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- Vol. 1 - Synopsis
- Vol. 2 - Prospects for Northern Development
- Vol. 3 - Northern Communications Requirements
- Vol. 4 - General Information and Broadcasting Services for the North
- Vol. 5 - Terrestrial Systems
- Vol. 6 - Communication Satellite Systems
- Vol. 7 - Northern Communications Co-ordination and Planning.

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SYNOPSIS

This report describes the terrestrial system options and techniques that are available to serve the North with improved telecommunications. Detailed attention is given to High Frequency, Radio Relay, and Tropospheric Scatter radio systems.

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H.F. RADIO SYSTEMS

OVERVIEW

H.F. COMMUNICATIONS IN THE
CANADIAN NORTH

BY

D.M. HINTON

HF COMMUNICATIONS IN THE CANADIAN NORTH

GENERAL

Except for earlier maritime mobile operations, the 1930's saw the first HF radio communications established in the Canadian North. Since that time, particularly in the last twenty years, the communication systems reaching into the area have increased at a tremendous rate. From the earliest HF radio telegraph operations we have proceeded to the operation of troposcatter systems and in the near future to satellite systems.

In reviewing the past use of HF radio, the most noticeable point is the unplanned proliferation of many systems, of varying degrees of technical excellence, and the variety of both private and public systems. The justification of these systems ranged from the defence of our country to the guidance of a sportsman. HF communications have been used where no other radio communication system has been used where no other radio communication system has been possible from either a technical or an economic viewpoint.

Where one or two communication channels are all that is required, over route distances of one hundred miles or greater, it has not been feasible to consider any alternate to HF radio. Certainly where the numbers of channels required reach the 50-60 range, other modes of operation such as tropo-scatter and line-of-sight radio relay would be considered. With the advent of satellite systems, the availability of multi-channel multi-point facilities will be increased.

If we consider that multi-channel systems will be required between some main locations, then we could assume that HF radio will provide the communications between these main and lesser locations and that many more locations can be served. The important point here, is that even though there is a need for the multi-channel system, it will not reduce the future use of HF for the smaller localities.

How the increase in northern communications is carried out can bear heavily on how well we can employ HF communications regardless of the introduction of new multi-channel technology. Thus must be on the basis of using the best technique in each case based on economics, technology and the social needs of the area.

EQUIPMENT

The newer generation of solid state apparatus will provide reliability which is at least one order of magnitude better than the general

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run of equipment now in service. Maintenance of apparatus has and will always be a problem where skilled personnel are scarce and can not be readily transported. Fewer adjustments of this new equipment are required, and as a consequence few control knobs, etc., appear on new apparatus. This reduces illicit adjustment by untrained operating personnel.

The new equipment has a lower prime power requirement which permits its use in many locations where power may be a scarce item. In fact, emergency operation from batteries could be considered where the prime power source has failed.

For remote station operation, the radio equipment, switching and power equipment will require improvement in reliability. Power is the most difficult to improve. Traditional diesel generators are not the most reliable devices in the hands of inexperienced people. Consideration of fuel cells or other more sophisticated power sources could provide greater reliability. Back up emergency power should be considered where possible.

Main locations will usually employ higher power transmitters and on-site maintenance personnel would be available. For this reason the power supply is not as great a problem as it would be at remote low powered stations.

Wherever possible directional antennas should be used to increase circuit reliability and reduce interference. The use of non-directional antennas should be limited to low power stations.

FREQUENCY STABILITY

The frequency stability of radio apparatus will require improvement if the trend is towards unattended operation. If Lincompex equipment is to be considered, the overall stability of HF radio systems will have to approach an error figure of one cycle in 10^7 (assuming a 12-15 MHz upper limit). This could be overcome by a synchronizing scheme employing the received signal as the reference. Perhaps common calling channels could be used to transmit a reference signal from a common source. If Lincompex is not used then an error of one cycle in 10^6 would suffice for unattended operation of SSB equipment. This assumes an acceptable level of demodulation with an error not greater than 10 cycles, for telephone communication and data transmission, up to 1200 bps.

TRANSMISSION CONSIDERATIONS

If we assume that in the end, public communications in Canada will require interconnection, then to serve the total public sector, serious consideration must be given to the problems of compatibility. Development of communications in Canada's north which require

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conversion of transmission or signalling features should be minimized.

An example is the very likely use of accoustical telephone couplers for the transmission of data. Although present couplers are normally used for low speed data (100 wpm) there is no serious technical reason for this limit. If Lincompex equipped HF trunks are part of the network and are switched in tandem the data user would obtain an inferior graded service when compared to normal telephone facilities, even though from a speech point of view the facilities would be acceptable. The noise levels may be excessive for greater percentages of time for even low speed data and for speeds in the order of 1200bps the bandwidth and delay characteristics would limit the performance. It would seem likely that special techniques for data may be required to provide an acceptable performance level.

Today's manually switched or operated HF circuits allow for human monitoring of the circuit condition. The proposal for automatic unattended switching poses a real problem. Serious consideration must be given to the avoidance of unacceptable switching and supervisory failures on HF circuits. The using public will not understand why the failure has occurred - just that his service is not available or at least unsatisfactory.

Where possible, full-duplex trunks should be considered. Although the push-to-talk operation is understood and accepted by the remote user, on an interconnected call, the other user will be unfamiliar with the one-way at a time function. The resulting confusion frustrating experience.

Present day HF circuits are usually operated with an arbitrary net loss. The ability of future apparatus to operate with sufficient loss stability and to maintain echo and singing margins is not yet determined. The trunk loss should be kept as low as practical considering the design of the trunk, the echo tolerance of the user and the singing margin. Echo suppressors will be required if the round trip delay time exceeds about 45 milliseconds. Note the round trip delay of an HF trunk with Lincompex is at least 16 milliseconds. Two HF trunks in tandem plus a wire line facility at one end would likely be marginal and may require echo suppression or the increase of the design net loss of one or both trunks. As a comparison, the Lincompex equipment alone equals the delay in about 1000 miles of microwave system.

With any system where delays of this order are possible, switching should be carried out on a 4 wire basis and strict attention to terminations at 2 wire points. Care must be exercised to maintain good impedance matching to avoid reflections and consequent echo.

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HF PROPAGATION PREDICTIONS

In the past very little operational use has been made of the scientific predictions of the maximum useable frequency (MUF) or the optimum working frequency. These predictions are available and with improved computer service DOC could render the user the guidance necessary to more efficient spectrum useage.

Accurate predictions could allow a more accurate determination of geographical separation of stations assigned to the same frequency. This, along with a proper appraisal of the users operating hours, would allow optimal sharing of the radio spectrum.

An additional benefit derived from accurate and frequent predictions would be the better choice of frequency for the varying nature of HF propagation. This would permit the assignment, on a short term basis, of frequencies which are close to the optimum working frequency for that period. Note that day and night frequencies will change diurnally, seasonaly and over the sun spot cycle.

REGULATORY MATTERS

New tools such as accurate propagation predictions and computer filed assignment information should make it possible to plan the improved use of the HF radio spectrum. Before these tools can be employed to their fullest extent the following refinements are suggested.

(1) Publication of guidelines and procedures for the HF bands, similar to those for the microwave bands.

(2) An investigation of the spectrum occupancy using new monitoring techniques. This will establish the necessary geographic separation of stations.

(3) The improved classification of users.

(4) The possibility of frequency assignments for shorter periods of time.

(5) Consideration of the licensing for specific hours of operation.

(6) Making available optimum working frequency maps to users of multifrequency systems.

(7) Re-evaluation of frequencies assigned large users on a traditional basis.

HIGH FREQUENCY RADIO

Ionospheric Sounding as an
Aid to HF Communications

by

Doris H. Jelly

Ionospheric Sounding as an Aid to HF Communications

1.0 Introduction

Most of the techniques used to improve the quality of HF communications are concerned with improving the system's performance under poor channel conditions where conditions are poor because of interference or ionospheric conditions. Methods generally employed are of the following types: improved antenna design, higher-powered transmitters, signal and detection techniques matched to the HF medium, diversity techniques, and error correction based on either error detection and repetition or forward error correction codes. Although these methods usually result in some improvement, the performance of HF circuits is often still below acceptable standards and below the level that may be obtained, largely because of the problem of choosing a good frequency on which to operate. It has been demonstrated that communications can be substantially improved with ionospheric sounding to aid in the selection of good frequencies.

