REPORT 743-1

TRANSMISSION QUALITY ASSESSMENT OF DIGITAL CHANNELS IN MARITIME MOBILE SERVICES

(Question 42/8)

(1978–1982)

1. Introduction

Modern requirements with regard to the transmission quality of digital maritime HF channels raise a number of complex problems. The increasing requirements imposed on the maritime radiocommunication system can only be met by automation of message preparation, transmission and recording processes and of call set-up and error detection and correction procedures.

The CCIR has already made some progress in this direction:

- it has recommended a direct printing system with error detection and correction which has already been used by a number of countries for several years;
- valid solutions are being found to problems of establishing a digital selective-calling system designed to meet future requirements in the maritime mobile service.

Future studies sponsored by the CCIR call for the development of means of automating radiocommunications using discrete information transmission channels. The improvement of the equipment and methods used for information transmission in digital maritime channels requires that an objective means be found of evaluating the effectiveness of the technical solutions applied. One criterion which might conveniently be adopted is the variation in the probability that a given quantity of information will be transmitted with an acceptable standard of reliability within a given time. Given the critical relation between the various methods of improving digital information transmission media and the variation in the transmission conditions in the channels concerned, the first essential is to identify the character and range of the variation in qualitative channel characteristics and to develop a methodology which can be applied in CCIR studies in comparing the findings of equipment tests carried out by the administrations of various countries.

Digital channels to carry ship-to-shore direct printing telegraph services have low individual transmission rates, but in busy areas many channels would be required to carry the traffic in both the satellite services and the terrestrial HF and VHF services. There is a possible future need for higher rate data transmission of the computer type, and digital transmission of speech and facsimile could also be advantageous in some conditions, but these require consideration separately from the direct printing application.

Performance tests with digital equipment may be made for two purposes, the first to assess the performance of complete message transmission equipment, the second to establish the distribution of errors caused by the propagation path so that equipment design may be improved by changing modulation, coding or diversity methods.

In evaluating the quality of maritime mobile service channels it is very important to consider the effect on the test results of the duty period, the test parameter averaging intervals selected within the duty period and the total number of duty periods, i.e. the scale and algorithm of statistical processing.

2. Methods of performance assessment

2.1 Work by France on laboratory tests with coded radio signals has indicated a method to produce high-level white noise by frequency modulating a carrier with noise. This work is reported in relation to Reports 499 and 501, and would be applicable to tests of equipment in a white noise environment. They are minimum tests to be performed, and would not give complete information for HF tests in which noise must have a burst characteristic.

2.2 The ultimate assessment of the effectiveness of equipment must be based on measurement of its performance in service, so as to ensure that all relevant factors are taken into account. Such tests must be made over the whole distance range at which the equipment is intended to be used, and in all types of propagation conditions. The measured performance will depend especially on the path attenuation, noise and interference conditions prevailing at the time of the test, and because these conditions are variable it is only possible to compare the performance of different equipments by averaging results from tests made over many months. In addition to the propagation factors mentioned, changes in multipath propagation delays can introduce telegraph distortion and bursts of digital errors even when other conditions are favourable for reliable communication.

2.3 The difficulty in making repeatable performance measurements of equipment by sea trials, and the long time that these take, has led to the use of ionospheric path simulators, with which laboratory tests of equipment may be made under controlled conditions. The important advantage of making tests with a channel simulator instead of with a real ionospheric path is that comparisons may be made between equipments when working under exactly the same conditions and that any required conditions may be reproduced without waiting for them to arise fortuitously.

3. Work of Study Group 3

The performance assessment of fixed HF telegraphy circuits has been studied by Study Group 3 of CCIR. Reports 203, 345 and 435 are relevant, but are concerned mainly with the relative performance of telegraph modulation and coding methods. The following Reports are particularly concerned with performance measurement.

Report 200. – Telegraph distortion, error rate. This relates especially to the relevant CCITT Recommendations on distortion measurement.

Report 349. – Single-channel radiotelegraph systems employing forward error correction. Test methods and results are given for several candidate systems.

Report 345. – Performance of telegraphy systems on HF radio circuits. This summary of more recent tests indicates that a measurement of telegraph distortion is a more useful way to assess transmission quality than the measurement of channel efficiency.

Report 549. – HF ionospheric channel simulators. The model which represents the transmission path and the method of simulating it with delay lines, attenuators and adders are described.

4. Measurements with path simulators

4.1 Many path simulators have been experimentally used and at least one is available for purchase, but few administrations have access to such equipment. They differ in the detail with which they simulate the propagation mechanism.

4.2 When using a path simulator, its capabilities in representing real reception conditions must be considered. The model should accurately reproduce the fading conditions over the spectrum occupied by the signal and therefore produce the same signal distortion as multipath propagation. In addition, the path simulator must have a sufficient dynamic range to represent realistically the wide variations in signal level encountered in practice and have provisions for accurately simulating different noise characteristics (for example, atmospheric noise and man-made noise) over a wide range of signal-to-noise ratios. Insufficient data exist to determine accurately the parameters to be used in simulating specific propagation paths. Nevertheless, it has been found that tests over a range of representative propagation parameters carried out by several administrations on a comprehensive simulator, for example, as described in Report 549 can provide a reliable indication of how the equipment will perform under practical conditions, and that even a simple model of the multipath mechanism can be helpful for comparison of performance of different equipments, providing that the path parameters chosen are reasonably representative of the actual ionospheric paths.

4.3 Recommendation 520 suggests ranges of signal parameters which would be appropriate for HF communication. It notes that the simulator may produce not only the radio path properties but also those of parts of the radio equipment such as automatic gain control, frequency drifts and jumps in frequency and phase such as might be produced by some frequency synthesizers. These additional facilities are required to test modems independently of the receiving equipment. Report 549 also comments on the need for further information on parameter values, and in particular no specific values for signal strength and noise level are proposed for use in equipment tests.

