer burst-error correction capability might be beneficial to cope with the lower fading rates.

3.3.2 Figs. 1 to 4 represent the results of the tests described in § 3.1. It was found that, under the particular test conditions described in § 3.1.2, the filter-assessor method of demodulation gave markedly superior results in the presence of selective fading. This can be accounted for by the distortion effects that arise from multipath propagation when using narrow predetection filter bandwidths with limiter-discriminator detection [Groves and Ridout, 1966].

With the filter-assessor method of demodulation, all forward error correction systems tested gave an improvement over the reference system, the performance of individual systems being within 1 or 2 dB of one another.

With the limiter-discriminator method of detection and under conditions of selective fading with a fade rate of 10 fades/minute, the individual performances of the different systems varied more widely. The performance of the reference system, under these conditions, was equal to or better than the performance of some of the forward error correcting systems. This may be ascribed to the lower modulation rate of the reference system, and the consequently lower distortion experienced.

With respect to the curves of system D', it must be remembered that the predetection bandwidth for this system was 500 Hz as compared to 180 Hz for all other systems with limiter-discriminator demodulation. The threshold of the third decision detector was set to approximately 50% of the peak detector output.

3.3.3 Selective fading characteristics corresponding to those produced by five equal amplitude, independently phase-varying, path components with incremental time delays of 0·5 ms were chosen in the tests of § 3.2 as being representative of fairly severe multipath conditions. Fading rates of 10, 30 and 40 fades/minute were used to evaluate the effectiveness of the forward error correcting methods, which have a fixed amount of burst error correction capability.

3.3.4 Figs. 5 to 8 represent the results of the tests described in § 3.2. Both the residual error rate (E_R) and the undetected error rate (E_u) (see § 3.2.2.5) are shown in these figures.

Under all conditions, E_R improves with increasing fade rate, as would be expected from the fixed value of time delay between the first part and the second part of the (14 element) character.

Under flat fading conditions, E_R approaches E_u at very high S/N ratios, indicating that under these conditions most of the residual errors are undetected. Application of third decision detection shows a significant decrease in E_u for both fading rates, and thus a significant decrease in E_R at high S/N ratios.

Under selective fading conditions, E_R does not approach E_u at very high S/N ratios, and the results show that most of the residual errors are detected but uncorrected. Application of third decision detection shows again a marked decrease in E_u, but in this case a slight increase in E_R, indicating an increase in detected but uncorrected errors.

3.4 Phasing time is an important aspect of the application of forward error-correcting systems. Phasing time of the different systems under all test conditions was measured in the tests described in § 3.1. Systems D and E invariably phased in less than one second. The median times for systems A, B and C were of the order of 15 s. The phasing times observed in 99% of the tests of these three systems were less than 21, 47 and 25 s respectively. In conditions of very high error rate no system was able to achieve phase.

4. Conclusions

Performance of uncoded frequency-shift-keyed systems is, amongst others, dependent on multipath time delay spread and configuration (i.e. number and activity of individual paths), modulation index and predetection filter bandwidth in the case of limiter-discriminator detection.

For coded systems, fading rate also becomes an important factor as this has a significant influence on the time distribution of the errors.

Attention is drawn to the importance of standardizing test conditions, the parameters of ionospheric channel simulators and typical patterns of ionospheric behaviour to enable the comparison between laboratory results to be improved (see also Question 21/3).

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Table I

Summary of results

1	2	3	4	5	6	7
Document Ref.	Trial and circuit details	Characters passed	Errors detected and corrected	Detected but uncorrected error rate	Residual uncorrected error rate	Overall error rate
XIII/82	Ship-to-shore, double-sideband transmission, single path reception	36 600	3·41 per 1000 characters	2·27 per 1000 characters	0·055 per 1000 characters	2·33 per 1000 characters
XIII/82	Ship-to-shore, single-sideband transmission, space-diversity reception					0·84 per 1000 characters
XIII/120	Ship-to-shore, double-sideband transmission, space-diversity reception (1) (2)	287 776		1·26 per 1000 characters	0·56 per 1000 characters	1·82 per 1000 characters
XIII/120	Ship-to-shore, single-sideband transmission, space-diversity reception (1)	42 952		1·42 per 1000 characters	0·54 per 1000 characters	1·96 per 1000 characters
XIII/120	Shore-to-ship, FSK transmission, single path reception	297 464		0·88 per 1000 characters	0·3 per 1000 characters	1·18 per 1000 characters
XIII/120	Shore-to-ship, FSK transmission, single path reception	54 508		1·76 per 1000 characters	0·31 per 1000 characters	2·07 per 1000 characters

(1) The distance between the two receiving antenna systems is rather small for space-diversity operation.

(2) For these trials the ship transmitter was reduced to ¼ of nominal power for technical reasons.

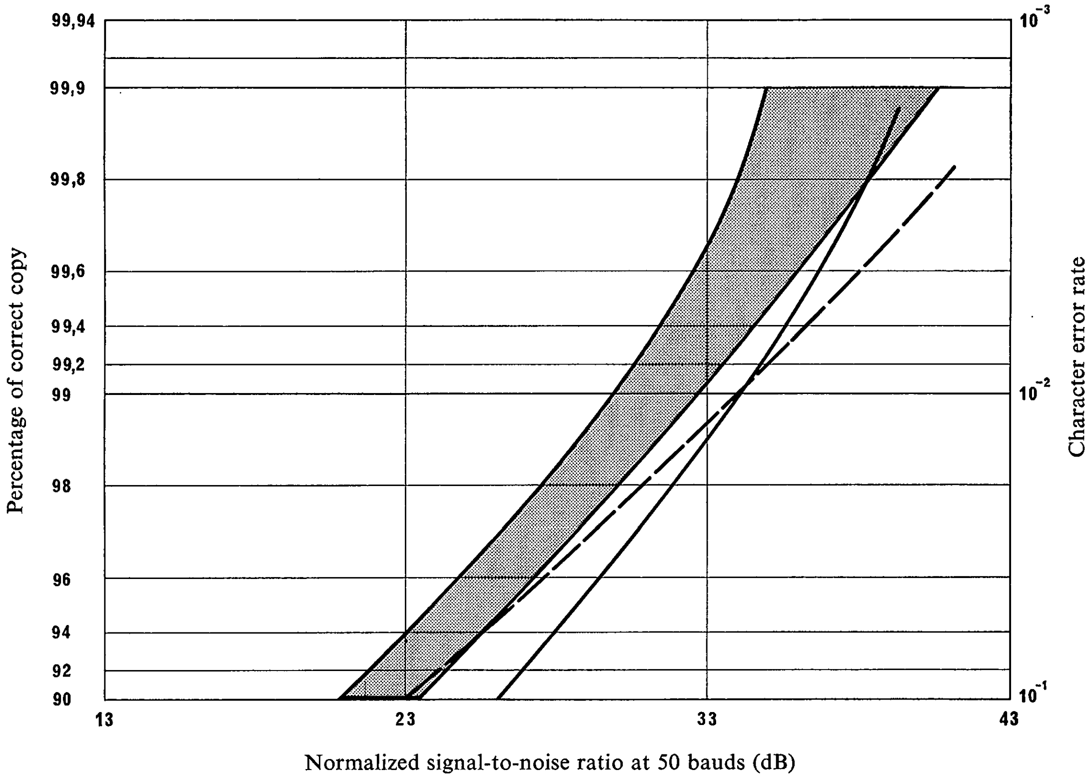


FIGURE 1

Comparison between forward error-correcting systems

Fading rate: 10/min, flat
Detector: filter assessor or limiter-discriminator
Diversity: none

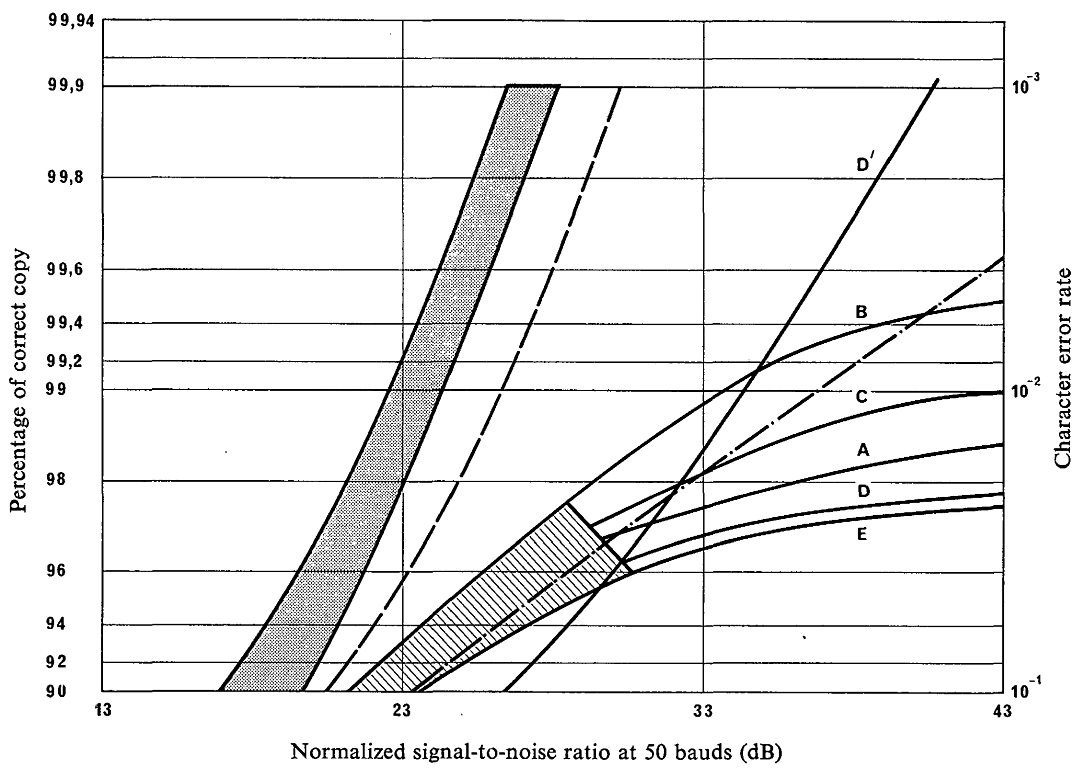


FIGURE 2

Comparison between forward error-correcting systems

Fading rate: 10/min, selective, 2 ms path-time difference
Detector: filter assessor of limiter-discriminator
Diversity: none

— — — reference system – filter assessor
(shaded) all other systems – filter assessor
—·—·— reference system – limiter-discriminator
——— system *D'*
(hatched) all other systems – limiter-discriminator