The problem of using good frequencies has two aspects, namely, frequency assignment and frequency selection. The present system of frequency assignment does not make efficient use of the spectrum. Frequencies are assigned to a specific agency for a specific circuit or group of circuits to the exclusion of all other users. This means that if a frequency is not used or even useable for the service assigned, it is not available to another agency lacking an appropriate frequency. Most users are restricted to a limited number of frequencies, both by assigning agencies and by equipment limitations. If enough frequencies were pooled, sounding could aid in better spectrum management by acting as a clearing house in assigning frequencies as and when required.

Sounding can also be very effective as an aid to selection of good frequencies. The frequencies that may be reflected by the ionosphere vary diurnally, seasonally and with the sunspot cycle. In addition, ionospheric storms have devastating effects on radio propagation, particularly over much of Canada where auroral zone and polar cap effects occur. Considerable effort has been invested in improving frequency selection by means of frequency predictions. These are of a statistical nature and provide an estimate of the best frequencies for a circuit for each month. They are useful for providing guidance in the choice of frequencies, particularly at the system-design stage of choosing an appropriate frequency complement for a given circuit. However, there is a large day-to-day variation about the median and to make most effective use of the ionosphere as communication medium, real-time rather than statistical evaluation is a must. Sounding systems are designed to perform the real-time sampling and evaluation of frequencies. Furthermore they may have the capability of sampling interference

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and noise on a channel and then rating performance on a signal-to-noise basis. Sounding systems are designed according to specific needs and may have any degree of sophistication.

1.1 Types of Sounding

Sounding may be of three types, vertical incidence, oblique incidence and backscatter.

1.1.1 Vertical Incidence

For vertical incidence sounding, the transmitter and receiver are located at the same site. By synchronously varying the frequency of the transmitter and receiver, information is obtained about the range of frequencies that is reflected by the ionosphere overhead. A world-wide network of vertical incidence sounders exists and from these sounders have come the data which form the basis of all prediction systems. Although relatively little real-time use has been made of vertical soundings, they could be modified to aid in frequency selection, particularly on short circuits. A proposed system is outlined later.

1.1.2 Backscatter

Backscatter systems are also based on a collocated transmitter and receiver. In this case, the signals are transmitted and received obliquely usually after two ionospheric reflections and one ground reflection. Although research is continuing into the possibility of utilizing backscatter modes, there are difficulties in the interpretation of the received signals. This seems to be a particularly serious limitation at auroral latitudes where many of the signals are reflected directly from ionospheric irregularities. This difficulty would probably restrict the use of backscatter systems to low and medium latitudes (1).

1.1.3 Oblique Sounding (2) - (8)

Oblique-incidence sounding takes place over the actual HF path and, through experimental programmes, has already contributed much to the understanding of HF propagation. Operational systems to aid in real-time frequency selection have been proposed and developed with varying degrees of complexity. The information of prime importance that can be provided is the signal strength of frequencies that can be supported on that circuit at a given time. A knowledge of the noise and interference level on each channel is of almost equal significance. The complexity of a system is dependent on the extent to which these measurements are augmented by other quantities important to the transmission of intelligibility, e.g., fading, and time and frequency dispersion.

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The complexity also varies with the degree of automation of the system. Up to the present the costs of such systems have tended to be higher than people have been prepared to pay for improving HF which is often relied on to provide inexpensive communications. With expanding use of communications of all types, HF included, the potential traffic plus the increased crowding of the HF band may make sounding operationally attractive and economically feasible to users. Ideally, for optimum use of the spectrum the frequencies of every HF circuit would be controlled by an integrated sounding system.

Several systems that have been developed are described in greater or less detail with the intention of indicating the potential use of sounding systems and the present stage of development.

2.0 The CURTS Concept (9) - (14)

One of the most complex oblique systems yet devised is the CURTS (Common User Radio Transmission Sounding) system. It was developed to aid in the real-time frequency management of the HF circuits of the U.S. Defense Communications System (DCS). The magnitude of the problem of frequency selection in the DCS has been illustrated as follows: if six frequencies were assigned in each direction on each HF link of the system, the DCS itself would require the entire HF fixed band allocations. Not only do they not have all these assignments and hence have to share frequencies within the system, but they also have to compete with HF users from other organizations and other nations for the assignments they do hold. Thus the major problem for the DCS is not just to select a complement of frequencies that will support propagation but one that will minimize the effects of interference. To accomplish this the CURTS system monitors, processes and predicts (on a short term basis) the parameters that directly affect the quality of HF communication and continuously predicts the quality of each frequency assigned to a network. The system also continuously monitors the quality of the frequency in use on each link. The parameter that is used as the criterion of the quality of a frequency is the binary error rate (BER).

2.1 The CURTS Test Network

The basis of the CURTS system is a network of oblique ionospheric sounders with a transmitter at each major mode of the HF system and a receiver at each connected point in the network. A test network was operated in the Pacific area with transmitters at six sites and receivers at two sites. The equipment sounder each of the 120 assigned frequencies on each of the circuits every 10 minutes. The signals were digitized and passed to a control computer where the data were compared with a time

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history tape and then added to that tape for use on following days at the same time. A measure of the time dispersion (multipath delay) was also determined from the sounder pulses and added to the time history. An automatically tuned receiver sampled the level of the noise and interference background on each of the assigned frequencies and passed it to the computer in digitized form. The frequency dispersion on the operating frequency was also measured and stored. The computer then evaluated each assigned frequency falling in the range of observed frequencies using the measured parameters and considering the list of assigned frequencies and the frequencies already in use. In this way, possible interchannel interference was considered. The computer logic also made use of ionospheric predictions, and forecasts of disturbances in assessing the frequencies. A quality figure based on the BER was assigned to each frequency. The frequencies were then ranked in descending order of quality figures and listed as a teletype output which was transmitted to the stations to aid in frequency selection.

2.2 Results

From the test network the feasibility of the CURTS system was established and several advantages were demonstrated. The system was shown to be capable of choosing the best frequencies in environments of poor propagation, high interferences or both. Various measures of the degree of improvement have been given and as an example 98% of the frequency changes resulted in immediately acceptable traffic compared with 70% without the CURTS system. Another advantage was the reduction in effort required by operators; for instance, attempts to find a useful channel during propagation outages were eliminated. Also it was established that the amount and duration of HF propagation outages have been greatly exaggerated. In one test most outages were due to interference and equipment failures. Confidence in the CURTS system was such that poor performance due to equipment problems could be idenfified. Most important for the DCS was the conclusion that higher data rates than had been previously transmitted by the HF medium were considered feasible.

2.3 CURTS/AUTODIN Test

The ability of the HF to carry higher traffic rates was investigated with a separate test using the CURTS system applied to the AUTODIN data transmission system which has a rate of 2400 bits per second. In the AUTODIN (automatic digital network) system, data are transmitted in blocks to which an error-detecting code has been applied. If no errors are detected in a received block it is accepted, otherwise, the receiver uses a feedback channel to request the transmitter to repeat the erroneous block.

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During the CURTS-controlled portion of the CURTS/AUTODIN test, the average throughput was 97.4%. It was concluded from the test that with the CURTS system of frequency selection, the quality of HF can be made to approach (within its bandwidth limitations) the reliability, availability and quality of other media such as satellites and cables. Studies were also made of the effectiveness of forward-error-correction (FEC) with the CURTS AUTODIN system (that is without a repeat). The rate of data transmission can be increased by FEC coding only if its use produces a decrease in the rate of erroneous blocks that more than compensates for the redundancy required to implement the code. In one test using the AUTODIN system, only, an improvement of a factor of 3 to 5 in the error rate was reported. In another test with both CURTS and AUTODIN no improvement resulted. The conclusion was drawn that FEC could possibly be used to advantage when a poor quality frequency had to be used but would not further reduce the error rate when the frequencies were selected by the CURTS system.

2.4 Further Comments on CURTS

In all, the CURTS system was shown to provide substantial improvement for HF communications, particularly for data transmission. Despite the convincing evidence of the advantages of the system, economics continue to be the deciding factor and the system has not received financial support.

It should be noted that the studies that have been reported on the CURTS system have all been at low or medium latitudes and extrapolation of the conclusions to high latitudes is not necessarily valid.

3.0 CRC Proposed Systems

The CURTS system is a highly sophisticated and costly system which would be of interest to organizations that require very high reliability communications and have the financial resources to meet their needs. However, the principle of sounding may be applied in more rudimentary forms to aid substantially in improving HF communications.