4.4 It may be concluded that at the present time the channel simulator is the most satisfactory way to evaluate different communication equipments, but that for the final determination of whether the performance is adequate for the demands of the service, the equipment must be tested under operating conditions in the actual ship, shore station and propagation path environment.

5. Sea trials

Digital channels may also be represented on a statistical basis by their error rate and error pattern behaviour. This should include error probabilities and types of error patterns (for example, random patterns, burst patterns, systematic patterns) as a function of time-of-day, month (or season) and sunspot cycle, as well as path length and geographical location.

A large-scale measurement programme is in progress in the USSR to provide a data basis from which mathematical models could be derived to evaluate the performance of digital transmission equipment under practical operating conditions. This work needs to be continued to provide a comprehensive data base which may represent a wide variety of actual communication channels.

5.1 Since 1967, experiments have been conducted in the USSR to evaluate the qualitative characteristics of HF maritime channels using direct-printing equipment with and without error correction. Studies have also been conducted on the determination of the character of error grouping in HF maritime channels with synchronous working and for the evaluation of the size of sample required in deriving conclusions on channel quality.

The test procedures and some of the results obtained are described below.

5.2 *Purpose of tests*

One feature of the maritime mobile service is the need for brief exchanges of information between ships and shore stations. Communications are exchanged in the form of separate short duty periods preceded by the necessary call setup procedures. The relatively large selection of frequencies used for ship-shore communications, the constant changes in the ship's position during the voyage and the various times in the day and season at which calls have to be made all result in a wide variety of space, time and frequency characteristics. Before any duty period, the "working" HF channel must be selected but the quality of transmission varies within very wide limits from one duty period to another, largely owing to the different propagation conditions of the working frequencies used and the degree to which they are "contaminated" by interference. The variation in location, distance, time and frequency of the duty periods is one of the basic operational properties of the maritime mobile service and must be taken into account in defining the qualitive characteristics of digital HF maritime channels.

The main purpose of the studies was to identify the law governing the variation in transmission quality of digital maritime HF channels from one duty period to another. In the studies, channel working states were selected with various location, distance, time and frequency values.

The second objective was to collect the necessary statistical data on the character of error grouping in digital HF maritime channels in synchronous operation using different modulation rates.

The next aim was to explain the correlation between the test sample and the validity of results obtained from HF band trials.

5.3 *Parameters studied*

The method most widely used in recent years to assess the quality of digital channels consists in transmitting a test signal of a given structure on a channel and in determining the error distribution in time (in bits or alphabetical characters) or some of its numerical parameters at the channel output. As the quality of digital HF maritime channels can be fairly comprehensively described by the probability that a given volume of information will be transmitted to the correspondent within a given time with an acceptable standard of reliability, it was laid down in the studies that error distribution in time must be obtained at the channel output adequate to define all the required parameters. In a study of channels using direct printing without error protection (see Figs. 3, 4, 6, 7, 8 and 9) in which the test signal was transmitted for fixed-time segments at constant speed, the channel quality can be conveniently defined by the distribution of character error rates determined in the individual duty periods.

The above remarks are also true for the synchronous transmission of test signals (see Figs. 1, 2 and 5) which were also transmitted in fixed time segments without a backward channel at a given speed. Digital channel quality in the Maritime Service is also defined by the bit error rates measured in the duty periods. Apart from yielding information on the error rates for the individual duty periods, the bit error distribution in time obtained can be used to define the error grouping rates for blocks of varying length, the distribution of lengths of adjacent error bursts and a number of other probability characteristics required for the purpose of selecting methods of enhancing digital transmission reliability.

5.4 *Test conditions*

The transmission quality of HF maritime channels using direct printing equipment was evaluated using typical radio equipment with F1B emission.

In devising the test programme and method, full account was taken of the operating features of a real communication system, since this factor is decisive for the accuracy of the results obtained.

About 60 foreign-going ships scattered throughout the world participated in the tests carried out to evaluate transmission quality in links using direct-printing equipment. The links with these vessels were maintained by five coast stations using more than 70 frequencies during the test period.

As a test text, we transmitted all characters of the Russian alphabet arranged in such a way that the structure of the sequence of information bits contained in them was nearly recurrent. The test programme included over 900 duty periods involving the transmission of about 4 million characters. The duty periods occurred at various times of day. The test results are given only for the shore-to-ship direction because of the limited sample size obtained in the ship-to-shore direction.

In view of the wide variation in communication conditions in the channels studied versus time and the inevitable dependence of the error rates from the length of the duty period, the mean duration of real duty periods, amounting to 10 min, was taken as the basis for the test periods.

The received test signal was recorded on punched tape. The received text was compared with the transmitted text to obtain the character error stream together with its numerical parameters.

The synchronous working tests were carried out with specially designed instrumentation for determining and recording the error distribution in time. The error stream was also recorded on punched tape by binary registration of the numbers of the test signal bits in which the mistakes occurred. This representation of the varying error rate was extremely compact and convenient for computer processing of the test results. To ensure stable synchronization of the transmitted and received test signal, the test signal adopted was a regular sequence of binary signals of the type 1 : 1. The experimental study of HF signals with this type of working was carried out on two ships – the "Novoaltaisk" on the Leningrad-Australian ports-Leningrad run, and the "Shota Rustaveli" plying between Odessa-England-Pacific islands-Australian and Indonesian ports. The test signal was transmitted in the direction shore-to-ship by four shore stations using 30 frequencies in all HF long-distance sub-bands.

The sample size for 700 duty periods amounted to more than 20 million bits.