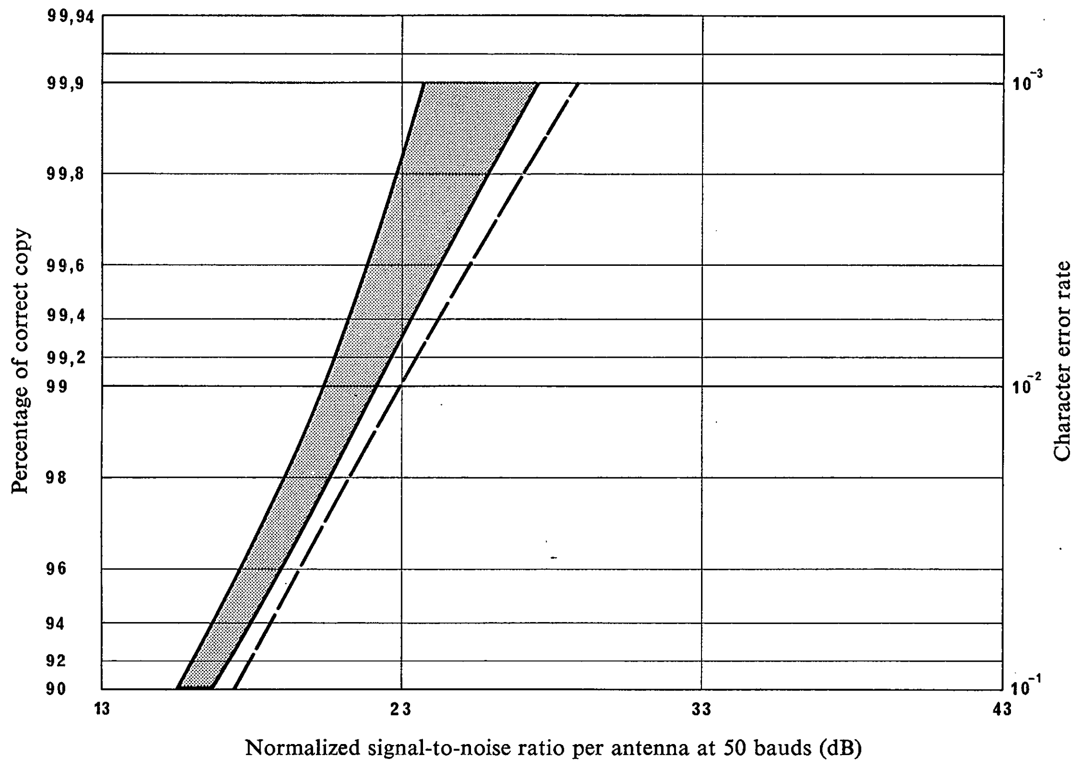


FIGURE 3

Comparison between forward error-correcting systems

Fading rate: 10/min, flat
Detector: filter assessor or limiter-discriminator
Diversity: dual-spaced antennae

— — — reference system

all other systems

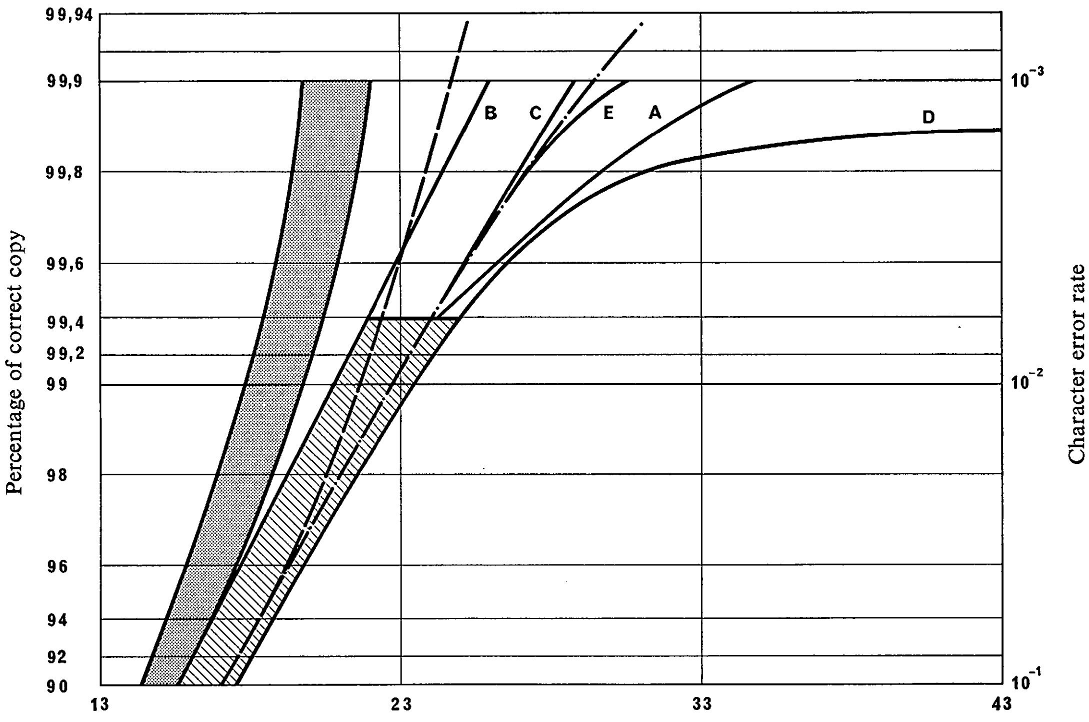
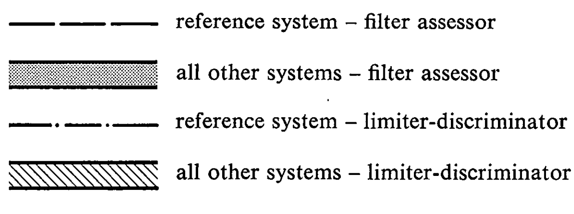


FIGURE 4

Comparison between forward error-correcting systems

Fading rate: 10/min, selective, 2 ms path-time difference
Detector: filter assessor or limiter-discriminator
Diversity: dual-spaced antennae



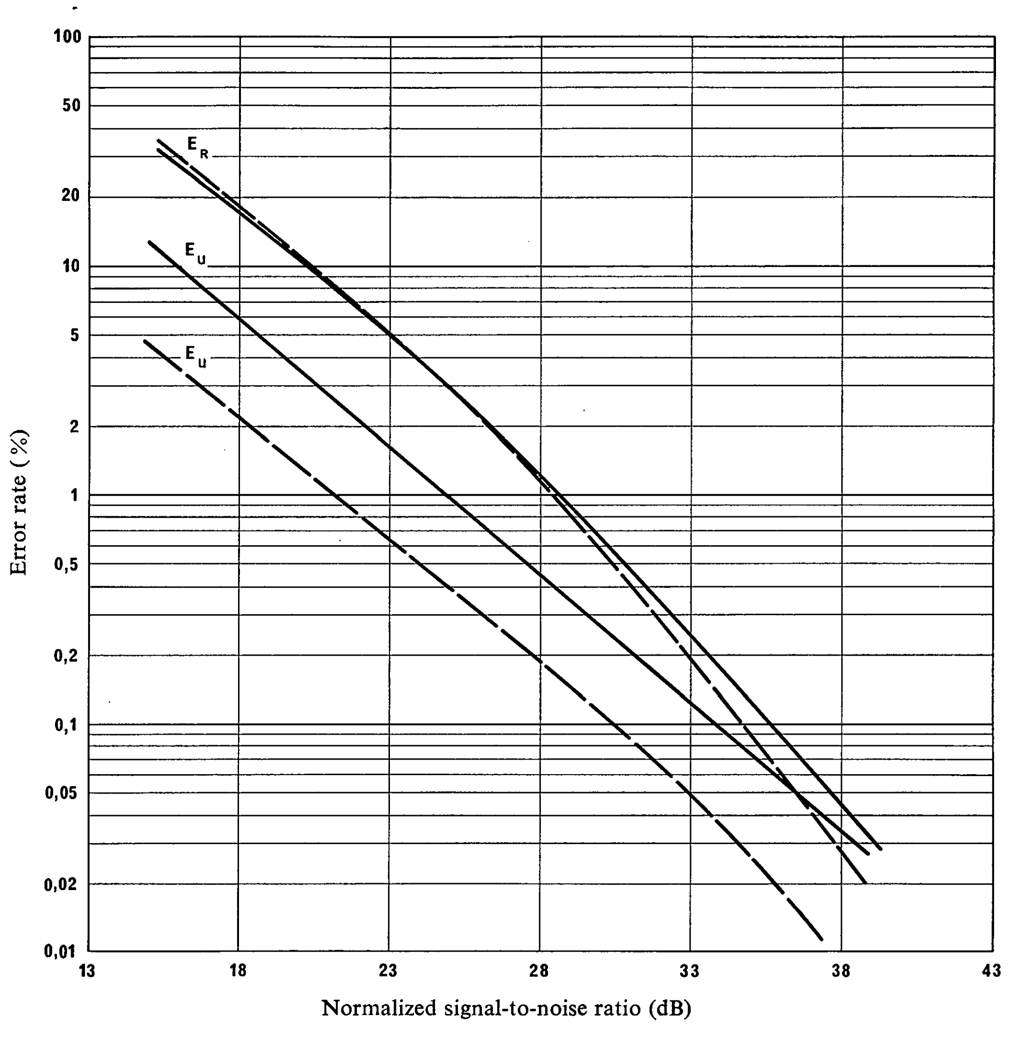
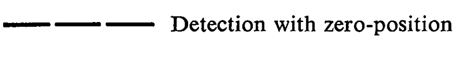


FIGURE 5

Residual error rate (E_R) and undetected error rate (E_u)