Based on many years of research CRC (DRTE) has acquired considerable experience in the principles of sounding. A number of references are included which summarize some of the significant contributions but are not intended to be exhaustive. In the beginning, vertical incidence soundings were used to acquire data on which were based a frequency prediction system which was published in 1954 as DRTE Report 1-1-3(1) and forms the basis of the current prediction system. Oblique soundings were first used to test and improve the predictions and to derive a better understanding of ionospheric propagation (2). Later, the oblique-sounding technique was suggested as a real-time aid to communications (3). From the earliest proposals have evolved a series of variations of the sounding technique, each matched to a particular requirement. Some of the proposals have been tested in field trials and in each case the usefulness of sounding has been verified. Some systems which have been tested will be briefly described as well as a system which has been proposed specifically for the Canadian north.

3.1 The CHEC System (16)

3.1.1 Ground-to-Air

A system patented as CHEC (Channel Evaluation and Calling) was developed by CRC to aid in maintaining good communications on HF air-ground links. For this system, the assumption was made that the air-ground path was the difficult one because of limited power and an inefficient antenna on the aircraft. Therefore if air-ground communications were possible then ground-air communications on the same frequency should also be possible.

The ground communications centre, with its conventional transmit-receive facilities was also equipped with the CHEC stepped-frequency, ground-interference receiver for measuring the encoding ground interference levels and with the stepped-frequency sounding transmitter for the transmission of the coded sounding transmissions. Both air and ground units were maintained in time and frequency synchronism by internal, crystal-controlled clocks.

The system was evaluated using a series of flights with Canadian Armed Forces aircraft. The equipment was designed to accommodate 16 frequencies between 3 and 21 MHz. A sounding was completed in 64 seconds and then could be repeated as often as every 2 minutes. In the sounding process, first the ground interference level on a specific frequency was determined and encoded for transmission to the aircraft. This was followed by a transmission on the same frequency to enable the aircraft to determine the signal strength. If that frequency could propagate to the aircraft, the CHEC equipment on board was designed to determine the signal-to-ground interference level (S/GIL). A receiver display registered if the S/GIL was greater than a present level. The output of the receiver display could have been recorded on a paper chart to provide a history of channel performance to be used as a ready reference for channel evaluation. The trials demonstrated the effectiveness of the CHEC system in the air-ground-air operational environment.

A method was also suggested for improving the system by including a calling sub-system. The aircraft communicator selected the appropriate channel and called the ground station during a sounding sequence. As the ground interference receiver stepped

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through each frequency during the sequence, the call would be intercepted at the ground terminal. Whenever the ground station wished to call an aircraft, the call would be included on the sounding transmissions. Upon its receipt at the aircraft, on any of the assigned channels, the coding would be recognized and displayed automatically. Thus if communications were at all possible on any one frequency, it would be possible to call the aircraft. Furthermore, the need for a bank of receivers at the ground terminal, guarding a number of frequencies, would be eliminated.

3.1.2 Point-to-Point

The CHEC system was later modified and tested on a point-to-point circuit. The operational requirement called for two independent sounding links operating in parallel with each of the communication links. However, in the trials, it was decided to sound in one direction only, in parallel with the aided communications link. Standard operational equipment was used where possible. The data collected during the trial consisted of the quality figures indicating individual channel performance and the statistics concerning the per cent teletype copy received over the associated communications system on the channel selected for traffic. The most significant feature that was evident from the analysis of the results of the trials was the high circuit reliability that was attained. Over a six-week trial, the average circuit performance achieved with sounding-aided operations was 94.6% compared with a potential performance of 98.6%. The discrepancy was mainly due to time required for frequency changes and equipment malfunctions.

3.2 Channelsonde

Another patented system, denoted as Channelsonde, has been proposed and tested for short range communications. This system uses vertical incidence sounding to aid communications between a base station and a remote station within a distance of 250 miles. At the base station the Channelsonde sounds the assigned frequencies. If a frequency is reflected by the ionosphere overhead, it is assumed to be capable of propagation to a nearby station. The facility for channel sounding can be incorporated into a portable HF transceiver by designing it to operate in both sounding and communications modes. For fixed station applications a completely separate Channelsonde is suggested as more practical. During the trials, Channelsonde performed according to expectations.

3.3 Availability and Cost

In implementing any of the proposed systems, the features included would depend on the requirements of the particular

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application. The cost of such systems is therefore not easily assessed. However, an order-of-magnitude figure can be obtained from estimates that have been made. For instance, a company was prepared to build a CHEC system for about $10K per aircraft terminal. The Channelsonde was estimated to add about 20% to the cost of a standard HF transceiver. With the CHEC point-to-point circuit, a system suitable for testing could be constructed largely from shelf items.

4.0 Summary

Each system that has been tested has demonstrated that sounding is an effective aid to communications. Advantages have been found to be the following:

(a) Improved quality of communications because the channel used is one which is good in terms of

  (i) propagation conditions,
  (ii) low noise and interference.

(b) Better use of spectrum resulting in reduced interference.

(c) Time to establish contact is reduced.

(d) The operator is aware when contact is not possible and does not continue trying, thus producing unnecessary interference.

(e) When conditions improve, contact is re-established in a minimum time.

(f) Propagation outages are recognized as such and hence, equipment problems are more easily identified.

(g) Operations can be largely automated to eliminate the need for skilled operators.

(h) Automatic calling can be included.

With added sophistication, frequencies may be chosen on the basis of:

(i) low time and frequency dispersion

(ii) low fading rate

(iii) past history of conditions

(iv) predictions and forecasts of disturbances.

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4.1

Sounding should be particularly advantageous for mid and northern Canada where communications are dependent on a very irregular ionosphere. Difficulties are associated with low ionization due to the low solar angle, irregular increases in absorption, high fading rates and sporadic ionization in both F-and E-regions. Despite these difficulties, good operators can at present maintain communications during a high percentage of the time. With a wide range of frequency assignments to take advantage of the ionospheric irregularities and sounding-aided operations, the outages would be further reduced and the channel quality improved.

5.0 Proposed System for Northern Canada

From current surveys of the requirements of communications in the remote areas of Canada, it becomes apparent that the most satisfactory solution would be an integrated HF system that could then be completely integrated with all other modes of communications, i.e., the national trunk system, satellites, etc. The forms that an integrated system could take are innumerable. One model for such a system is being developed at CRC. Details of the whole system will not be included here, only a brief account of the HF operation. The complex features of the system would be concentrated at control centres where computers could control frequency assignments, billing, etc. Channel sounding of propagation and interference conditions would be a fundamental part of the system and would be incorporated in the system control. As far as the user is concerned, the system would operate with a simple procedure little different from a standard telephone.

5.1 System Features

Breifly the proposed HF system has the following features:

(a) Centralized control in regional districts.

(b) Regional HF communication zones of approximately 500 miles in diameter.

(c) Integration with national trunk systems.

(d) Integration with local exchange.

(e) Integration with multiple access communications satellite network (described in CRC 661-12 (NCL) Programme 9, February, 1970).

(f) Automatic local exchanges.

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(g) In band tone signalling (Touch Tone).

(h) Dynamic frequency management.

(i) Dynamic channel measurement.

(j) Dynamic frequency predictions.

(k) Separate calling frequencies.

(l) SSB modulation.

(m) Fourth generation solid state transreceivers with multiple frequency operation.

(n) Either voice operated simplex or time division duplex.

(o) Syllabic infinite compandors (equivalent of Lincomplex).

5.2 Systems Operation

Communications within the HF system is illustrated by referring to Fig. 1. Any subscriber can call any other subscriber by direct dialling. Suppose a subscriber A at terminal 231 wishes to call B at terminal 242. A picks up the handset, listens for a dial tone and dials 242. When he has finished dialling, local HF station 23 automatically sends a signal to control centre R2 with the information that 231 is calling 242. This signal is sent on successive calling frequencies until a reply from R2 is received by 23. In this reply R2 informs 23 that 24 will be contacted on communications frequency, f_c,where $f_c$is determined from sounding information and a knowledge of frequencies in use. 23 changes frequency to f_c and calls 24. In the meantime, R2 calls 24 and informs it that 242 is going to be called on f_c. 24 changes to f_c to receive the call. 23 and 24 make local connections to 231 and 242. When A hangs up the handset, 23 will return to the calling frequency, thus informing R2 that the call is completed and that f_c is again free.

5.3 Advantages

Advantages of this particular system are considered to be

1) All the advantages of prediction and sounding techniques, (see Section 4.0).