Trials were carried out in the USSR, the goal of which was to obtain information on variations in the characteristics of digital channels depending on the scope of the experimental period. These trials took place during a 6-month period on board ships of the "Puskin" and "Magnitogorsk" type with direct-printing equipment according to Recommendation 476. A total of 572 615 blocks were transmitted and 286 recordings were made during the trials.

5.5 *Analysis of test results*

The sample mean of the character error rates $\overline{CER}$ for all test duty periods amounted to 3.9×10^{-2}. The sample mean was obtained from the formula

$$\overline{\mathrm{CER}} = \frac{1}{n} \sum_{i=1}^{n} \mathrm{CER}_i \tag{1}$$

where n = total number of test duty periods, and CER_i = character error rate for the ith duty period.

Hence the sample mean of the coefficients of the bit error rates $\overline{BER}$ amounted to 9.2×10^{-3}. In order to establish a statistical law of variation in the error rates and to assess the effect produced on this variation by the frequency, space and time characteristics of the duty periods, all the data obtained were reduced to statistical series (samples) on the principle that one or another of the duty period characteristics remains constant. In view of the wide range of values obtained for the character error rates *CER*, and for the bit error rates *BER* ($ER_{max} = 5 \times 10^{-1}$; $ER_{min} = 2.3 \times 10^{-5}$) in plotting the histograms of the series formed and calculating the distribution curves approximating them, error rate logarithms were used (the symbols m' and m'' are used below to denote the logarithms of *CER* and *BER* respectively). Despite some differences in the individual statistics, all the samples, represented in interval form by variation series, are statistically stable and satisfactorily approximated by Gram-Charlier curves [Mitropolsky, 1971; Korn and Korn, 1970]. To illustrate this conclusion, some histograms and theoretical curves are given below for 10 variation series (see Figs. 1 to 9) derived from test results and covering a wide range of distinctive characteristics. The characteristics of the series reflecting the test conditions, together with the sample sizes and the sample means of the error rates for each series, are given in Table I. For purposes of comparison, Figs. 1 and 2 show the histograms and theoretical curves based on data obtained on reception by the "Novoaltaisk" of the test signal, in synchronous working, from two different coast stations, in Moscow (see Fig. 1) and Odessa (see Fig. 2). On all Figures, the y-axis shows the values of the relative frequency with which the error rates occur in the i th class interval i.

$$h_i = \frac{n_i}{n} \tag{2}$$

where n_i = number of duty periods with an error rate CER_i or BER_i occurring in the i th class interval, and n = the total sample size in the duty periods. For purposes of clarity, the x-axis shows the mean interval values CER_i or BER_i, although the curves were plotted for the logarithms of these values (m' and m'').

The plotted curves show results over a range of bit error-rates and character error-rates of about 2×10^{-5} to about 5×10^{-1}, but it is suggested that future tests should relate to a practical range of equipment performance and a range 10^{-1} to 10^{-4} should be used for tests.

Figures 1 and 2 show a clear and distinct difference in quality of communication between the Odessa and Moscow stations. Figures 3 and 4 are histograms and distribution curves for log *CER* for the Moscow station communicating in direct-printing working with the same ship crossing the Atlantic (see Fig. 3) and Indian (see Fig. 4) Oceans ("Novoaltaisk", Leningrad-Australian ports-Leningrad). As can be seen from the figures, there is also a difference in quality of communications, but the statistical law remains unchanged.

TABLE I

No.	Sample size in duty periods	Sample mean of (bits or character) error rates	Number of frequencies used	Name of shore stations taking part in the test	Name of ships taking part in the test	Cruising area of ships	No. of figures illustrating empirical and theoretical sample distributions	Remarks
1	54	9.5×10^{-3} (bit)	7	Moscow	“Novoaltaisk”	Indian Ocean	Fig. 1	Significance level of the criterion of agreement between empirical and theoretical curves for each of the samples did not exceed 0.05
2	110	7.4×10^{-3} (bit)	5	Odessa	“Novoaltaisk”	Indian Ocean	Fig. 2	
3	71	2.9×10^{-2} (character)	8	Moscow	“Novoaltaisk”	Atlantic Ocean	Fig. 3	
4	62	4.5×10^{-2} (character)	10	Moscow	“Novoaltaisk”	Indian Ocean	Fig. 4	
5	263	9.2×10^{-3} (bit)	12	Moscow, Odessa	“Novoaltaisk”	Atlantic and Indian Oceans	Fig. 5	
6	572	3.9×10^{-2} (character)	23	Moscow, Odessa, Vladivostok, Leningrad	Different ships	Atlantic, Indian and Pacific Oceans	Fig. 6	
7	373	3.8×10^{-2} (character)	14	Moscow, Odessa	“Novoaltaisk”	Atlantic and Indian Oceans	Fig. 7	
8	199	4.0×10^{-2} (character)	19	Archangel, Murmansk, Leningrad, Moscow, Odessa	Different ships	Atlantic Ocean, Mediterranean and Black Seas	Fig. 8	
9	104	2.2×10^{-2} (character)	7	Vladivostok	“Shota Rustaveli”	Pacific Ocean	Fig. 9 Curve 1	Without signal regenerator
10	109	8.1×10^{-3} (character)	7	Vladivostok	“Shota Rustaveli”	Pacific Ocean	Fig. 9 Curve 2	With signal regenerator