Flat fading, 10 fades/minute



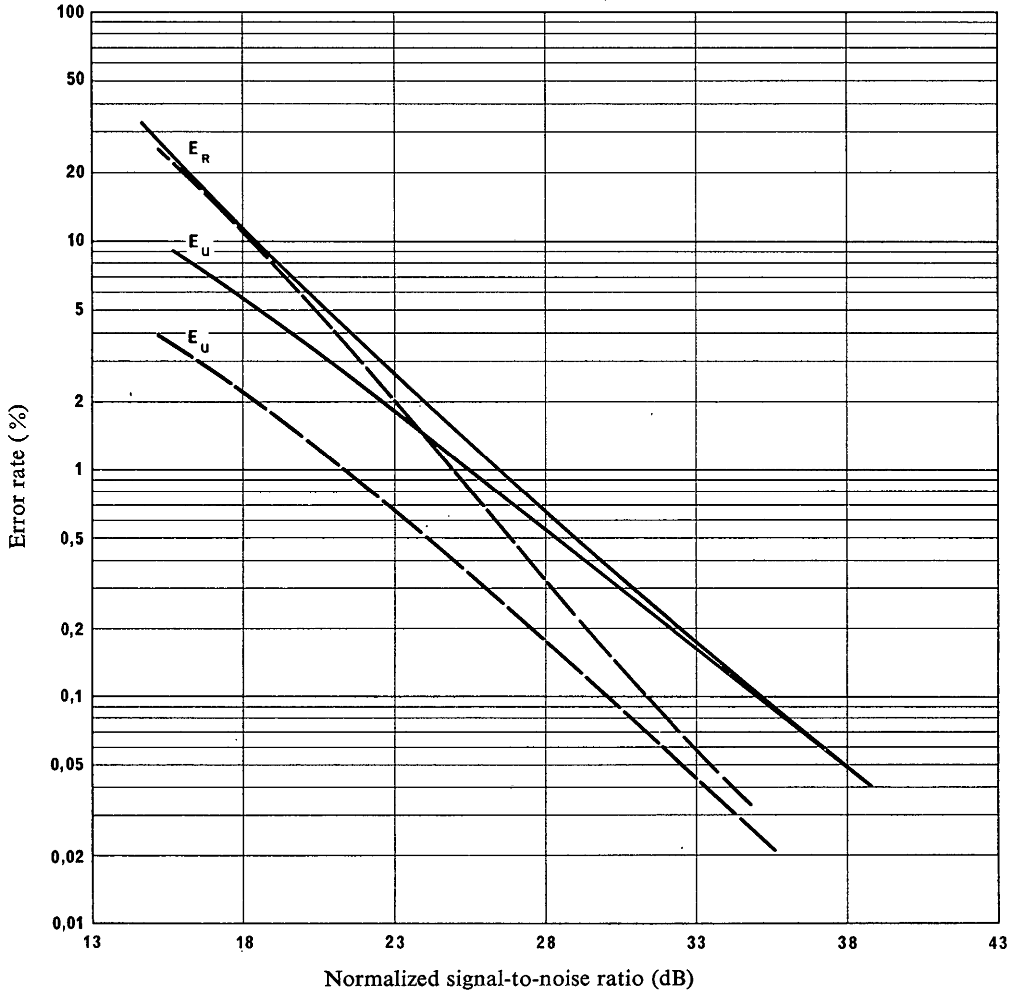


FIGURE 6

Residual error rate (E_R) and undetected error rate (E_u)

Flat fading, 40 fades/minute

——————— Normal detection

— — — — Detection with zero-position

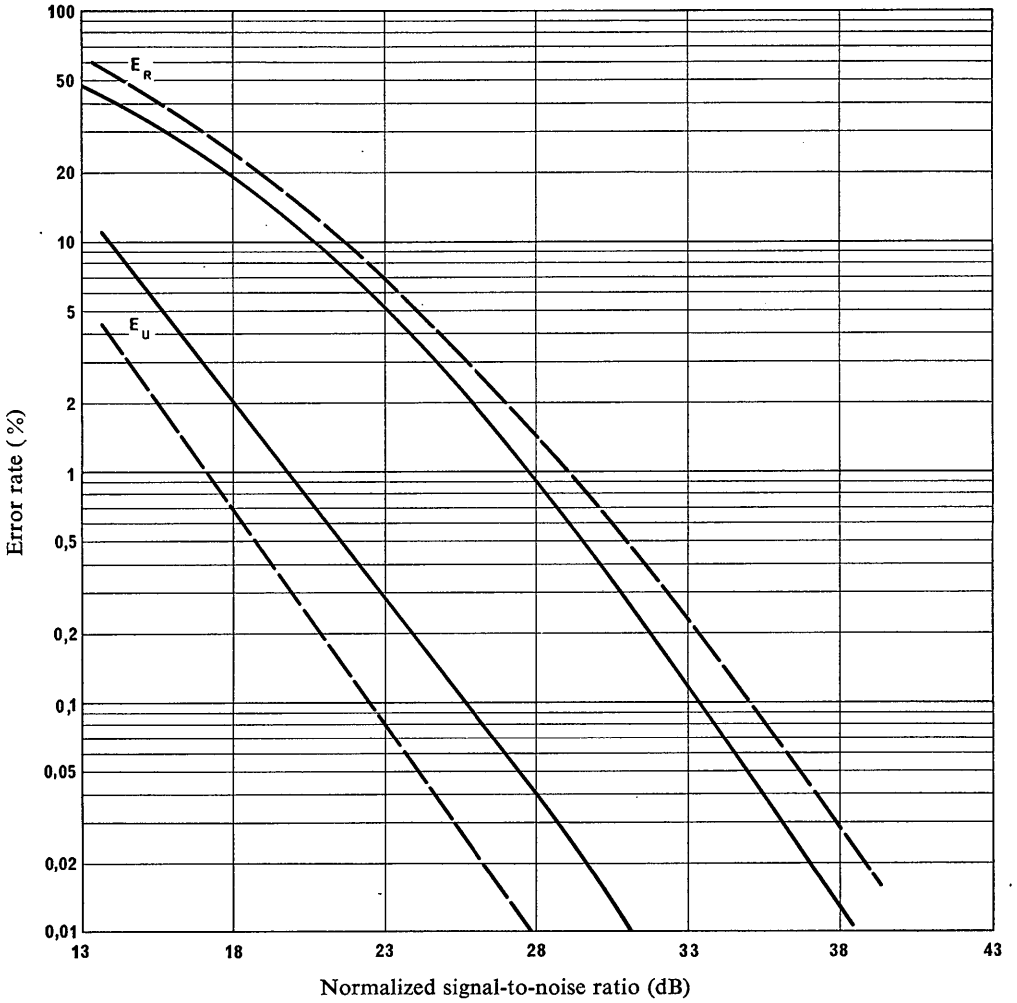


FIGURE 7

Residual error rate (E_R) and undetected error rate (E_u)

Selective fading, 10 fades/minute

——————— Normal detection

— — — — — Detection with zero-position

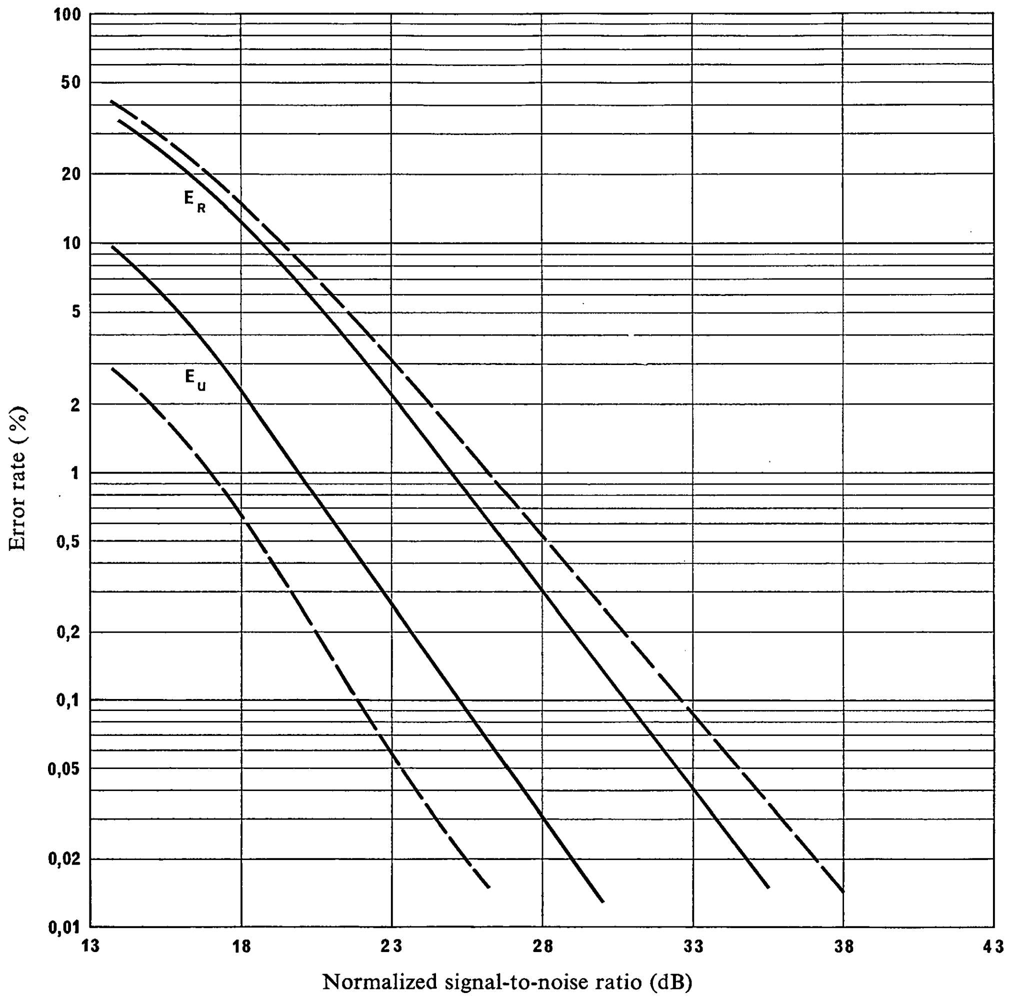


FIGURE 8

Residual error rate (E_R) and undetected error rate (E_u)

Selective fading, 40 fades/minute

——————— Normal detection

— — — — Detection with zero-position

REPORT 350*

SINGLE-CHANNEL DUPLEX ARQ TELEGRAPH SYSTEM

(1966)

1. Nowadays, multiplex systems effecting error correction by automatic repetition (ARQ), are frequently used in the transmission of telegraph signals over radio circuits. The characteristics of such ARQ systems are laid down in Recommendation 342-2.

2. Where the volume of traffic does not justify the use of more than one channel, a single-channel ARQ system seems appropriate. A possible solution is to follow the principles laid down in Recommendation 342-2, Annex I, §§ 1, 2, 4, 7**, 8*** and 9 where they apply to single-channel operation.