2) Pooled HF frequency assignments, resulting in optimum use of the spectrum. A greater range will be available for each circuit and a minimum of interference will be allowed.

3) Interconnection of all subscribers with the national system in a flexible manner.

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4) Simplified operation and equipment for local users by centralizing all decision functions at the regional control centres.

5.4 Comments

This proposal for an integrated HF system includes many attractive features. However, it is at a very preliminary stage and is presented here to illustrate one plan whereby current technology could be applied to aid communications in the north. Before it could be considered for implementation, the full ramifications would have to be investigated.

References

1. R.D. Hunsucker and H.F. Bates "Survey of polar and auroral region effects on HF propagation", Radio Science, Vol.4, pp 347 - 365, Apr. 1969.

2. J.H. Chapman, K. Davies and C.A. Littlewood, "Radio Observations of the Ionosphere at Oblique Incidence", Can.J. Phys. Vol.33, pp 713 - 722, 1955.

3. W.L. Hatton, "Oblique-Sounding and HF radio Communications", IRE Trans. on Communication Systems, Vol. CS-9, Sept. 1961 pp 275 - 279.

4. L.E. Petrie and E.S. Warren, "The Propagation of High Frequency Waves on the Winnipeg-Resolute Bay Oblique Sounder Circuit", Ionospheric Radio Communications, ed. K. Folkestad, Plenum Press, N.Y.1968.

5. D.H. Jelly, "The Effects of Polar-Cap Absorption on HF Oblique-Incidence Circuits", Jour. Geophys. Res. Vol.68, pp 1705 - 1714, 1963.

6. G.W. Jull "HF Spatial and Temporal Propagation Characteristics and Sounding Assisted Communications". Ionospheric Radio Communications, ed. K. Folkestad, Plenum Press, N.Y. 1968.

7. G.W. Jull, D.J. Doyle, G.W. Irvine and J.P. Murray, "Frequency Sounding Techniques for HF Communications over Auroral Zone Paths", Proc. IRE Vol.50, pp 1676 - 1682, July, 1962.

8. H.P. Williams "Possible Reduction in Propagation Outage Times as Deduced from HF Oblique Soundings between Bodø and Den Haag", Shape Technical Centre, Technical Memorandum, Oct. 1969.

9. S.E. Probst, "The CURTS Concept and Current State of Development", Ionospheric Radio Communications, ed. K. Folestad, Plenum Press, N.Y. 1968.

10. J.L. Ramsey, K.D. Felperin, T.I. Dayharsh, "A Demonstration of the Consistent Operational Success of 2400 Band HF AUTODIN Data Transmission Using the CURTS Phase II System: Stanford Research Institute, Menlo Park, Calif., Contract DCA 100-67-C-0068, Final Report Part I, Aug. 1967.

11. K.D. Felperin, T.I. Dayharsh, J.L. Ramsey and S.C. Tupper, "The Operational Validation of the CURTS Concept Using 2400 - Band AUTODIN", SRI, Menlo Park, Calif., Final Report Part 2, Jan.1968.

12. T.I. Dayharsh, J.L. Gnagy and S.E. Probst, "Automated CURTS HF: Real-Time Management and Administration of HF Systems and Frequency Resources", SRI, Menlo Park, Calif., Final Report Part 3, Feb.1968.

13. H.J. Crowley, "A Field Text of Error Control Systems", IEEE Trans. Communications Technology, Vol. COM - 17, pp 569 - 571, 1969.

14. J.L. Ramsey, "On the Effectiveness of Coding for HF AUTODIN", IEEE Trans. Information Theory, Vol.II-14, pp 759 - 761, 1968.

15. Prediction of Optimum Traffic Frequencies for Northern Latitudes DRTE Report 1-1-3. Nov. 1954.

16. E.E. Stevens, "The CHEC Sounding System", Ionospheric Radio Communications, ed. K.Folkestad, Plenum Press, N.Y. 1968.

HIGH FREQUENCY COMMUNICATIONS

BY

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Introduction

All natural resources are not unlimited in capacity. As our awareness of these limits increases so does our concern with preserving the usefulness of these resources. The natural resource called the "radio spectrum" is no exception.

Since Marconi's first experiment in 1901, a mere 69 years ago, (less than the life span of a present day man) communication technology has advanced to such a degree that in many societies long distance communications is a well established business and pleasure necessity rather than an awe-inspiring luxury. This has resulted in a temendous expansion of all facets of the communication industry. Some, such as the VHF and Microwave industries have expanded faster than others. As a result, to prevent possible "pollution" of these portions of the spectrum (thereby ensuring the continuance of reliable communication) clear guide-lines and strict procedures to be followed have been established by the government. To achieve this goal in other portions of the spectrum well established, as well as new, scientific techniques which will aid in the planning of these parts of the radio spectrum must be relied upon.

The HF portion is one of these "other portions of the spectrum". As the need for cheap reliable communications for isolated areas of Canada (such as the North) expands, the need increases to plan the HF spectrum as well as utilize techniques which will strive at reliable communication. In the past few years advances in high frequency propagation technology have become readily available to the communications engineer and operator so that the tools to use the high frequency portion of the spectrum effectively are now at his disposal.

In the following sections I will outline one of these tools. Its use in both the planning of the high frequency spectrum and the planning of specific communications system will be discussed. Spectrum management revisions which must be considered in order to make efficient use of these new tools are also suggested.

The Ionosphere

Communications using high frequencies (2 to 30 Megahertz) relies on the region which is located approximately 70-400 Km above the surface of the earth. This region is called the "ionosphere" (a phrase coined by Sir Watson-Watt to describe that region in which ions are formed by the sun's radiation). The ionosphere consists of four distinct layers, each of which will reflect radio waves of a certain frequency range. From which layer the radio wave is reflected dictates to a large extent the distance the radio wave will travel from the transmitter. Because of the large seasonal, diurnal and cyclic variation in the radiation from the sun, both the height and the density of these layers varies. This, in turn, causes variations in the frequencies the layers will reflect. Thus, like the weather which controls our way of life, the ionosphere controls our way of communicating with high frequencies. The ionosphere must, therefore, be studied to determine the frequency that will satisfy the communication requirements during that time. An HF communication system must clearly be able to adapt itself to this varying ionosphere. For a somewhat more complete discussion of the ionosphere and how it varies see the Appendix.

Development of Predictions

In the very early days of ionospheric studies the world was divided into longitudinal zones. The ionosphere in each zone possessed specific characteristics which varied from zone to zone. Before this method was abandoned there existed four such zones - an east zone and a west zone and two intermediate zones. These zones seemed quite accurate as long as there were few ionospheric data gathering stations scattered throughout the world. However, as more data gathering stations were established, it became evident that a three dimensional mapping of the ionosphere in longitude, latitude and time was desirable.

In 1954 the Communications Research Centre (CRC - fermerly Defense Research Board) collected the data which had been gathered by these stations over the past number of years. They then tabulated all the data necessary to calculate the maximum frequency each layer will reflect at any given time at any geographic location north of 35 degrees north latitude.

These CRC tables made possible the manual calculations of maximum frequency the ionosphere would propagate at a particular time and geographic location. If a large time span had to be considered the manual method became extremely cumbersome, if not impossible. At the same time mp accpimt cpi;d ne taken of the antenna system-ionosphere interation. Therefore only the "physics picture" of HF communications system could be presented.

Over the years a great deal of scientific research has been carried out in investigating propagation via the ionosphere and the effects of antenna parameters on propagation. However, very few of the results of this research have filtered down to the people who actually use the ionosphere for communications. There are many reasons for this, one of them being that most books, articles and seminars that deal with the subject are written for a reader with a physics background. In recent years an attempt has been made to correct this situation by such books as AGARDograph 104 whose main purpose is "to be a provision of simple up-to-date information on different problems which may arise in radio wave communication to give simple explanations for these and, when possible, point out how to circumnavigate these problems". Members of CRC give seminars throughout Canada for communication engineers and operators and ESSA in the United States also give similar seminars. Nevertheless the state of the art is such that the scientist can now predict more accurately the reaction of the ionosphere to a radio wave, than the engineer can specify the parameters of this communications system.

In the mid 1950's members of the Department of Transport met with members of CRC (then DRB) to suggest that prediction systems of the day be automated in some way, to facilitate their use by non-scientific personnel. This resulted in one of the first automated systems to predict MUF's and FOT's using a difital computer (7). This system, however, considered only the variability of the ionosphere and assumed the transmitting receiving system was such as to take full advantage of these vaiables. This automated system was the forerunner of the present system described in the next section.