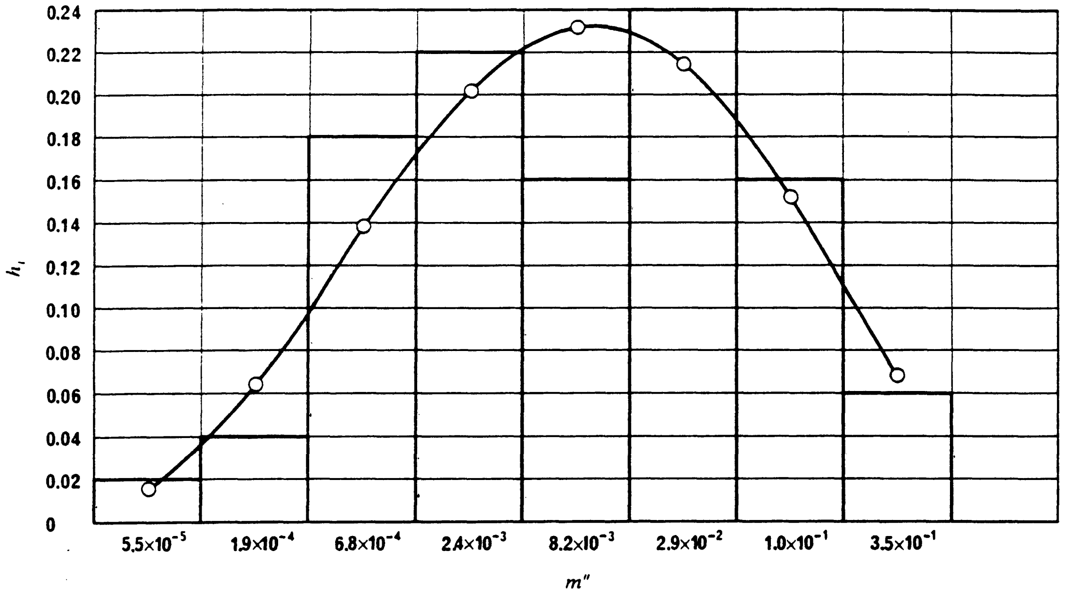

FIGURE 1

(See Table I, No. 1)

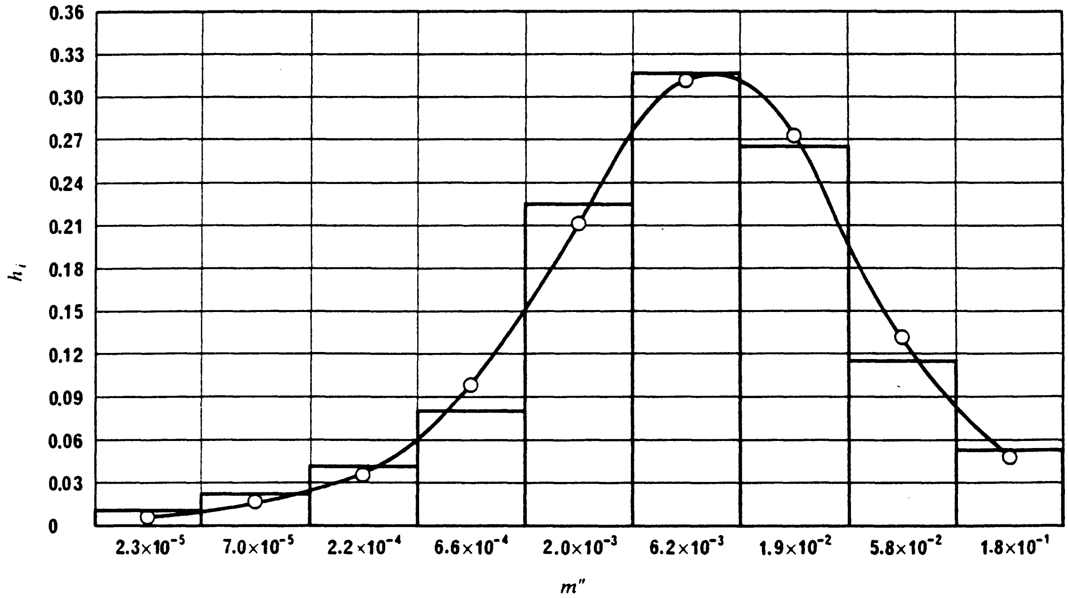

FIGURE 2

(See Table I, No. 2)

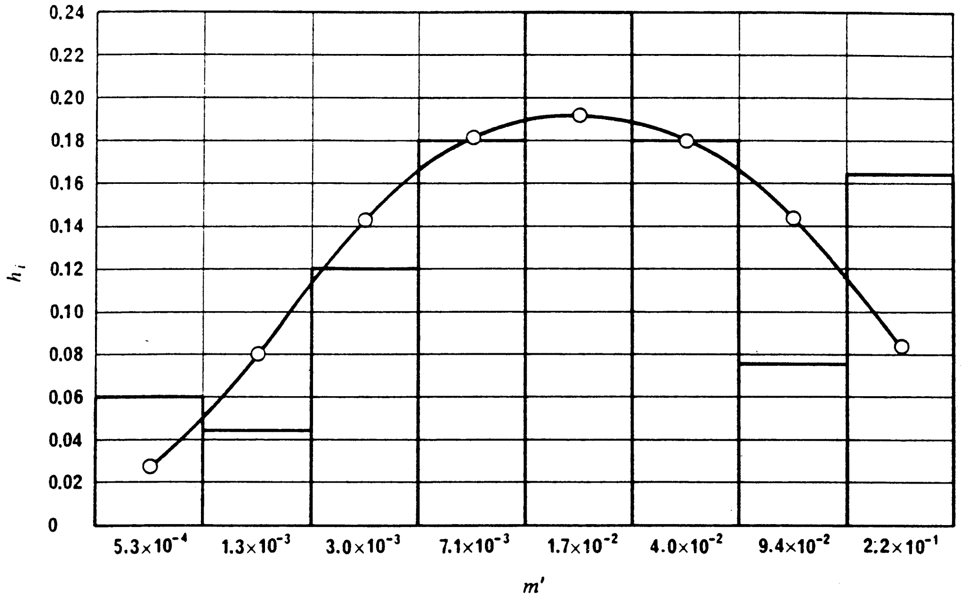

FIGURE 3

(See Table I, No. 3)