REPORT 351-2*

QUALITY OF PERFORMANCE OF RADIOTELEGRAPH SYSTEMS

(Study Programme 1A-2/3)

(1966 – 1970 – 1974)

1. Docs. III/23 (Federal Republic of Germany) and III/106 (Rev. 1), pp. 3 to 16 (Companhia Portuguesa Radio Marconi), 1963–1966, report on tests which were carried out on short- as well as on long-range ARQ-radio circuits, operated with a modulation rate 192 bauds, to analyse whether a correlation can be shown to exist between the results of the efficiency factor measurements and the assessment of the signal performance of the radio circuits.

Measurements of efficiency factor were made, using time intervals of 15 minutes (Doc. III/23) and intervals of 10 minutes, 1 minute and 20 seconds (Doc. III/106). Moreover, the mean value of the telegraph distortion and the relative field strength were recorded at the same time bases.

In addition, the following data were recorded in Doc. III/23: the operating frequencies, the variation of the geomagnetic field, the observed MUF and LUF values applicable to the circuits, the weekly and daily forecasts of MUF and LUF, the assessment of the quality of the circuits according to the SINPO code; and the following data were mentioned in Doc. III/106: the operating frequencies, the transmitting power, the class of emission, the transmitting and the receiving antennae gains, and the type of reception.

Identifiable disturbance due to causes other than the propagation medium were excluded from the results.

A critical study of results of the tests made shows that a correlation exists between the efficiency factor measured and the telegraph distortion at the radio receiver output. On several circuits, where the efficiency factor was measured over periods of 15 minutes, a correlation coefficient of between 0·8 and 0·5 has been established [Frommer *et al.*, 1965].

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

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

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* Adopted unanimously.

** For the purpose of this Report, Recommendation 342-2, § 7.1.2, Annex I, should be read as: "After appropriate counts of A and Z elements..."

*** For the purpose of this Report modulation rates of 48, 72 and 96 bauds with transmission cycles of 145 $^5/_6$, 97 $^2/_9$ and 72 $^{11}/_{12}$ ms apply respectively.

2. Doc. III/26 (Federal Republic of Germany), 1966–1969, describes an operational piece of equipment which was developed to enable simultaneous monitoring of up to 40 telegraph channels at a single supervisory position. This equipment continuously measures the distortion on each telegraph channel by comparison of two waveforms, one derived directly from the received keyed signal and the other from a local clock which is kept in long term synchronism with the received signal. Since only the absolute value of the distortion is of interest, no difference is made between early and late occurrence of transition points.

The measured distortion is indicated on strips consisting of ten lamps, each lamp representing a distortion range of 5 %. The length of a particular illuminated strip thus indicates the degree of distortion occurring on a specific channel. The indicated values are erased every 10 seconds, at which time a new measuring interval starts. Any lamp which is activated within a given measuring interval stays "on" during the remainder of this interval, thus providing a steady and easily readable presentation. At the end of each indicating strip, a specially marked warning lamp is provided which is activated whenever a predetermined degree of distortion is reached. In addition, a 40-track pen recording facility is included which provides for each channel a permanent record of the times that the distortion exceeded the maximum permissible threshold.

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

3. Doc. III/82 (United Kingdom), 1966–1969, describes the arrangements for centrally controlling a large group of radio receivers. Associated with a control panel for each receiver is a chart recorder with a memory of three hours which shows the level of the pilot carrier and the incidence of telegraph distortion at the receiver output. The latter information is derived from a telegraph distortion (short element) counter, set up to operate at 30 % element distortion which continually feeds an element integrater having a time constant of 80 seconds. The recorder is set so that the full scale deflection corresponds to 10 % of the elements exceeding 30 % distortion.

This is found to be a sensitive method of assessing the quality of the received signal and preferable to the use of the efficiency factor which is often determined by circumstances other than the propagation conditions over the radio path.

4. Doc. III/95 (U.S.S.R.), 1966–1969, reports on measurements of the transmission quality of a number of radiotelegraph circuits in the U.S.S.R., made throughout the years 1966–1968.

To evaluate transmission quality a "satisfactory operation factor", η, is defined as follows:

Satisfactory Operation Factor: the ratio of the time that the degree of distortion is within acceptable limits to the whole operating time. Degree of distortion is defined as that part of the total number of element transitions occurring in predetermined intervals that deviate more than a predetermined amount from the ideal instants.

For these tests, the degree of distortion was considered acceptable when the number of transitions with $\geqslant 40$ % distortion was less than 15 per minute. During the tests, the satisfactory operation factor was monitored automatically [Bukhviner, 1965; Bukhviner and Malygin, 1969].

Experimental tests on circuits of 2800, 5100 and 5400 km length showed an annual variation of the satisfactory operation factor with values between 0·87 and 0·92 in winter, and between 0·92 and 0·95 in summer [Bukhviner *et al.*, 1969]. The correlation γ between the degree of element distortion and the character error rate is closer when the element distortion becomes more pronounced. For distortion exceeding 40 %, γ was found to be greater than 0·85.

Doc. 3/17 (U.S.S.R.), 1970–1974, presents the results of simultaneous observation of the transmission quality at the two reception points of a 3000-km duplex radiotelegraph circuit. It was found that the difference between the satisfactory operation factor for the go and the return direction was always less than 5% (for any time of the day or night), and that the probability of coincidence of hourly values of η increases with the radiocircuit quality, as shown in Table I.

TABLE I

η % value	> 95%	95–90%	90–80%
Probability of coincidence of corresponding hourly measurements	1·0–0·83	0·8–0·6	0·65–0·6

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

It was also found that η increases when the ratio, m, of the operating frequency to the MUF is raised; however, for $m \geqslant 0{\cdot}65$ the value of η remains practically constant.

5. Conclusions

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

To evaluate radio transmission quality, the use of the satisfactory operation factor, as defined in § 4, is proposed. However, in those cases where it is impossible to use the value of measured telegraph distortion for the assessment of the efficiency of ARQ-circuits, as for instance with a "flex" system, the measurement of channel efficiency might be operationally preferable.

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REPORT 352*

USE OF PRE-EMPHASIS AND DE-EMPHASIS FOR PHOTOTELEGRAPH TRANSMISSION OVER HF RADIO CIRCUITS

(Study Programme 1A-2/3)

(1966)

1. Introduction

The relationship between the picture density and the degree of modulation at present used, concentrates the deterioration produced by noise at the darker end of the density range, whereas a linear relationship over the whole graduation range of picture density would distribute the effects of noise and so improve the picture quality. A further advantage would be to make the effect of frequency errors in transmission less noticeable.

To keep this relationship, a technique was introduced in Doc. III/31 (Japan), 1963–1966, which is described below.

2. Description of technique

The output of the photocell is proportional to the intensity of the reflected luminous flux, while the density of a picture is inversely proportional to the logarithm of the reflected flux.

The quality of the picture may be improved considerably when the signal is transmitted through a pre-emphasis network with a logarithmic characteristic, and received through a de-emphasis network with the inverse characteristic.

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REPORT 435*

ERROR STATISTICS AND ERROR CONTROL IN DIGITAL TRANSMISSION OVER OPERATING RADIO CIRCUITS

(Study Programme 18A/1)**

(1970)

1. Introduction

This Report describes some studies on error statistics in digital transmission over operating HF radio circuits. Some studies on the applicability of error control techniques are also included.

2. Error statistics

Brayer [1968] reports error-pattern data gathered from operational HF digital data transmission systems over long haul trans-equatorial paths. In one test, a four-level time differential phase-shift keying (PSK) modem with eight and sixteen tones for transmission rates of 1200 and 2400 bit/s, respectively, was used. In another test, three different types of PSK modems were used. In both tests, a sixteen-tone frequency-shift-keyed modem was used for reference purposes.

* Adopted unanimously.

** This Study Programme replaces Study Programme 5A/III.

Error patterns are classified into three classes:

— relatively random patterns,

— burst-error patterns,

— systematic error patterns (periodicity).

Cumulative distributions of error-free gap length show the frequent occurrence of periodic error patterns with the period corresponding to the number of sub-channels in the modem. It appears also, that the probability of short gaps is generally much higher than what would be expected from independent error patterns.

Moyes and Taylor [1966] report error statistics collected on a 5000 km medium-latitude HF path. A binary frequency-shift keying modem (without frequency-division multiplexing) was used at a transmission rate of approximately 72 bit/s. The average bit error rate for the entire test was $4{\cdot}7 \times 10^{-4}$ which is normal over this path. The data showed pronounced clustering of errors.

Greim [1960] reports error statistics collected on an HF teleprinter link from Bermuda to New York. A frequency-shift keying 60 words/min circuit modem was used with a frequency shift of ± 170 Hz. The data indicated that errors were dependent and highly correlated.

Konopleva (see Report 197-3, §4 and [Brayer, 1967; Brayer and Cardinale, 1967]) gives experimental results on the dependency of error rate on distance.

3. Error-control techniques

Brayer [1967] and Brayer and Cardinale [1967] report computer-simulated studies on the effectiveness of error-control techniques applied to the data they reported. The results indicate that:

— relatively random error patterns which, in general, were found to occur only at error rates of 1×10^{-4} and lower, can be corrected by applying long block codes such as the Bose-Chaudhuri (255, 123, 19) code;

— for burst type error patterns this type of code is not effective. For these patterns a relatively short block code, such as a modified Golay (24, 12, 3) code, with interleaving can be applied effectively;

— a relatively short block code with interleaving is also effective for relatively random patterns. All patterns which could be corrected by a (255, 123, 19) code could also be corrected by interleaving nine blocks of the (24, 12, 3) code;

— for periodic patterns the choice of the number of blocks to be interleaved is extremely important;

— a Massey half-rate diffuse convolutional code performed at least as well as any of the above interleaved or non-interleaved block code techniques.

Moyes and Taylor [1966] give the distribution of blocks of length n ($n = 15, 21, 23, 31, 33, 35, 39, 45, 51, 63$) which have m or less errors after applying interleaving of up to 32 s, as well as the same distribution without interleaving. These statistics indicate that the block code with and without interleaving improved the character error rate by approximately three and two orders of magnitude, respectively, over the raw character error rate.

Kohlenberg [1965] provides an example of the relationship between error statistics and code used. On a tropospheric circuit with burst type error statistics, a particular diffuse convolutional code gave about one order of magnitude improvement for an uncorrected channel error rate of 0·1, about two orders of magnitude for an uncorrected error rate of 0·01, while for an uncorrected error rate of

1×10^{-3} the decoded error rate was too low to be measured within the framework of the test. He points out that the use of this same code on the same channel but with a randomized error rate of 0·1 would have degraded the channel rather than improved it.

Greim [1960] analyzed the teleprinter error data and concluded that:

— multiple bit-errors per character error are common, which may preclude effective operation of parity type error detection or error correction schemes;

— although more than one character error is likely to be experienced within a one-minute interval, extreme bunching (greater than eight) of character errors is unlikely.