Many other countries (such as Britain, USA, France, etc.) have used this scientific knowledge to devise tools which will predict the behaviour of the ionosphere in the future based on its behaviour in the past. Sometimes these tools are in the form of maps which give the maximum frequency for each geographic location and time, or in tables but more often these are in the form of computer simulation. For example, one of the American systems is a ray tracing simulation. Very simply, a radio wave is represented by a ray and its progress as it traverses the ionospheric layers is simulated with the use of a computer. There are numerous other systems each with its own peculiar advantages and disadvantages but all are based on the same basic information - i.e. the data gathered by ionospheric stations. For a comparison of the American, British and French systems see reference(3).

In the remaining sections the system used by Radio Regulations Department of Communications will be discussed.

Selection of Optimum High Frequencies

In 1967 a joint effort between Radion Regulations and CRC resulted in a system which gives this overall "engineering-physics" picture of the HF communications system. A digital computer is used to predict the variations in the optimum working frequency and then from this prediction selects the optimum complement of frequencies (1).

To calculate the variations in optimum working frequencies the CRC tables of ionospheric data mentioned earlier are used. To select the optimum complement of frequencies for the particular communication system, CCIR's atmospheric and galactic noise data and the parameters of the system under study are used. The system parameters considered are:

- the life of the circuit (length of time in years during which the circuit is expected to be operational)
- the required hours of operation (daytime, nighttime or both)
- per channel transmitter power
- receiver bandwidth
- required signal to noise ratio
- man made noise at the receiving location

- type of transmitting antenna
- type of receiving antenna
- geographic location of receiver and transmitter
- type of emission
- skill of the operators or desired quality or acceptable error rate.

Once these parameters are accurately supplied not only can the optimum complement of frequencies be calculated statistically but the probability of communications for the life of the circuit can also be calculated.

Because the computer simulates the conditions a radio wave encounters as it travels through the ionosphere from the transmitter to the receiver each individual parameter can be studied and optimized. For example, the advantages of an increase in power (increase in reliability) sufficient to overcome the disadvantages (increase in equipment cost and increase in the probability of interference to other users)? By investigating the effects of each parameter the optimum location (from the point of view of local and atmospheric noise), power, type of antenna etc. can be found. Evidently this is a planning tool which should be used to plan the total communications system i.e. the equipment parameters as well as the frequencies which will be required. The antenna system and the varying ionosphere must be considered together in order to optimize both communications and the use of the spectrum.

At the time of this report, the tool is limited to transmitting and receiving locations north of 35 degrees north latitude. This is because the data for the ionosphere south of 35 degrees north latitude is not available to our data base. Effects such as Polar Cap Absorption are not considered because not enough is known of their occurrence. These effects, however, are limited to very high latitudes and occur relatively rarely. It is also assumed that clear channels are available so that crowding is not automatically taken into account. CRC is presently in the process of expanding the tool to consider any location on earth. Also included in this extended program will be a calculation of the critical frequency of the F1 and sporadic E layer.

Evidently such a tool must be upgraded as new scientific techniques are developed. Equally evident is the requirement for the personnel who use such tools, to keep abreast of these new developments.

In the past before such tools were available to the non-scientific community, systems were developed on the basis of the experience gained on other systems. Since only a very general consideration of antenna parameters could be made, no mechanism was set up to obtain such information accurately. There could be no control of the system parameters such as power, which are of great importance when possibility of interference is considered. This system worked for a number of years as long as each user had a sufficient number of frequencies. It could continue until crowding would make communications prohibitive. However, as norther communications expand, this day could come sooner than expected. Fortunately the scientific tools which are now available will aid the future planning of the spectrum and hopefully push this day far into the future. However, in order to prevent misuse of these new tools, the present spectrum engineering methods as applied to HF must be re-evaluated. There are some changes in methods that should be introduced even if these tools were not available, e.g. introduction of guidelines. Other changes should be introduced because the tools are now available to use these changes to benefit the spectrum engineer as well as the communicator. One of these changes should be the shortening of the length of time for which frequencies are assigned.

Frequencies are now assigned for the complete life time of the system so that at any one time a user has been assigned frequencies which he will not need until the following season or even following years. Considering the variability of the ionosphere, in order to optimize an overall system a user should ideally be given only the frequencies he will require in the next month. This way he would have only the frequencies he immediately requires. Obviously the clerical and operational problems involved in such a monthly scheme would be prohibitive. Instead of a monthly basis, frequencies should be assigned seasonally, somewhat along the lines of the International Sackville Service of the CBC who, in order to make optimum use of their assigned frequencies, shuffle these frequencies among the international broadcast agencies of other countries every four months. However, considering the number of HF assignments in Canada this would probably wtill be prohibitive. As a compromise between the ideal and present situation assignments should be reviewed every three or so years. This would have two advantages:

(a) would help to relieve apparent congestion as only frequencies which are needed for immediate communication are assigned

(b) would increase reliabilities (the further ahead one is required to predict the more chance of inaccuracy in compensating for the variations of the ionosphere especially when a sunspot maximum is approached).

One could object to this on the grounds that it would result in a large increase in the work load of the already very busy assignment staff. However, this could poosibly be avoided. The possibilities of establishing a user classification system should be investigated. There is a large variety of HF users ....some who require communications over long distances, others who require reliable communications over medium distances, and a number of small users such as hunting and trapping outfits who require short distance daytime communications in relatively unpopulated areas. These small users usually require low power. Because of their low power and daytime usage these small users present a small, if any, interference hazard to other users. For this type of user the paper work involved in specific frequency assignment could perhaps be avoided by the following. A range of frequencies could be assigned to areas rather than to each small user and these frequencies would be changed seasonally at the ionosphere changes. The users within this area will then share these assigned frequencies. S ch a user classification system is used in VHF where simple links are treated under a general formula and complex links are treated individually. The benefits to spectrum management of such a system are self evident.

In connection with this, a study should be made to determine the geographical separation required for various systems before the same frequency can again be assigned without interfering with existing stations. This would optimize sharing of frequencies.

Just as frequencies should be assigned for shorter length of time in order to allow compensation for the varying ionosphere, frequencies should also be assigned on the basis of day/night requirement of communications. Different frequencies are required for daytime and nighttime communications. Considering the large nighttime interference possibility (the radiation from the sun at the lowest part of the ionosphere is removed so that there is little absorption and the radio wave can travel further) it is necessary to establish a user's diurnal need and limit the use of his communication system to satisfy this need. If his requirement is a daytime one, frequencies for this communications need should be assigned and nighttime communications prohibited. Not only would this eliminate extraneous nighttime interference, but it would leave nighttime frequencies for users who really need nighttime communications. Presently most users have the required frequencies for twenty-four hour communication because no mechanism is yet available to establish a user's diurnal need. The difficulty of obtaining such information from the user can be appreciated as he will claim a 24-hour need "just in case" he needs this type of communication. The onus will have to be on the department to ensure that a user who claims to have a 24-hour need really has it.

Perhaps a type of brief as discussed in the next section in which a user must explain his communication need both in terms of hours of use and system parameters such as power would serve to discourage misuse of these parameters. A user who claims to have certain requirements such as power etc. should have to substantiate this requirement as in other systems such as VHF and Microwave. This serves both to protect users as well as optimize use of the high frequency spectrum.

The need for guidelines and procedures to be followed is obvious. Because of the need for accuracy in the parameters of a system a brief of sorts should be required by the departments in order that the user list his equipment in detail giving antenna types etc. This would not be a complex document only one to stipulate all parameters (including local noise which is virtually ignored at the present time). Perhaps in the absence of consulting firms who have the technical facilities to optimize a user's system, DOC which does have such tools should do this optimizing both for the economy of the user and the efficient use of the radio spectrum. This would ensure that the user make efficient use of his frequencies, as well as optimize his communication system with the ionosphere.

When more than one frequency is to be assigned, a guide in the form of maps, graphs or tables, such as maps of optimum working frequency versus local time should accompany the assignment. This would aid the communicator in deciding which of his frequencies to use at a particular time, thereby eliminating guess work on his part during quiet ionospheric conditions.