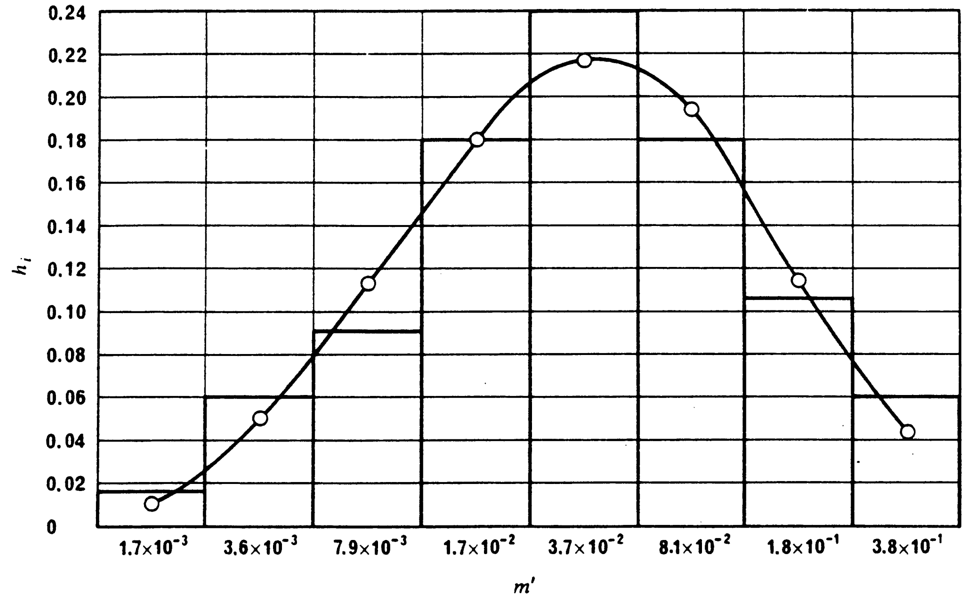

FIGURE 4

(See Table I, No. 4)

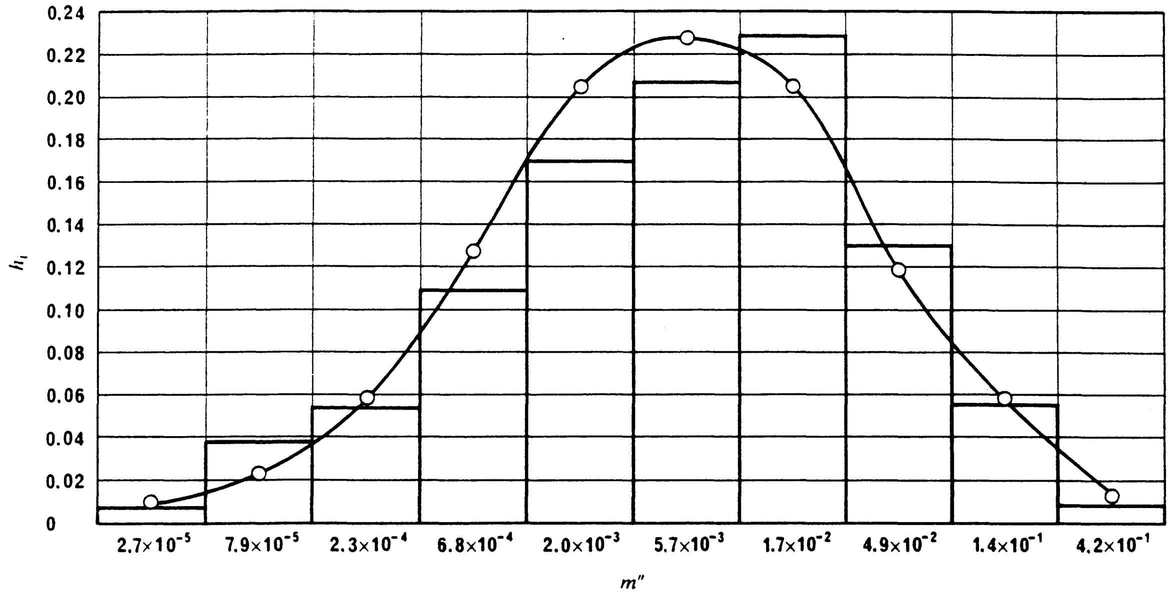

FIGURE 5

(See Table I, No. 5)