Fontaine [1961] studied error control techniques applied to HF radio teleprinter channels based on Greim's data [1960]. The results indicate that:

— error-correcting codes are impractical for improving the reliability of a teleprinter channel; however, he did not consider interleaving of code words;

— error detecting and repeat schemes with about 10% redundancy will reduce the probability of error to a negligible amount.

Moyes [1964] reports on-the-air comparison tests at teleprinter speeds over a path from Hawaii to New Jersey. Two codes were evaluated, a non-interleaved Bose-Chaudhuri (15, 7) code, and a Wagner code. In this latter code, a single parity bit is included with each teleprinter character; in case of a parity error at the receiver, a bit-energy detector determines the least reliable bit in the character and reverses its polarity. It was found that both codes gave at least an order of magnitude improvement for an uncorrected character error rate of approximately 5×10^{-4}.

Goldberg *et al.* [1968] investigated the effectiveness of various codes on data collected on a 4000 km HF path from California to New Jersey, using a modulation rate of 75 bits per second. Results given for a specific run of approximately 60 000 bits having an uncorrected error rate of 1×10^{-3} show that:

— a Gallager type half-rate convolutional code reduced the number of errors from 61 to 4;

— a Massey type half-rate convolutional code resulted in no output errors;

— an interleaved (23, 12, 3) Golay code would have corrected all errors, with as few as 10 (the smallest number tried) blocks interleaved.

An analysis of the collected data also showed the burst nature of error patterns and the occurrence of periodic error patterns corresponding to the number of sub-channels.

4. Conclusions

All the studies reviewed here agree at the point that the observed error patterns are, in general, very different from random patterns, which would be expected with independent occurrence of binary errors. Instead, errors tend to cluster, and when the modulation technique includes frequency-division multiplexing, periodicity of error pattern may sometimes be observed.

The effectiveness of short block codes with interleaving [Moyes and Taylor, 1966; Brayer and Cardinale, 1967; Goldberg *et al.*, 1968], diffuse convolutional codes [Brayer, 1967; Goldberg *et al.*, 1968], and error detection and repeat schemes [Fontaine, 1961] appears to be well established. However, procedures to select the best technique for a particular channel and particular desired error rate have not yet been established. Comparison between the various studies is difficult as the parameters of the tests reported vary widely.

There seems to be no single statistic of error data which can be used to compare different error control schemes. For example, the statistics asked in C.C.I.R. Study Programme 18A/1, § 3, are useful only to study the effectiveness of block codes without interleaving, and are of little or no help in the study of other techniques. If statistics are derived for one particular aspect of the data, some other aspects of this data will be lost. It is, therefore, recommended that the publication of raw error data be encouraged so that everyone can use the data to compare different techniques, including possible ones to be devised in the future. A rough estimate indicates that all the raw data analyzed by Brayer and Cardinale [1967] can be printed as a computer print-out of approximately 100 pages, which is not a prohibitive amount.

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REPORT 436*

EFFICIENT USE OF HF RADIOTELEGRAPH CHANNELS IN THE TELEX NETWORK BY MEANS OF AUTOMATIC SELECTION AND ALLOCATION PROCEDURES

(Study Programme 1A-2/3)

(1970)

1. Introduction

HF radio circuits are frequently used to link telex networks. The transmission of information passed over such circuits is protected to a sufficient degree by means of duplex ARQ circuits, the main characteristics of which are laid down in Recommendation 342-2.

The traffic delays occurring in ARQ circuits during periods of conditions unfavourable to radio reception are, due to cycling, of variable duration and interfere with fully automatic switching of telex circuits.

2. In view of the decision by the C.C.I.T.T. that charging on a fully automatic telex network should be made on the basis of elapsed time rather than on non-cycling time, it is desirable that radio sections of a fully automatic switched network should be designed to provide a good quality of service, while protecting the users against unreasonable charges. The main characteristics of such a system, called the "flex" system, are described in the Annex.

* Adopted unanimously.

3. The development of the "flex" system is based on the following principles and considerations:

3.1 The efficiency of each ARQ channel is monitored continuously. A given telex circuit will be cleared when the efficiency drops below a predetermined value and a new circuit is established, utilizing another ARQ channel of acceptable efficiency, to enable the subscriber to complete his call.

3.2 Although large parts of a telex circuit are duplex, it is to be noted that telex operation is basically simplex. The ARQ part of the circuit has the disposal of a "go" path and a "return" path, for which a radiotelegraph channel is busied in each direction. Depending on the direction into which information is transmitted in simplex operation, each of the radiotelegraph channels will function alternately as a go or as a return path. The return path is needed to close the ARQ loop, but no information is passed over it. Thus, in effect, only 50% of the total channel capacity is utilized. Moreover, during a telex connection, idle-time signals are transmitted over the go path when the active subscriber is not actually transmitting (stop intervals), with the result that, on the average, the channel utilization is even less than 50% of the total capacity.

3.3 If, for the destination considered, several ARQ circuits are available, a subscriber can be offered a circuit that is substantially free from cycling, if a method of re-routing his traffic is found, each time the busied ARQ circuit becomes inefficient. This method does not only offer improved service to the subscriber, but also increases utilization of the radiotelegraph channels. Thus, an ARQ loop will no longer serve as the go path in one direction and the return path in the other direction for one pair of subscribers, but each direction of the ARQ loop becomes a go path for a separate pair of subscribers, of whom the active subscriber occupies that go path as long as his traffic can be transmitted over it. In addition, during periods in which a large amount of traffic is offered, traffic that would otherwise be held up can, with this system, be transmitted over the available channels during idle periods of calls in progress.

ANNEX

1. The "flex" system is a method that deals with the automatic connection and disconnection of telex circuits to and from ARQ channels, which makes it possible:

1.1 to re-route telex circuits from ARQ channels in which the efficiency has dropped below a predetermined value to ARQ channels that are efficient;

1.2 to disconnect an ARQ channel from a telex circuit during the idle intervals in the traffic flow, so that the ARQ channel becomes available for another telex circuit;

1.3 to allot each of both paths of an ARQ channel to different telex circuits;

1.4 to effect forced clearing of a telex circuit if none of the functions described in §§ 1.1, 1.2 or 1.3 can be performed.

2. An ARQ channel is connected to the telex network at both ends via a telex adaptor panel (hereafter referred to as TP), which performs the functions prescribed in C.C.I.T.T. Recommendation U.20.

A number, N, of TP terminals and a number, M, of ARQ channels are interconnected by the automatic switching device of the flex system (N and M need not necessarily be equal). This arrangement replaces the direct connection between a TP and a specific ARQ channel via a patching board in conventional ARQ circuits.

3. If no telex circuit is established, all the TP in the flex system are disconnected from the ARQ channels, and all non-cycling ARQ channels transmit "signal β".

4. At the interface to the flex system, each TP has a sending and a receiving terminal. The sending terminal of a TP is automatically connected to the front end of an efficient ARQ channel when, from the landline circuit:

— a call criterion is received by the TP,

— traffic is brought into the storage device of the TP,

— a clearing criterion is received by the TP.

5. The front end of an ARQ channel can only be seized, if:

— the ARQ channel is efficient,

— the ARQ channel is not cycling,

— the front end has not yet been allotted to another TP.

6. Associated with each TP is an address generator which, as soon as the TP sending terminal is connected to the front end of an ARQ channel, transmits the address signal over this connection. The address signal is specific for each individual TP, and consists of a 5-unit signal, transmitted thrice in succession. The remote ARQ receiver recognizes a signal as an address, when at least two out of three signals are identical, and this group has been preceded by at least two consecutive "signals β". (It is considered that for an efficient ARQ channel the probability of receiving two transposed signals in a group of three, without a fault being detected, is extremely low.)

7. At its receiving end, the ARQ channel finds the corresponding TP receiving end terminal by means of the address signal.

8. A circuit is established to pass:

— a call,

— traffic,

— a clearing signal.

8.1 To pass a call over the ARQ channel, only the address is transmitted. The reception of only the address at an ARQ receiving terminal puts the required TP receiving end to the "called" position.

8.2 Traffic signals transferred over an ARQ channel immediately follow the address signal. The TP receiving terminal is disconnected from an ARQ go path as soon as the traffic flow is interrupted by pause signals (on the ARQ path at least two consecutive "signals β").

8.3 To pass a clearing signal over an ARQ channel, the address signal is immediately followed by seven "signals α". On receipt of two consecutive "signals α" the TP receiving end accepts the clearing condition after which it is disconnected from the ARQ receiver by the flex system.

9. The flex system disconnects a TP sending end from an ARQ front end when:

— during traffic, the traffic flow is interrupted because the TP storage is empty, and moreover three consecutive "signals β" have been successfully transmitted over the ARQ path,

— no traffic is yet available after a call signal has been passed, and three consecutive "signals β" have been transferred over the ARQ path,

— at reception of a clearing signal, seven consecutive "signals α" and three consecutive "signals β" have been passed over the ARQ channel,

— the efficiency of the ARQ channel drops below the predetermined value.

In the last case, the disconnecting of the TP sending end from an ARQ channel might cause the loss of three characters stored in the ARQ storage. However, the disconnecting and re-routing of a TP-user can be performed without loss of characters, by utilization of the system cycle in conjunction with an externally added dummy cycling storage.

10. A peculiar situation arises when a TP-user has a telex circuit at his disposal but fails to re-establish an ARQ connection because all efficient ARQ channels are engaged. In such a case one of these channels is temporarily disconnected from the transmitting TP busying it, and is allotted to the first mentioned TP, only to enable it to transmit a forced clearing signal over the ARQ route. The ARQ channel is returned to its previous user as soon as this clearing signal has been transmitted.

The clearing signal is also sent to the subscriber who was using the TP that cleared the connection over the ARQ route.

REPORT 437*

OPERATIONAL USE OF THE EFFICIENCY FACTOR

(Study Programme 1C/3)

(1970)

1. Introduction

With the introduction of fully automatic switching for international telex services in world-wide networks, the establishment of appropriate criteria for determining when an HF radio channel can be switched in or should be switched out of the circuit has become urgent.

Doc. III/20 (Japan), 1966–1969, reports on a series of tests carried out during the month typical of a season, i.e. January, June and October, over HF radio channels between Tokyo and San Francisco, Manila, Brussels, Buenos Aires and Hong Kong.

Doc. III/87 (Rev. 1) and Corrigendum to Doc. III/87 (People's Republic of Poland), 1966–1969, describes work carried out on circuits between Warsaw and New York in which the autocorrelation of the efficiency factor was determined for differing circuit conditions.