Conclusion

Throughout the preceding sections the stress has been laid on howthe present system must be changed in order to fully use the scientific planning tools which are now available. It is becoming quite evident that in order to preserve the reputation of HF as a cheap and reliable system, the spectrum will have to be planned. This reputation is being destroyed in some cases by a lack of clear channel and improper operating conditions which result in unreliable communications. Many users are not aware of the variables involved in this type of communications. It is the responisbility of the department to educate and aid the user in his communications problems by making available such literature as guidelines, explanations of assignments, etc. CRC and their seminare have already taken the initiative in this type of education.

Other countries have made full use of these tools. The United States (ESSA) has a system (reference 6) which automatically calculates various effects on specific systems. A user hooks into a central computer via a terminal and receives all the information (FOT's etc) for a specific circuit. ESSA also predicts short term conditions. By having continual contact with observatories ESSA warns of disturbance effects on specific circuits. This type of system is not feasible for high latitudes where disturbances are more prevalent and mechanisms which cause these disturbances are not fully understood.

The Canadian system used by Radio Regulations is not automated to the same extent as that of ESSA. At the present time the variables and assumptions made in the program must be understood. The results must be interpreted. However, given money and computer time the system could be fully automated. Canada does not at present have the short term forecast facility.

The high frequency radio wave respects no boundaries. In order to compete in the international "spectrum market" full use of these tools must be made and awareness of new techniques developed.

Summary

Scientific techniques which have developed into valuable tools for the efficient use of high frequency systems are now readily available to the communications engineer and operator. These tools will aid in the planning of the high frequency spectrum as well as in the planning of systems. In this way users can be evaluated to ensure they are using their assigned frequencies efficiently. However, before these tools can be used to their fullest extent certain refinements as have been discussed in the preceeding sections should be considered. Below is a summary of these refinements:

1. Guidleines and procedures for the high frequency band should be established.
2. The crowding of this portion of the spectrum should be investigated. Aspects of sharing such as the required geographic distance between systems of the same frequency should be established.
3. Because HF communications attract such a variety of users the possibility of establishing a user classification system as discussed in the text should be investigated.
4. Assignments should be made for shorter time periods. Perhaps every 2-3 years communications systems should be re-evaluated.
5. Systems should be designed to meet specific communications requirements. For example, communications during hours other than those for which the system was licensed should be prohibited.
6. Guides for operational use (such as maps of Optimum Working frequency versus local time) should accompany all assignments of more than one frequency. This will ensure that optimum use of the assigned frequencies will be made, as well as aid the user in communications.
7. In the past some large users had frequencies assigned on a traditional basis - in a planned band these users may be required to release these frequencies.

The exact form of the proceedures would have to be thoroughly investigated in order to ensure efficient spectrum utilizatin without restricting the user to unnecessarily expensive equipment. This would require the co-operation of the spectrum manager, operator and user.

In order to help establish the guidelines perhaps a questionnaire could be sent to the main users to establish present and future equipment plans as well as present communication problems. The guidleines could be then slanted along these lines. The guideline should also be accompanied by a short outline in layman's language to explain propagation via the ionosphere and associated problems that could be expected.

Crowding of the spectrum should be investigated. This could be done by:

a) Investigating the frequency assignment lists to establish how assignments are concentrated;

b) In the above-mentioned questionnaire establish when and for what purpose a user communicates;

c) Using new spectrum occupancy monitering systems to establish actual occupancy of the HF spectrum.

From these the user's needs can be taken into account when establishing methods of frequency sharing.

Because of the variety of users, just on what basis users should be classified is not clear. At a first glance classification should be in terms of power as this quantity almost completely controls whether a frequency can be shared. This classification would also list users in order of equipment sophistication. However, there may be a more optimum basis of classification. The user himself could probably give the answer if the correct questions are asked.

Summary #4 and #5 are self-explanatory. Guides for operational use as mentioned in Summary #6 should accompany assignments of more than one frequency. CRC presently produce maps of Optimum Working frequency versus local time automatically i.e. the computer not only does all the calculations but also plots the maps. These maps (an example of which is attached) tell the operator the maximum frequencies the ionosphere will support. Because it is wise to use a frequency close to this maximum the operator can tell which of his frequencies will give the highest probability of communicating under quiet conditions. Radio Regulations could either duplicate CRC's efforts and produce a similar system or could use CRC's system with their co-operation.

APPENDIX

The Ionosphere and High Frequency Communications

The region above the earth is composed of molecules of gases whose density decreases as height increases. Radiation from the sun (in the form of ultraviolet radiation, X-rays and soft X-rays) bombards these molecules causing electrons to be separated from the neutral molecules leaving a charged ion.

At certain ranges of height the concentration of ionizable material and the amount of radiation from the sun will be such that a layer of ions will be formed. There are in fact four such layers called D, E, Fl and F2 layers. There is another layer which sometimes forms above the E layer. This is called the "sporadic E" layer and occurs mainly at high latitudes. There are nine different types of Sporadic E.

As a radio wave travels vertically through a layer it is bent and reflected due to the gradient in refractive index as determined by Snell's law. As the frequency is increased, a certain frequency will be reached where the wave penetrates this particular layer and is reflected from the next highest layer. The highest frequency a layer will reflect is called the maximum usable frequency (MUF). The magnitude of this frequency is solely controlled by the ionosphere. There will exist a MUF for each layer. In order to communicate at a certain distace (i.e. using a specific layer) the frequency used to communicate must be less than the MUF. Because this maximum level is controlled by the ionosphere which in turn experiences diurnal, seasonal and cyclic variation (with the varying radiation from the sun) one can well understand how the frequencies for which the ionosphere supports communication will vary.

These Maximum Usable Frequencies are measured by ionospheric stations scattered throughout the world which investigate the ionosphere directly above them. These measurements are then tabulated as in the CRC tables mentioned in the main sections of this report. The total ionosphere is covered by interpolating from these measurements. Therefore for any point the MUF can be found from such tables.

Because of the large number of molecules and ions in the lowest or D layer, a radio wave as it travels through this layer will suffer both physical billiard ball type collision as well as coulomb* type collisions. As a result the radio wave loses energy and is to some extent "absorbed". This D layer is called the absorption region. During the night, because of their large concentration, free electrons and ions recombine as the radiation from the sun is removed and this layer disappears. At this time lower frequencies and communications over far distances is possible as the radio wave does not lose much energy.

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* Coulomb's Law concerning the forces exerted by charged particles.

As there is an upper limit to the frequency that can be used there is also a lower limit below which communications is impossible. This limit is called the LUF (lowest usable frequency). As the ionosphere controls the MUF, the system parameters (power, receiver bandwidth, signal to noise ratio, noise, type of transmitting and receiving antenna) control the lowest usable frequency. For a co mplete discussion of this see reference 5 and 6. When the LUF exceeds the MUF communications is impossible.

Noise is an extremely important parameter in HF systems. The full importance of this parameter is not full appreciated by many communications engineers. There are three classifications of noise which can affect a communications system. These are galactic, atmospheric and local or man-made noises. Atmospheric noise mainly originates with thunderstorms in the equatorial regions and travels via sky wave to other regions. The desirability of careful site choice keeping these factors in mind is obvious. One can see the difference a discriminating antenna in a north-to-south path could make, as far as discriminating against atmospheric noise.

There are disturbances which occur especially at high latitudes which play havoc with communications systems. Some of these are due to eaxcess radiation from the sun which cause large absorption. If advance warnings are given by observatories of these solar activities, alternate communication action can be taken. Usually, however, there is not enough time. The seriousness of these events varies in magnitude. The most destructive events usually occur two to three years after a sunspot maximum. A complete discussion of these interesting events can be found in references 4 and 5. Presently these events cannot be predicted because the mechanisms which cause these events to occur are not fully understood.

The foregoing has been a rather brief outline of the ionosphere. It does serve to illustrate the complexity of the variables of high frequency communications. With the advent of the computer these numerous variables could be taken into account and communications via the ionosphere reliably predicted.

References:

(1) Selection of Optimum High Frequencies for Northern Latitude Communication Circuits - E.D. DuCharme, L.E. Petrie and G. Roberts presented at the International Electronics Conference, Toronto.

(2) Ionospheric Radio Communications-edited by Kristen Folkestad.

(3) H.F. Prediction Methods - H.P. Williams Shape Technical Center.

(4) High Frequency Radio Communications with Emphasis on Polar Problems - Editor Finn Lied.

(5) Ionospheric Radio waves - Kenneth Davies.

(6) Predicting Long Term Operational Parameters of High Frequency Sky wave Telecommunication System - ERL 110-ITS 78, ESSA Barghausen et al.