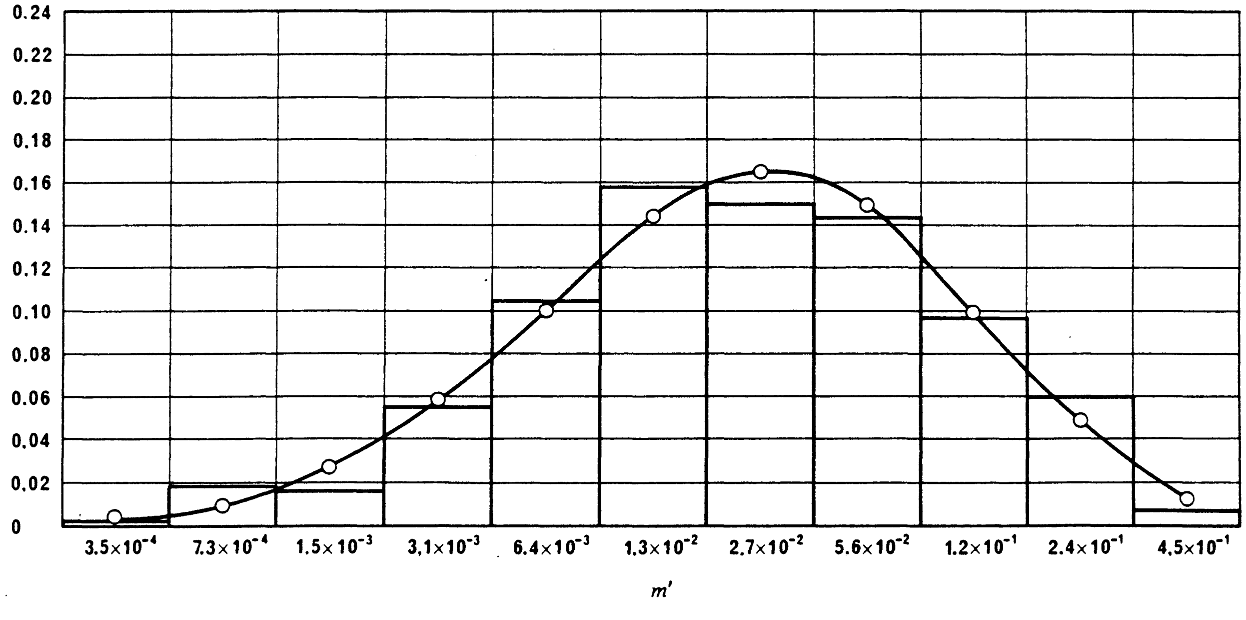

FIGURE 6

(See Table I, No. 6)

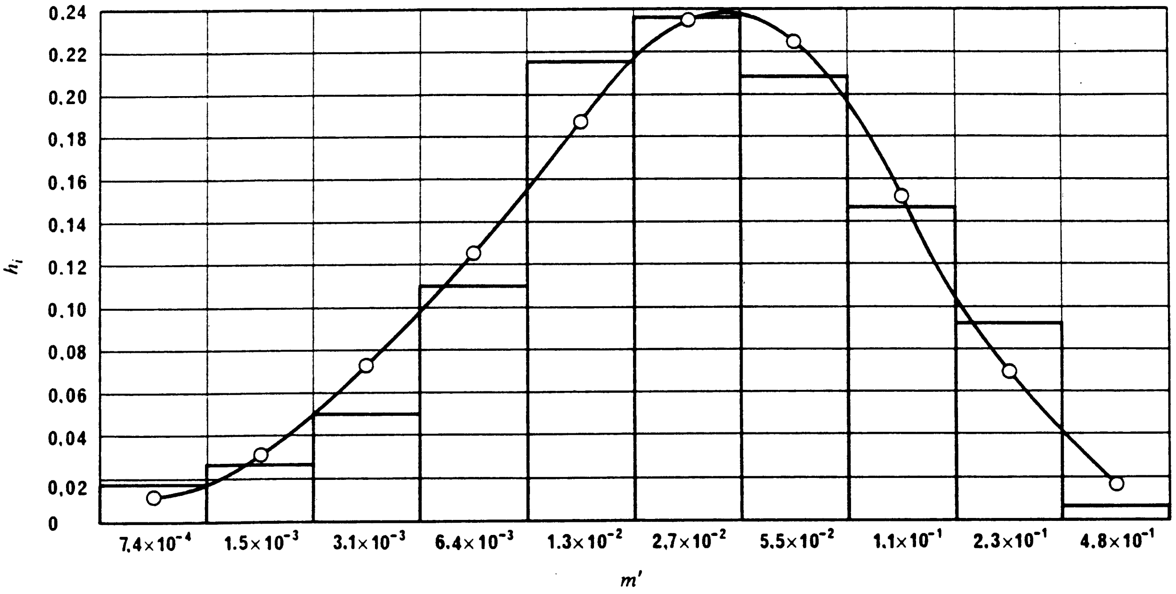

FIGURE 7

(See Table I, No. 7)

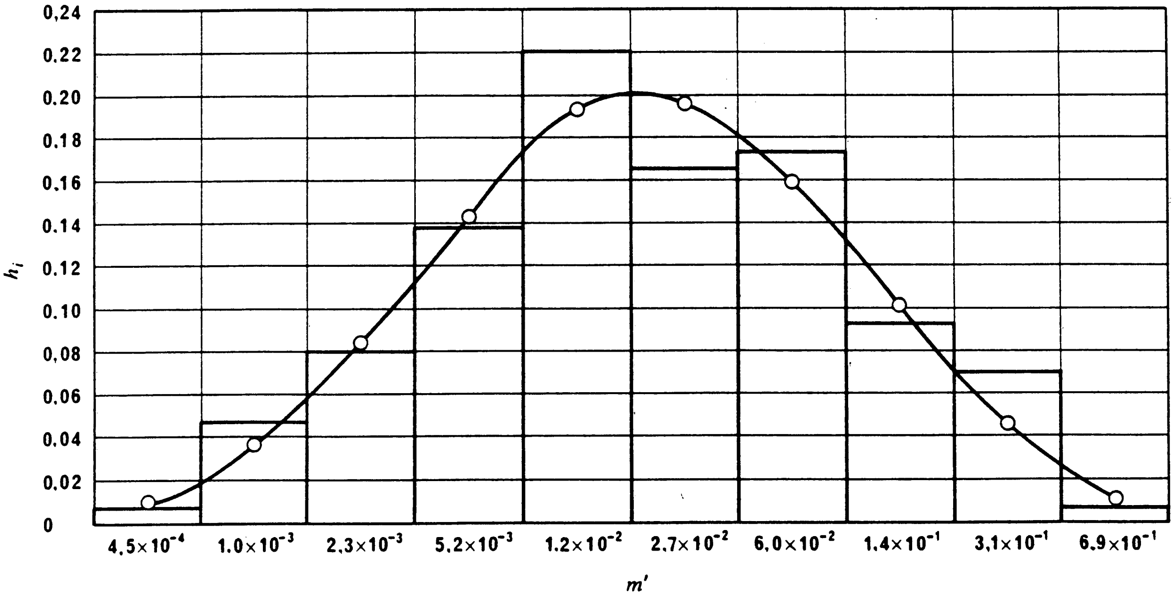

FIGURE 8

(See Table I, No. 8)