2. Results

2.1 A criterion that the efficiency factor is above 80% for an integration period of 20 s immediately prior to the establishment of a circuit is deemed acceptable for switching an operational radiotelegraph channel into the network. It was found that when this criterion is met the probability that the efficiency factor will remain above 80% for the next 8 minutes (average duration of a call) is 97%.

2.2 A criterion that, when the efficiency factor falls below 80% for an integration period of 60 s, an existing call should be interrupted was deemed to be inappropriate. Instead, it was found acceptable to use as a criterion that when the average value of the efficiency factor, integrated over the cumulative time period of the call, falls below 80% the call should be interrupted. Using this latter criterion, the average overcharge for a hypothetical call of 8 minutes duration for the routes Tokyo-Brussels and Toyko-Manila was found to be 7%.

2.3 However, the auto-correlation studies show that with an observation time of 20 consecutive 20-s periods (400 s in all) the circuit conditions may only be reliably predictable for periods of as high as 200 s depending upon the stability of the circuit conditions.

2.4 It was found that the statistical properties of the time behaviour of the efficiency factor vary as a function of year, season, distance and direction of the radio circuit. For this reason, it is recommended that for any specific circuit, observations of the efficiency factor should be carried out over a period sufficiently long to permit a decision to be made as to whether or not the circuit can be used in the fully automatic switched telex network.

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* Adopted unanimously.

QUESTIONS AND STUDY PROGRAMMES, DECISIONS, RESOLUTIONS AND OPINIONS

QUESTION 1/3

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

(1948 – 1966)

The C.C.I.R.

DECIDES that the following question should be studied:

what are the technical factors affecting the quality of performance of complete systems of the fixed service?

STUDY PROGRAMME 1A-2/3

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

Signal-to-noise and signal-to-interference protection ratios for fading signals; bandwidth, adjacent channel spacing and frequency stability

(1959 – 1966 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that the conditions for satisfactory performance of a system must take account of the need to receive signals propagated via the ionosphere, which are subject to fading and multipath effects and are accompanied by radio noise and interference;

(b) that studies requiring signal-to-noise and signal-to-interference protection ratios are closely related and that determination of necessary adjacent channel spacings requires, in addition, consideration of frequency stability and bandwidth of the systems;

(c) that there are a number of different techniques and systems in use in the radiotelegraph and radiotelephone services and, while it is essential to consider the most advanced state of the radio art, it is also necessary to give special study to conventional systems, either affecting integration of landline and radio services, or of concern to the I.F.R.B.;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. Classes of emission

The studies concern the following classes of emission in regular use in the fixed service but should also give due regard to new techniques and systems, including those under development, for application to the fixed service:

1.1 *Radiotelephony*

1.1.1 Classes of emission: A3, A3A, A3B, A3J, A3H, F3 (above 30 MHz only, with reference to ionospheric-scatter applications).

1.2 *Radiotelegraphy*

1.2.1 Classes of emission: A1, A2, A7, F1, F6;

1.2.2 Modulation rates:

— A1, A2, machine telegraphy: 50 and 120 bauds;

— A7, multi-channel VF telegraphy: 50 to 200 bauds per channel;

— F1: 50 to 600 bauds;

1.2.3 Codes:

— 5-unit start-stop;

— synchronous error-detecting and correcting systems using two-condition signalling codes other than the International Telegraph Alphabet No. 2;

— other systems.

1.3 *Facsimile, phototelegraphy*

1.3.1 Classes of emission: A4, F4.

2. Minimum conditions required for satisfactory service

2.1 *Acceptable criteria and values for:*

2.1.1 intelligibility over radiotelephone circuits, for the various grades:

— just usable, operator-to-operator (order wire),

— marginally commercial,

— good commercial;

2.1.2 the quality of radiotelegraph circuits (telegraph distortion; character error rate; efficiency factor for ARQ circuits);

2.1.3 legibility of copy over facsimile (phototelegraphy) circuits;

— the maximum duration and percentage of the time during which performance inferior to the standard values can be tolerated.

2.2 *Performance of the system as a function of:*

2.2.1 signal-to-noise and signal-to-interference (co-channel) ratios;

2.2.2 required signal-to-noise and signal-to-interference (co-channel) protection ratios for the acceptable standard values of intelligibility, error rate (efficiency factor on ARQ circuits), or legibility for the various services* and of the frequency of operation; considering:

2.2.2.1 signal fading, taking account not only of the amplitude distribution, but also of the autocorrelation function and the distribution of duration of the fades;

* For radiotelephone services, the signal-to-noise ratio required in the audio band must be specified, and from this the signal-to-noise ratio required in the radio-frequency band is established.

2.2.2.2 diversity (space, frequency or time) techniques: noise reducers, coding including the use of error-correcting codes or ARQ, use of more than two signalling conditions and optimum modulation and detection techniques;

Note. — It would be useful to compare the systems using the various telegraph codes, including those of § 1.2.3, in terms of undetected or uncorrected error rate for a given power and signalling speed, in words per minute, and operating under the same conditions. A 5-unit start-stop system may be used as the reference system by regarding each mutilated character as an error only. It is provisionally suggested that the ratio of error rates should be expressed for two-circuit conditions only; namely, when the system under test is subjected to an average of one undetected or uncorrected error per 1000 characters, and per 10 000 characters.

2.2.2.3 multipath effects;

2.2.2.4 interference effects of the predominant sources of radio noise such as atmospheric, or man-made noise:

— as described by the waveform and amplitude distribution of the instantaneous values of the noise;

— the effects as actually received, taking account of the method of detection, and of filtering prior to and following detection;

2.2.2.5 interference effects of co-channel signals representing the various classes of emission, taking account of the spectral and statistical (fading) characteristics of the interfering signal;

2.2.2.6 monthly mean signal-to-noise ratios and signal-to-interference ratios, required for circuits of various lengths and directions, to meet the acceptable standard values of circuit performance (§ 2.1) during the specified percentage of the time, taking into account:

— the distribution within an hour of the mean values of the short-term (fading) distributions of signals and noise;

— the distribution, within a month or season, for a given hour of the hourly mean values of the signal strengths and atmospheric noise levels (Report 322-1);

2.2.2.7 the total fading allowance derived from the day-to-day intensity fluctuations of signals and noise and short-term fading of signals.

Note. — The monthly mean values of atmospheric noise for various time blocks, and information on the distribution of values within the month, is given in Report 322-1; with regard to monthly mean values of signal strength, and distribution of hourly values within the month, Report 252-3 gives a method for computation.

This study is intended to lead to revisions or replacement of Recommendations 240-2 and 339-3

2.3 Minimum bandwidth required for satisfactory transmission and reception of the intelligence in a complete system.

2.4 Overall frequency stability of a complete system, and the parts of a system, required for satisfactory transmission and reception of information, with particular reference to the performance criteria of frequency synthesizers.

3. Determination of adjacent channel signal-to-interference protection ratios, and frequency separations between various classes of emission, considering:

3.1 the use of effective receiving band-pass filters no wider than necessary for satisfactory reception (see § 2.3 above, and Recommendations 237-1, 330 and 331-3);

3.2 the bandwidth occupied by the interfering signal;

3.3 the spectral distribution of the interfering signal in relation to the receiver bandwidth;

3.4 the frequency tolerance and stability of the wanted and unwanted signals;

3.5 the studies of § 2.2 above relating to co-channel signal-to-interference protection ratios.

Note. — The result of this study should be presented in the form indicated in the Table annexed to Recommendation 240-2.

STUDY PROGRAMME 1B/3

USE OF PILOT CARRIER IN SINGLE- AND INDEPENDENT-SIDEBAND SYSTEMS

(1970)

The C.C.I.R.,

CONSIDERING

(a) that single-sideband and independent-sideband radio systems in the fixed service commonly use a reduced level pilot carrier for controlling the gain and frequency tracking of the receiver;

(b) that a pilot carrier level of –26 dB relative to peak envelope power has been widely used on independent-sideband radiotelephone systems;

(c) that the level of pilot carrier used by other types of system, such as radiotelephony using a frequency-modulated control channel and frequency-division multiplex telegraph systems, is governed by different considerations from those applying to conventional radiotelephony;

(d) that advances in technique in the design of transmitters and receivers, including the application of automatic methods of operation, render a reappraisal of current practice desirable;

(e) that in the interest of operational simplicity a standard level of pilot carrier common to all types of system may prove desirable;

(f) that improvements in the frequency stability of carrier generating sources make it possible to consider dispensing with the frequency control functions of the pilot carrier in certain cases;

(g) that the general aim is to ensure that circuit failure due to contamination of the pilot carrier channel by noise at the receiver does not occur whilst the signal in the communication channel is otherwise commercial;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the levels of the pilot carrier for the various systems which will lead to the most efficient communication, bearing in mind the current state of development in transmitting and receiving equipment;

2. consideration of the advantages which would result from the use of a standard level for all systems using a pilot carrier;

3. determination in what cases and under what circumstances a pilot carrier could be dispensed with.

STUDY PROGRAMME 1C/3*

EFFICIENCY FACTOR AND TELEGRAPH DISTORTION ON ARQ CIRCUITS

(1970)

The C.C.I.R.,

CONSIDERING

(a) that the efficiency factor as defined in the "List of Definitions of Essential Telecommunication Terms" (Part I, 1961, No. 33.23; see also Recommendation 345) is very useful for defining and determining the quality of a communication circuit using error correction by automatic repetition;

(b) that the value of the efficiency factor of an ARQ circuit depends on the telegraph distortion in both directions of the radio circuit;

(c) that a continuous measurement of the efficiency factor is required by the C.C.I.T.T. for radiotelegraph circuits incorporating ARQ equipment, and operating in the fully automatic telex network (see Recommendation U.23, C.C.I.T.T., Mar del Plata, 1968);

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the way in which measurements of the efficiency factor may be used to analyze and predict the performance of systems with error correction by automatic repetition, especially at the commencement and finish of the operating period using one frequency;

2. the way in which the efficiency factor depends on the telegraph distortion measured at the incoming end (receiver) of the ARQ terminals at either end.

Note 1. — Measurements should preferably be carried out in successive periods of 20 seconds for detailed analysis and over a number of such periods for long-period evaluation.

Note 2. — Attention is especially drawn to § 9 of Recommendation U.23 of the C.C.I.T.T. with regard to the monitoring of ARQ circuits, which reads:

"9. *Precautions to be taken before incorporating circuits with ARQ equipment in automatic switching networks*

In spite of these precautions, fully automatic operation on a radiotelegraph circuit incorporating ARQ equipment can be considered only if this circuit possesses adequate stability.