(7) High Frequency Propagation Predictions Using an IBM 650 Computer - L.E. Petrie Communications Laboratory DRTE 1963.

LINCOMPEX AS AN IMPROVEMENT
TO THE
DOMESTIC H.F. NETWORK

BY

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INCORPORATED

1. ABSTRACT

Lincompex is a well proven method to improve H.F. point-to-point radiotelephone circuits and ship-shore circuits which are already meeting certain requirements.

In its present form, it is incompatible with most of the equipment used in the domestic networks. In simplex or duplex operation to a single base station simplification of the out station equipment is possible. Lincompex terminals could be redesigned to work with low stability equipment generally used in the networks. The radio equipment used in the networks could be modified or changed to work with Lincompex terminals. The possibility of modifying either the Lincompex terminal and/or radio equipment in use in Canada to make them compatible should be investigated.

2. LINCOMPEX

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 of the line remains constant. This requirement has so far limited the application of compandor techniques to H.F. radio circuits. If, however, the information concerning the degree of compression introduced at the transmitting end can be accurately conveyed to the expandor at the receiving end (e.g. by the use of a separate information channel), then such a system could be made to operate satisfactorily. Lincompex is a system to improve H.F. radio circuits using this concept. A sketch is shown in figure 1. The work "Lincompex" is an acronym for linked Compressor and Expandor. The speech is compressed to a constant amplitude and the compressor control current is utilized to frequency modulate an oscillator in a separate control channel. The speech channel, which contains only the frequency information of the speech, and the control signal channel which contains the speech amplitude information, are combined for transmission over the same channel. As each syllable is individually compressed, the transmitter is effectively loaded. On reception both the speech and control signals are amplified to a constant level by the fade regulator, the demodulated control signal being used to determine the expandor 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 at the transmitting end, the overall system loss can be maintained at a constant value. The d.c. control signal modulates the frequency of the oscillator so as to produce a 2 Hz frequency change for each 1 dB change in syllabic level at the input of the compressor.

3. FACILITY REQUIREMENTS

The composite line signal between terminals is composed of the compressed speech signal and the frequency modulated control signal. The composite signal is therefore subject to the effects of both amplitude variations and frequency variations that may be introduced by the interconnecting transmission facilities.

The interconnection facility exclusive of the H.F. radio path is composed of the voice frequency land line (carrier or physical) and the H.F. radio transmitter and receiver. To achieve optimum performance, the entire facility should have an essentially flat frequency response over the voice frequency band and should have an overall frequency translation error of two cycles or less. In addition, the delay distortion introduced by filters in the frequency range of the control channel signal slot should be less than about 2 milliseconds.

It is recommended that the facilities that connect the circuit to the lincompex terminal be non-compandored, and the Lincompex control signal be so redesigned that high stability of the frequency in the radio equipment is not required. This would require development of new equipment and is not presently available.

4. ADVANTAGES

The system maintains a constant loss in the circuit permitting full-duplex operation. The compandor action reduces the radio noise and interference and silences the received signal during inter-syllabic intervals. This has the effect of reducing the signal to noise ratio, apparent to the listener, by about 12 - 15 dB and allows operation down to signal-to-noise ratios of about 10 dB at the receiver input. The fade regulator minimizes radio circuit fading effects which cause variations in the received signal level.

This system does not create a signal where none exists due to the propagation conditions but it does extend the time that a path can be used. Furthermore, the traffic carrying capacity will increase by more efficient use of the circuit. The British Post Office also reports that the requirement for operator supervision is reduced 24-fold from two operators per circuit to twelve circuits per operator.

5. CIRCUITS USING LINCOMPEX

Extensive field trials which started as early as 1964 have shown the technical and operational advantages of using Lincompex on H.F. radiotelephone circuits. In Canada, field trials have just started.

Many administrations are now using Lincompex on their circuits. The total sales of Lincompex terminals is estimated at 500. The AA&T System operates approximately 200 full-duplex point-to-point H.F. radio circuits to other countries. The majority of these circuits are now working with Lincompex.

As per their objective established in May 67, the A.T.T. System still plans to replace all of their existing channel terminal equipment with Lincompex terminals as soon as practicable, subject to corresponding changes being made at the other end. The system has also proved to be extremely effective on ship-to-share circuits.

6. PRICE INFORMATION

The Canadian price for a Lincompex terminal is $8,500.00 ± 10% T.N.I.P.

7. USERS' EQUIPMENT

All land station compatible a.m. single sideband radio telephone transmitters and receivers operating in the 1.605 - 28 MHZ band with maximum R.F. power output rating not more than 10KW PEP must meet DOT's Radio Standards Specification 122, RSS 122 sets forth the minimum standards required for the type approval of radiotelephone non-multiplex transmitters and receivers as described above.

The frequency stability and the audio response requirements which are specified in paragraphs 33, 39, 65 and 68 of RSS 122 are extremely lax in comparison to the state of the art or to the facility requirements of Lincompex.

Manufacturers' cater to a market which is very competitive. Therefore, they produce a commercial line of equipment which does not largely exceed RSS 122. Most users including common carriers buy this line of equipment.

Most radios presently used in remote stations are transceivers which can only operate in a half duplex or simplex mode. These sets can not provide simultaneous reception and transmission. They are equipped with a push-to-talk button that the operator pushes when he wishes to transmit on voice operated relay.

8. CONCLUSIONS

There is enough evidence to prove that Lincompex can considerably improve H.F. circuits. However, it must be realized that the existing basic circuit must meet stringent requirements from the point of view of frequency stability, frequency response and delay.

A brief look shows that the majority of equipment purchased by Canadian users does not meet the stringent requirements needed to operate with Lincompex. Lincompex terminals could be redesigned to compensate for the lack of frequency stability of certain equipment. A second fixed master control tone could be transmitted to the receiver terminal. The difference in frequency of the two control tones will remain constant while the transmitters and receivers are drifting. This difference in frequency between the control tones could be used to control the expandor of the receive terminal. The radios could also be modified to improve their frequency stability or their frequency tracking and the fixed control tone could be used for carrier recovery.

More investigations are required on the frequency response and delay characteristics.

Lincompex is excellent system; but it can not compensate for all the weaknesses that can be found in some of the radio equipment and it can not compensate for the absence of a radio signal, therefore introduction of Lincompex will only be effective if a parallel program of improvement of frequency management, operating procedures, maintenance procedures, and other equipments is carried out.

9. REFERENCES

1 - CCIR Report 354, Oslo 1966.

2 - American Telephone and Telegraph Company, Long Lines Department, New York, N.Y. "An improved Transmission System for High Frequency Radiotelephone Circuits" Issue 2, May 67.

3 - Department of Transport "Radio Standards Specification 122". Issue 1, April 1966.

ERROR DETECTION AND CORRECTION
FOR DATA TRANSMISSION
ON H.F. RADIO

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ERROR DETECTION AND CORRECTION

INTRODUCTION

H.F. Radio facilities have been used for many years to send voice, morse telegraphy and to a lesser extent teletype communications around the world. As the business world has moved into the field of Electronic Data Processing, requirements for teletype and higher speeds of Data Transmission have appeared. Data Modems have been developed to suit a wide variety of speed requirements but were designed largely to operate on land line or line of sight radio facilities. On these facilities, acceptable error rates are usually achieved without error correction or with simple forms of error detection. Highly sophisticated Modems designed to cope with the less stable parameters of H.F. Radio have been used primarily by the military but could be used wherever the expense could be justified. The features of these latter modems such as in-channel time and frequency diversity combined with various types of improved H.F. radio communications would be classed as error prevention. With or without these preventive features, we often require the additional safeguard of error detection and correction in order to provide an acceptable error rate performance.

PRELIMINARY

In this article, we will attempt only a generalized description of various methods of Error Detection and Correction (EDAC) applicable to H.F. Radio Transmission. The requirement for EDAC will vary, since due to natural redundancy, plain language teletype transmission could remain intelligable with error rates as high as 1 in 10^2 while transmission of numeric information between business machines may demand error rates lower than 1 in 10^2. We will assume, for discussion, an error rate of less than 1 in 10^2 before EDAC where no more than 1 in 10^5 is acceptable.