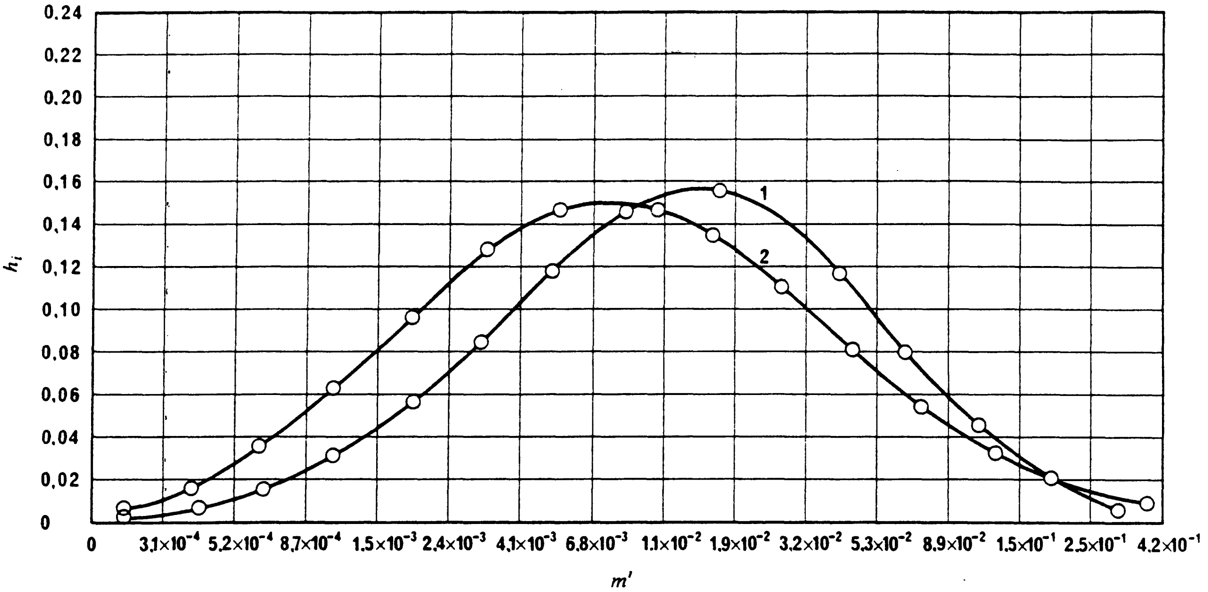

FIGURE 9

(See Table I, Nos. 9 and 10)

The histograms and distribution curves in Figs. 5, 6, 7 and 8 were plotted, as distinct from the previous curves, on the basis of a much greater sample size, which considerably improved the agreement between the empirical and the theoretical curves. These curves also provide clearer confirmation of the statistical stability of the variation series and of the constant character of the approximating curves, despite the fact that, in the formation of the series, a summation was made of the data obtained from operation with several shore stations communicating with different ships in the most widely scattered locations.

Distribution curves 1 and 2 in Fig. 9 (the histograms of the experimental data are not given, in order not to complicate the figure) relate to the experimental data obtained simultaneously with identical duty period frequency and space characteristics in a channel without (curve 1) and with (curve 2) a signal bit regenerator.

Figure 9 is a good illustration of the way in which distribution curves for log *CER* can be used to assess the effectiveness of various technical solutions in telecommunication channels. For example, Fig. 9 shows that, on average, a signal bit regenerator increased the reliability of information transmission from 2.2×10^{-2} to 8.1×10^{-3}. The type and size of the change in curve 2 in relation to curve 1 clearly shows the scale of the advantage to be derived from the use of this equipment.

Thus, in view of the stability of the law of variation of log *CER* or log *BER* with different combinations of frequency, space and time characteristic values of the duty periods (in selecting the working condition of an HF channel), there is a genuine possibility of objectively assessing the effectiveness of a new technical solution in the channel. Hence, when new equipment is tested, sufficient statistical data must be obtained on the condition of the channel both before and after the equipment is used. Experience gained in statistical studies of the quality of maritime HF channels warrants the tentative conclusion that 100-150 ten-minute test duty periods provide a basis for statistical generalizations within a quite acceptable margin of error. When an equipment is tested by the administrations of a number of countries, differences in the assessment of the quality of the initial channel condition are perfectly understandable and acceptable. In assessing the effectiveness of new types of equipment in HF channels, these differences may be standardized on the basis of the data obtained by all administrations. The standardized values can be applied for purposes of a comparative assessment of the effectiveness of various technical devices without any need for joint full-scale tests.

In the experimental work on board the "Puskin" and "Magnitogorsk" the relative transmission rate V_r was determined in addition to the above-mentioned characteristics using direct-printing equipment in the ARQ mode, thus providing information concerning the average values of the lengths of series of unbroken erroneous blocks and the nature of the distribution. V_r is defined as the ratio of the number of blocks N_c received correctly to the total number of blocks N transmitted. V_r was determined for separate intervals within each duty cycle in order to determine the dynamics of changes in channel quality during the duty period. The purpose of this investigation was to assess the necessary duration of the measuring periods when determining the performance of digital channels on a statistical basis.