Before incorporating a circuit with ARQ equipment in the fully automatic switching network, the Administrations (or the Recognized Private Operating Agencies) must carry out extended trials.

These trials should be made under normal traffic conditions, over a minimum period of three consecutive hours chosen from the busy period (or periods), when heavy traffic is foreseen to occur on the route under consideration (allowing for the traffic, whether terminal or transit which prevails on the route according to the season).

The condition which must be fulfilled before a circuit can be accepted for use in the fully automatic network is that its mean efficiency factor, measured over periods of 20 consecutive seconds each, shall not fall below 80% for more than 10% of the total time involved in the measurements.

The measurements must be repeated as often as will be necessary for the Administration to have an assessment of the suitability of the circuit.

The attention of Administrations is drawn to the fact that, before offering fully automatic transit working on a radio route incorporating ARQ equipment, the grade of service on the route under consideration must be in accordance with that proposed in Recommendation F.68, § 11*b)*, i.e. only one call lost in 50.

If these conditions are not complied with, it would be better to retain semi-automatic operation."

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* This Study Programme replaces Study Programme 18A/III.

QUESTION 2/3

ARRANGEMENT OF CHANNELS IN MULTI-CHANNEL TELEGRAPH SYSTEMS FOR LONG-RANGE RADIO CIRCUITS OPERATING ON FREQUENCIES BELOW ABOUT 30 MHz

(1953)

The C.C.I.R.,

CONSIDERING

(a) that lack of uniformity in the arrangement and designation of the channels in multi-channel telegraph systems, for long-range radio circuits operating at frequencies below about 30 MHz may give rise to certain difficulties when one transmitting station has to work with more than one receiving station;

(b) that many such systems are in use;

UNANIMOUSLY DECIDES that the following question should be studied:

what is the best way of arranging and designating the channels in multi-channel telegraph systems for long-range radio circuits, operating at frequencies below about 30 MHz?

QUESTION 3/3

DIRECTIVITY OF ANTENNAE AT GREAT DISTANCES

(1948 – 1951 – 1953)

The C.C.I.R.

DECIDES that the following question should be studied:

experimental study, by Administrations and various organizations, of the directivity of antennae realized at great distances (taking full advantage of existing transmissions), by any suitable method, for example, by use of mechanically or electrically steered antennae.

STUDY PROGRAMME 3A-2/3

IMPROVEMENT OBTAINABLE FROM THE USE OF DIRECTIONAL ANTENNAE

(1953 – 1956 – 1959 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that Study Programme 1A-2/3 requires knowledge of the improvement in the signal-to-interference ratio that can be obtained by the use of directional antennae on long-distance circuits;

(b) that the performance of a system under fading conditions may also be improved by the use of appropriate directional antennae;

(c) that it is important to know the discrimination given by directional antennae for various ranges and directions of both the wanted and the interfering stations;

(d) that it appears practicable to obtain some reduction of interference by using a null method at the receiver;

(e) that it is important to know the antenna directivity under various environmental conditions such as ice and snow;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the signal power gain in the main lobe provided by practical directional antennae used under actual propagation conditions, relative to a half-wave horizontal dipole* at the height of the centre of the directional antenna; the median value and cumulative distribution with time of the values of gain during short periods (as, for example, less than an hour), should be observed; observing periods should be suitably distributed and the data studied on a statistical basis, so as to show dependence of results on time of day and season for normal propagation conditions, and the effect of especially critical propagation conditions such as encountered near time of sunrise and sunset, and at times of failure of the operating frequency near the MUF, and at times of ionospheric disturbances;

2. determination of the signal power gain in directions outside the main lobe and/or values of discrimination provided by the antenna between the wanted and interfering signals. The data should include the variations with time, referred to in § 1, and should specify the directions of the wanted and interfering signals;

3. the effect of the antenna directivity pattern (antenna diagram) in reducing multipath distortion;

4. the effects of the antenna height in increasing the number of hours of useful transmission and in the reduction of interference;

5. the usefulness of a null method of minimizing the interference. The data required to evaluate the usefulness might consist of:

5.1 logs of commercial receiving stations, showing outages due solely to interference and the relative azimuth bearing of interfering stations,

5.2 experimental data on the use of directional antenna systems and antennae with adjustable directions of null, under conditions where interference is experienced;

6. the effects of the environmental conditions such as ice and snow on the directivity of the antenna.

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* The median values of the gain can also be expressed relative to the isotropic antenna.

STUDY PROGRAMME 3B/3

DIRECTIVITY OF ANTENNAE FOR THE FIXED SERVICE USING IONOSPHERIC-SCATTER PROPAGATION

(1959)

The C.C.I.R.,

CONSIDERING

(a) that systems are at present in service using ionospheric-scatter propagation, at frequencies above 30 MHz and that extension of use of this mode of propagation may be expected in the international fixed service;

(b) that it is desirable to establish the preferred characteristics of such systems needed to facilitate their international connection, and that it is particularly important to have similar or matched directivity of the antennae at opposite terminals of the circuit;

(c) that antenna directivity, including the characteristics of radiation pattern, gain, beamwidth and direction of the main lobe or lobes, significantly affects transmission loss and the possibility of occurrence of multipath propagation and interference to and from other services;

UNANIMOUSLY DECIDES that the following studies should be carried out:

studies of the desirable characteristics of the directivity of transmitting and receiving antennae for the international fixed service, using ionospheric-scatter propagation above 30 MHz, including gain, beamwidth and direction of the main lobe or lobes, and tolerances for the radiation pattern outside the main lobe, taking into account:

— dependence on propagation characteristics of the scattering medium, including dependence on scattering angle, size and inhomogeneity of the scattering region;

— effects of meteoric ionization, and the techniques of beam slewing and beam splitting, and how these may depend on season and time of day;

— operating frequency;

— diversity;

— polarization;

— multipath propagation, in relation to the modulation technique used;

— interference to and from other services.

QUESTION 4/3

RADIO SYSTEMS EMPLOYING IONOSPHERIC-SCATTER PROPAGATION

(1956)

The C.C.I.R.,

CONSIDERING

(a) that experiments have already shown the possibility of utilizing frequencies above 27·5 MHz for transmission by ionospheric-scatter propagation to distances well beyond the horizon;

(b) that systems using this mode of propagation are already in service;

(c) that it is desirable to determine the preferred characteristics of such systems needed to facilitate their international connection;

(d) that the frequency bands, which might be used for such systems, are already intensively used by other services;

UNANIMOUSLY DECIDES that the following question should be studied:

1. how do the propagation characteristics, relevant to the exploitation of systems employing ionospheric-scatter propagation, vary with frequency;

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

3. what are the radio-frequency and baseband characteristics of such systems, which it is essential to specify for the transmission of telephony or telegraphy to enable two systems to be interconnected, and what values should be specified?

QUESTION 7/3

INFLUENCE OF FREQUENCY DEVIATIONS ASSOCIATED WITH PASSAGE THROUGH THE IONOSPHERE ON HF RADIOCOMMUNICATIONS

(1956 – 1959 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that Recommendation 246-3 recommends that, for frequency-shift systems working on two conditions only and operating between 3 and 30 MHz, the values of frequency-shift should be 200, 400, and for modulation rates above 250 bauds, 500 Hz;

(b) that preferred values for the channel spacing and frequency-shifts of multi-channel voice-frequency telegraph systems for use on HF radio circuits are given in Recommendation 436-1;

(c) that study of frequency deviations, associated with passage through the ionosphere, has shown that the resultant frequency variations may reach values of a few hertz while instantaneous deviations may reach much higher values (see Report 111 and the Annex to Recommendation 349-2);

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the statistical distributions of frequency deviation associated with passage through the ionosphere in magnitude, duration and frequency of occurrence;

2. what minimum value of frequency-shift is required for frequency-shift systems operating by HF ionospheric propagation, to take into account:

— the frequency stability of the equipment (see Recommendation 349-2);

— the frequency deviations referred to in § 1?

QUESTION 8/3

FREQUENCY-SHIFT KEYING

(1948 – 1959)

The C.C.I.R.,

CONSIDERING

(a) that frequency-shift keying is employed in radiotelegraphy for the fixed services and it has also been extended to the mobile services;

(b) that it is desirable to standardize the main operating characteristics of systems employing frequency-shift keying;

(c) that various technical factors influence the choice of operating characteristics in such systems, in particular:

c.a the overlap of marking and spacing signals due to multipath propagation (in this respect a small shift is preferable);

c.b the possible advantage of frequency diversity for reception (an advantage which increases with shift);

c.c economy of bandwidth and the consequent necessity for controlling the shape of the transmitted signals;

c.d instability of frequency, which is one reason for the relatively large shift employed in many existing equipments;

c.e the choice of receiving systems, whether with separate filters or with frequency discriminator;

UNANIMOUSLY DECIDES that the following question should be studied:

1. fixation of one or more standard values of shift for fixed and mobile services in the various frequency bands, having regard to the various factors, in particular:

— the frequency spectrum resulting from the keying operation;

— the degree of frequency diversity desired;

— economy of bandwidth;

— instability of frequencies;

2. compilation of a standard terminology regarding the characteristics of systems employing frequency-shift keying.

QUESTION 12/3

DISTORTION CHARACTERISTICS REQUIRED FOR SINGLE-SIDEBAND AND INDEPENDENT-SIDEBAND SYSTEMS USED FOR HIGH-SPEED DATA TRANSMISSION OVER HF RADIO CIRCUITS

(1966)

The C.C.I.R.,

CONSIDERING

(a) that an increasing demand is noted for high-speed data transmission over HF radio circuits and further increase in such demand may be expected;

(b) that recent developments are leading to systems having greatly improved bandwidth efficiency, i.e. a larger capacity in bits per second per unit bandwidth;

(c) that it is desirable that the effects of the random variations and disturbances in the propagation medium be the ultimate factors governing the performance obtainable with such systems;

(d) that the characteristics of a "3 kHz channel" have largely been evolved from the use of such a channel for telephony;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the permissible limits of amplitude, phase and delay distortion on HF radio circuits intended for high-speed data transmission (e.g. 2400 bit/s and above), excluding *a priori* effects due to the radio propagation medium;

2. are these limits likely to be exceeded in HF systems of the fixed service currently available;

3. should new channel arrangements for data transmission be recommended, differing from the present standards for the 3 kHz channel, as defined in Recommendation 348-2 for radiotelephony;

4. in evaluating high-speed data transmission systems, what statistical parameters should be used to describe the radio propagation medium and what values should be considered?