Figure 10 shows a unified histogram and a curve of the distribution of the probability density h_i versus the relative transmission rate V_r during a duty period. The curve in Fig. 10 as well as those in Figs. 1 to 9 follow the Gram-Charlier law.

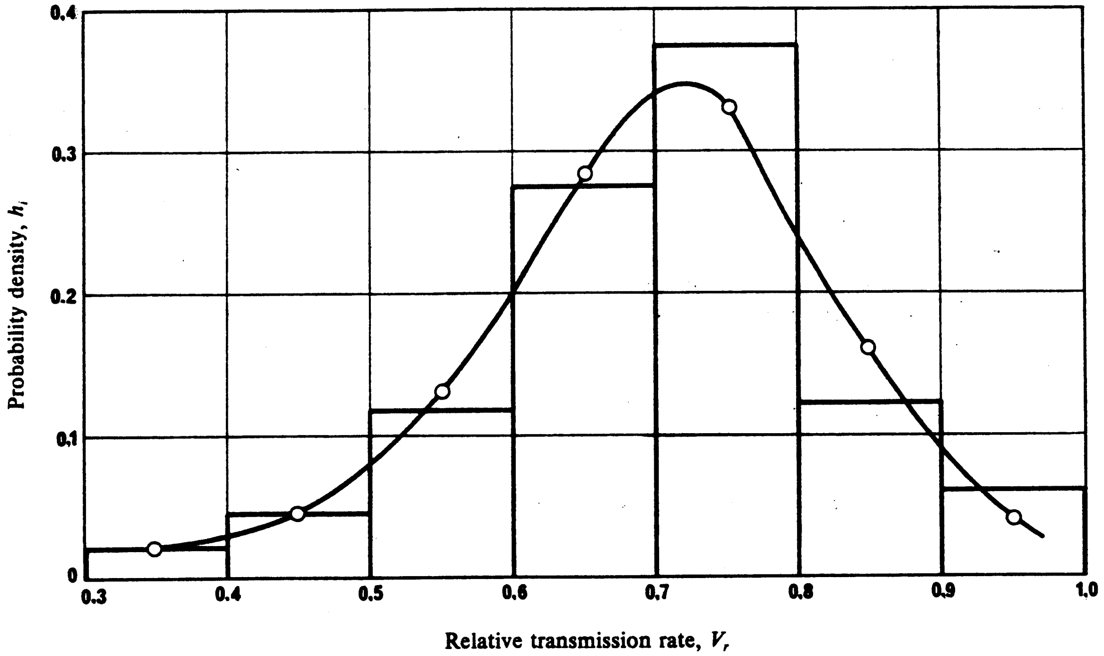

FIGURE 10 – *Distribution of the probability density*

During the tests it was established that the interval over which V_r should be averaged in order to obtain a meaningful operational assessment of the channel quality during the duty period should not be less than 100 blocks. The lengths of the duty periods for the tests should not be less than 10 to 12 min, taking account of the off-on/on-off channel state transitions characteristic of the HF bands.

6. Preferred methods of performing tests

6.1 From the sea trials performed and the analysis of the results by the USSR, together with the methods reported by other workers for testing complete equipments, a known sequence of characters, including shift coding if used, should be transmitted, the performance being expressed as received character error-rate. For establishing optimum design methods, a long random sequence of digits is used, the complete sequence of correct and error digits being recorded on paper or magnetic tape for subsequent analysis by computer to give error burst statistics, or to be applied as error occurrences to digitally coded characters for comparing different coding and error control methods. Instead of the pseudo-random stream, some workers have used the sequence 010101 which simplifies the code synchronizing problem at the receiver but does not give an accurate simulation of message traffic.

6.2 When complete equipment tests are made under real conditions the tests must at least include all hours of the day, summer and winter. If equipments are to be compared, tests should be made alternately on the same frequency channel.

6.3 Tests of digital transmitting equipment on VHF and UHF maritime mobile links are much less difficult than HF tests because the main contributors to multipath propagation are terrestrial reflecting objects, which give similar wave interference patterns from one day to another. The multipath delays are also much shorter than at HF so that there should normally be no frequency differential fading over the bandwidths used for the VHF channels. So long as tests are made over routes with several representative environments, it should be possible to make reliable comparisons of the performance of equipments and to establish the probable service range.

6.4 Tests of digital equipment using satellite relay should take into account both reflection from the ship structure by transmitting in many directions at different angles of elevation, and also reflection from the sea surface by making tests with the range of sea states likely to be encountered.

7. Conclusions

7.1 The documentation in Study Group 3 is directly applicable to HF aspects of this question.

7.2 Statistics for the range of signal strengths and noise levels to be expected in HF ship-to-shore communications at all times and ranges are not available. Therefore a final assessment of equipment performance must at present be made on real transmission paths. Owing to the variability of propagation conditions with time, season and frequency, reliability can only be attained with tests over a long period. Direct comparison of different equipment should be made simultaneously, or not more than minutes apart.

7.3 HF path simulators have been made but cannot be considered generally available to administrations. Such simulators enable test conditions to be closely defined and repeated, if necessary, so that reliable comparisons of equipment can be made. There is however insufficient information about ship-to-shore signal strength and noise conditions to enable the path simulator to be set up with the confidence so it represents the communication conditions which occur in practice.

7.4 Until the transmission path parameters and noise statistics which are relevant to ship-to-shore communication conditions have been established, the range of values given in Annex I to Recommendation 520 should be used for path simulator tests.

7.5 Since the tests carried out do not cover all aspects of the problem of the objective evaluation of the quality of digital channels, and considering the importance of finding a solution, experimental and theoretical work should continue to provide answers to Question 42/8.

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