QUESTION 13-1/3

IMPROVEMENTS IN THE PERFORMANCE AND EFFICIENCY OF HF RADIOTELEPHONE CIRCUITS

(1966 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that there is a need to improve the quality of transmission of HF radiotelephone circuits;

(b) that the use of diversity techniques may offer the prospect of such improvements;

(c) that other methods of improvement, for example, the adaptation of compandor principles, might become available;

(d) that the efficiency of HF radiotelephone circuits can be enhanced by converting from manual to semi-automatic operation;

(e) that these techniques might be used either separately or in combination;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the various methods whereby diversity can be obtained on HF radiotelephone circuits;

2. what other methods are available for obtaining such improvements;

3. what devices are most suitable for semi-automatic operation on HF radiotelephone circuits;

4. what improvement in performance and efficiency can be expected with these methods?

QUESTION 14/3

AUTOMATICALLY CONTROLLED RADIO SYSTEMS IN THE HF FIXED SERVICE

(1966)

The C.C.I.R.,

CONSIDERING

(a) that successful development of fully automatic transmitting and receiving terminals may offer important improvements in efficiency, reliability and economy of operation in the fixed service;

(b) that certain features of automatic control may require cooperation and exchange of information between transmitters and receivers as, for example, for change of frequency and power;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what features of automatically controlled radio systems in the HF fixed service require cooperation between Administrations;

2. what are the preferred methods of exchanging and utilizing such information?

STUDY PROGRAMME 17A-1/3*

VOICE-FREQUENCY (CARRIER) TELEGRAPHY ON RADIO CIRCUITS

(1951 – 1953 – 1959 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that different methods are now in use for voice-frequency telegraphy on radio circuits operating below 30 MHz subject to fading, noise and interference:

— either using equipment normally designed for landline working and suitably adapted for radio;

— or using equipment especially designed for radio working;

(b) that studies carried out so far show that it is impossible to compare transmission systems in which the two significant conditions of modulation are obtained either by the frequency exchange method or by the method of frequency-shift of a single voice-frequency oscillator, without taking into account all the properties of the equipment and of the propagation medium;

(c) that experience in reception of voice-frequency telegraphy over radio circuits has shown that frequency-modulated voice-frequency telegraph equipment for use on radio circuits may differ substantially from voice-frequency landline equipment; this equipment may, therefore, have to be designed and constructed with their special purpose in mind;

* This Study Programme does not derive from any Question under study.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. comparisons of the different systems used to transmit and receive voice-frequency telegraphy on radio circuits subject to the effects of fading, multipath propagation, noise and interference, with a view to standardizing their characteristics, taking into account the following techniques and factors:

— frequency-shift keying of one voice-frequency oscillator,

— transmitting the two significant conditions of modulation by the two-tone method,

— other modulation systems, e.g., phase-modulation systems, or systems of modulation employing more than two significant conditions of modulation,

— reception by discriminator or separate filters;

2. influence of the modulation index (frequency-shift (hertz)/modulation rate (bauds)), the channel spacing and the parameters of the regenerators on the error rate.

STUDY PROGRAMME 20A/3*

OPERATIONAL IONOSPHERIC SOUNDING AT OBLIQUE INCIDENCE

(1965 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that sounding of the ionosphere at oblique incidence has proved to be an effective method for observing the behaviour of HF radio waves propagated via the ionosphere;

(b) that the information obtained from oblique incidence sounding may be used to improve the performance of some long-distance radio circuits;

(c) that such sounding carried out as an operational procedure may give rise to harmful interference, particularly if used indiscriminately;

(d) that with increasing use difficulty may be experienced in identifying emissions from particular sounders;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the methods by which the information obtained from sounding of the ionosphere at oblique incidence (see Study Programme 12A-1/6) could be used to improve the operational efficiency of long-distance radio circuits;

2. the limitations, if any, in such characteristics as emitted power and number of simultaneous emissions that are desirable to avoid harmful interference;

3. the measures necessary to enable such emissions to be identified;

4. the preferred characteristics of the equipment used for operational ionospheric sounding that will promote effective cooperation between the greatest number of users.

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* This Study Programme does not derive from any Question under study.

QUESTION 21/3

HF IONOSPHERIC CHANNEL SIMULATORS*

(1970)

The C.C.I.R.,

CONSIDERING

(a) that on circuits operating in band 7 (HF), the distortion caused by multipath effects, manifested by selective fading and time-variant frequency spread and delay distortion, degrades the quality of the received signals;

(b) that the type of multipath effect encountered differs appreciably depending on the length of the radio circuit, its global routing and the frequency used for transmission, and thus gives rise to a wide range of distortion and fading patterns;

(c) that for a particular system of transmission, the performance of a radio circuit may differ appreciably with differing types of distortion and fading;

(d) that fading simulators or ionospheric channel simulators have been constructed by various laboratories and are useful instruments to study system performance;

(e) that it is essential for the time-variant distortion and fading patterns generated in the simulator to be representative for the patterns actually encountered on such radio paths;

(f) that it is desirable for such a simulator to take account of atmospheric and man-made noise characteristics, and to facilitate study of interference between signals;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what patterns of fading, time-variant frequency spread and delay distortion should be considered as giving markedly differing types of circuit performance;

2. how should these patterns, and the parameters of a model of HF ionospheric transmission, be specified so as to assure fully representative laboratory simulation of various transmission conditions in band 7;

3. how should atmospheric and man-made noise be represented, and how can a simulator be used to study interference between signals?

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* This Question has been brought to the attention of Study Group 6.

QUESTION 22/3*

TRANSPORTABLE FIXED SERVICE RADIOCOMMUNICATION EQUIPMENT FOR RELIEF OPERATIONS

(1972)

The C.C.I.R.,

CONSIDERING

(a) that rapid and reliable telecommunications are essential for relief operations in the event of natural disasters, epidemics, famines and similar emergencies;

(b) that, through damage or from other causes, the normal telecommunications facilities in disaster areas are often inadequate for relief operations and cannot be restored or supplemented quickly through local resources;

(c) that the World Administrative Radio Conference for Space Telecommunications (Geneva, 1971) has adopted Recommendation No. Spa2 – 13;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics and frequency bands for transportable fixed service equipment, operating at frequencies below approximately 30 MHz, for the provision of relief telecommunications when:

— the equipment is used in liaison with a transportable earth station;

— only terrestrial relief telecommunication facilities are involved?

QUESTION 23/3**

USE OF COMMON-FREQUENCY SYSTEMS ON RADIOTELEPHONE CIRCUITS

(1963 – 1966 – 1970 – 1974)

The C.C.I.R.,

CONSIDERING

(a) that relief of the present congestion of the HF (decametric) band is a matter of urgency;

(b) that, in certain cases, the use of the same carrier frequency in both directions of a radiotelephone circuit (in combination with techniques that prevent simultaneous transmission in both directions) may result in important economies in spectrum utilization on a radiotelephone circuit;

UNANIMOUSLY DECIDES that the following question should be studied:

1. in which cases does the use of the same frequency in both directions of transmission result in more effective sharing of frequencies;

* See also Questions 22/4, 22/8 and 20/9.

** This Question replaces Question 19/1 and is identical with that text.

2. in such cases:

2.1 what are the characteristics to be specified for radiotelephone systems using the principles of common-frequency operation;

2.2 what should be the minimum difference in level at the input to the receiver, between the received signal from the distant station and signals from the nearby transmitting station, to avoid interference between the wanted signal and that from the nearby transmitter operating on the same frequency;

2.3 to what extent will the use of transmitting and receiving antennae with different transmission characteristics reduce the possibilities of application of this technique;

2.4 to what extent will the possibilities of application of this technique be reduced by the presence of different noise levels at the receiving locations;

2.5 what other factors should be taken into account when planning such systems, for example:

- non-linearities in the transmitting and receiving equipment,
- carrier-filter bandwidth,
- frequency stability of the equipment?

QUESTION 24/3*

REMOTELY CONTROLLED HF RECEIVING STATIONS IN THE FIXED SERVICE

(1974)

The C.C.I.R.,

CONSIDERING

(a) that HF receiving stations in the fixed service should be sited in locations practically free of man-made noise;

(b) that there exists a general trend to encourage automation and so to reduce the technical personnel required;

(c) that reduction of the interference level and introduction of automation could result in a better operation of the receiving stations and so could improve the quality and reliability of HF communications;

(d) that several Administrations are studying the problems involved in applying remote control to HF receiving stations and are encountering certain difficulties;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the problems raised by the remote control of HF receiving stations in the fixed service;

2. what are the special characteristics of an HF receiver designed to be installed in a remote-controlled station;

3. what are the required characteristics of the controlling system, taking into account reliability of control and economy of circuits and equipment?

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* This Question, together with Question 24/8, replaces Question 12/1.

QUESTION 25/3*

AUTOMATIC CONTROL OF THE OUTPUT POWER OF HF TRANSMITTERS IN THE FIXED SERVICE

(1974)

The C.C.I.R.,

CONSIDERING

(a) Recommendation 38 of the "I.T.U. Panel of Experts" in its Final Report, Geneva, 1963;

(b) that No. 694 of the Radio Regulations requires that all stations shall radiate only as much power as is necessary to ensure a satisfactory service;

(c) that nevertheless, for a considerable part of the time, stations using frequencies in the bands between 4 and 27·5 MHz radiate powers considerably in excess of those necessary to ensure a satisfactory service;

(d) that manually operated methods of adjusting the power of transmitters are not fully adequate to meet No. 694 of the Radio Regulations;

(e) that the use of automatic control of the output power of transmitters would assist in reducing the congestion in the HF spectrum;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the most suitable methods for automatically controlling the output power of radio transmitters of the HF fixed service to ensure, as far as practicable, that the radiated power is no greater than is necessary to ensure a satisfactory service, taking into account the distances of reception points and the existing conditions of propagation?

* This Question, together with Question 25/8, replaces Question 21/1.

QUESTION 26/3

IMPROVEMENTS IN THE PERFORMANCE OF HF RADIOTELEGRAPH CIRCUITS

(1976)

The C.C.I.R.,

CONSIDERING

(a) that several systems for the transmission of telegraph and data signals over HF radio circuits have been devised;

(b) that further improvements in these systems could benefit spectrum utilization and/or reduce error rates;

(c) that the use of digital techniques for data and speech transmission is increasing;

DECIDES that the following question should be studied:

1. what improvements can be made to existing telegraph systems;
2. what new techniques could be employed which offer advantages over existing techniques?

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