ERROR DETECTION AND CORRECTION

Error detection and correction will always require the insertion of some redundancy to an existing code. A simple form of detection is the addition of a parity bit. Each character of, say an eight bit binary code will use the first seven bits to convey intelligence. If even parity is used the eighth bit will be filled only if an odd number of the seven intelligence bits were filled at the sender. The receiver knows that all characters will have an even number of marking or 1 bits. When an odd number is received, an error is indicated. This is vertical or character parity and will provide only detection with no correction as there is no indication of which intelligence bit was in error. If an even number of errors occurs in one character, no error would be indicated. We can improve the detection reliability and add some correction capability by adding block or horizontal parity. This could be accomplished with the above code by inserting a parity character after each block of, say eight characters. The parity character is formed by filling the first bit only if the sum of marking bits in the first bit position of the preceding eight characters was odd. As the name implies the vertical even parity ensures an even number of marking bits per character in a nine character block. The horizontal even parity ensures an even number of errors occuring in horizontal and vertical bit rows so that error detection is more likely or we can say the detection code is more powerful. The code rate is an indication of the ratio of the information bits to the total bits. For the vertical parity above, the code rate would be 7/8, for the horizontal and vertical block parity the code rate would be 7/9. In general, the more powerful the code, the lower the code rate or the more powerful the code, the lower the transmission efficiency. Having detected the error, we can attempt to correct the error by evaluating the received information. In the case of horizontal and vertical parity, if we receive one horizontal error and one vertical error, we would assume the one common bit to be in error and we would correct accordingly. This is forward error correction (FEC). We could also request a retransmission of the entire block (ARQ). ARQ has the disadvantage of requiring duplex radio channels and during times of high error rate, may lock up with continual retransmissions of one block of characters.

FEC has the disadvantage of requiring much more powerful codes to provide the same degree of error correction but has the advantage of providing near real time transmission and does not require duplex facilities.

If we separate errors into three types, random, burst, and periodic, the burst type will be the most difficult to detect or correct. The problem is that although 50% of the total errors may occur in bursts the time occupied by the bursts will be a low percentage of the total transmission time. If we use a code powerful enough to detect and correct these concentrations of errors the inherent high redundancy of the powerful code will produce low transmission efficiency 100% of the time. Two methods currently used to alleviate this problem are:

1) While maintaining the same code rate if we lengthen the code, we can correct larger concentrations of errors.

2) After coding at the sender, we interleave 2 or more code blocks, that is we send the first bit of each block, then the second bit etc. A code powerful enough to correct 2 errors per block will still only correct 2 errors per block but by interleaving we attempt to distribute the concentrated errors of a burst over a number of blocks in order to lower the errors per block to a number the code can handle. In effect, we are randomizing the bursts so that a weaker code can correct and thus maintain a higher transmission efficiency. Care is required here to ensure the period of the interleaving does not match the period of any periodic error cause or we will concentrate periodic errors within one code block possibly defeating the distributive effect of the interleaving.

SUMMARY

Application of any EDAC technique should be based on a knowledge of the error characteristics to be encountered. Where duplex facilities are available and real time transmission is not necessary a combination of FEC and ARQ may provide the best error protection with the highest transmission efficiency.

Since costs can vary from 3 or 4 hundred dollars for vertical parity detection to 5 thousand dollars for simple FEC or ARQ and much higher for more powerful arrangements, the costs of preventing errors by improving the data channelizing equipment should be considered if very low error rates are not required.

REFERENCES

1 - William R. Bennett, James R. Davey. "Data Transmission"
McGraw-Hill Book Company

2 - CCIR Report 196-1 and 197-1 OSLO 1966

ERROR DETECTION AND CORRECTION

AS AN AID TO HF COMMUNICATION

by

Doris H. Jelly

Error Detection and Correction as an Aid to HF Communication

by Doris H. Jelly

An HF channel may be improved by reducing the number of errors so that intelligibility is increased, or lower transmitter power may be adequate or higher data rates may be used.

Error detection and correction (EDAC) is a very broad and complex field. The techniques range from simple ARQ (automatic repetition of detected errors) to forward error correction (FEC) based on highly sophisticated mathematical codes. The codes, which may be designed for error detection or error correction or both, are effected by adding redundant bits to the information which is being transmitted in a binary format. At the receiver, decoding is matched to the particular encoding. If a feedback channel is available, detection coding alone may be very effective. In this case, when an error is detected at the receiver, the output is stopped and a signal sent via the return channel requesting a repeat of several characters including the one in error. This technique tends to fail when the error rate is high in which case the system goes into almost continuous cycling. Also, if a feedback channel is not available, as is often the case with HF, codes performing various levels of detection and correction may be applied.

In error correction and detection, one of the major problems is matching a suitable code to the error characteristics of a given communications medium, be it cable, HF or VHF scatter. If the errors were random, the solution would be relatively simple mathematically and in implementation. However, the problem is greatly complicated by the presence of random, periodic, and burst or grouped errors. Although burst errors are not peculiar to HF, they constitute an especially severe problem in that medium because of fading. Considerable research effort has been and continues to be expended in determining typical error characteristics of HF channels. Once these are established, the effectiveness of codes can be compared by computer simulations.

Fairly low power EDAC devices are now commercially available. These may provide adequate improvement for many applications. Research continues in developing powerful codes to permit very reliable high-speed data transmission. The cost increases steeply as the error-correcting capability is improved and efforts are concentrated on devising more efficient codes and implementation methods.

Some codes have already been developed and tested and could be used if the requirement justified it. A complete comparison of their cost effectiveness should be carried out in order to choose the best code for the job. Such a study is too extensive to be done for the present study. Some of the techniques that are being considered will be mentioned here along with references.

Two main types of codes are block codes and convolutional codes. With block codes the decoding is applied repetitively to each block of bits. For vonvolutional codes, the information is not divided into blocks but the decoder operates continuously as the information is received. Interleaving is a technique that may be applied to block codes to reduce burst errors to near random errors. It involves re-ordering the bit sequence at the input such that burst errors are spread over the ever-free spaces. Then a random error-correcting code is applied. The interleaving process can be repeated in which case the coding is referred to as tandem or concatenated.

Examples are shown in Fig. 1 and 4 demonstrating the effectiveness of some of these codes in correcting errors in specific HF tests. Fig. 1 (a) and (b) shows the application of a type of block code (BCH) with interleaving to a data sample with a BER (bit error rate) of 2.7 x 10^{-3}. For each block length n, the results are plotted as a function of improvement factor, code rate and normalized delay in seconds. The improvement factor is defined as

$$\frac{1}{1 - \frac{\%\text{ of errors corrected}}{100}}$$

The code rate is the number of information bits per block k, divided by the total number of bits, n, and is an indication of the redundancy. The delay (the second number in the brackets) is the delay introduced by the coding and is one of the penalties paid for error correction. A second example, Fig. 2 (a) and (e) shows the effectiveness of the same code on a second data sample, in this case with a BER of 1.2 x 10^{-2}. The same data samples were also tested using a tandem code which was found to be superior to the single code.

Various other tests and comparisons have been made. For instance, Cohn et al. have compared interleaved BCH codes, concatenated codes and convolutional codes. FEC was also tested on the CURTS system but was not found to reduce the error rate significantly.

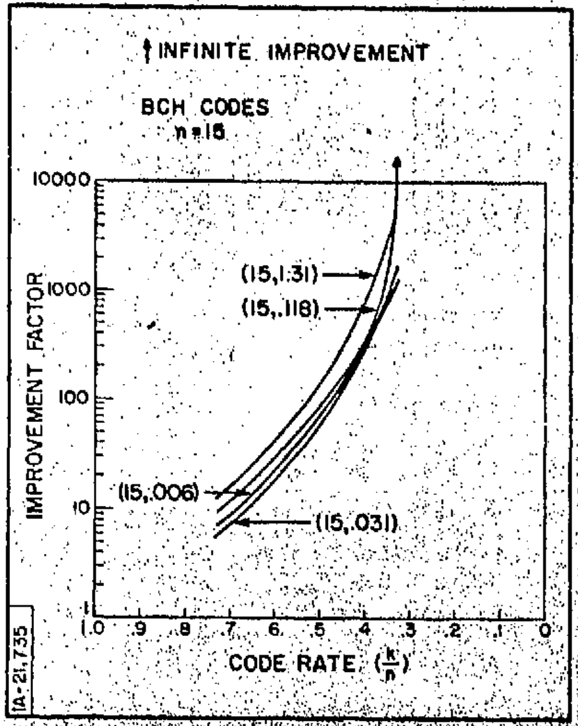

Figure 1a. BCH Code Performance, Test Run 12, n = 15

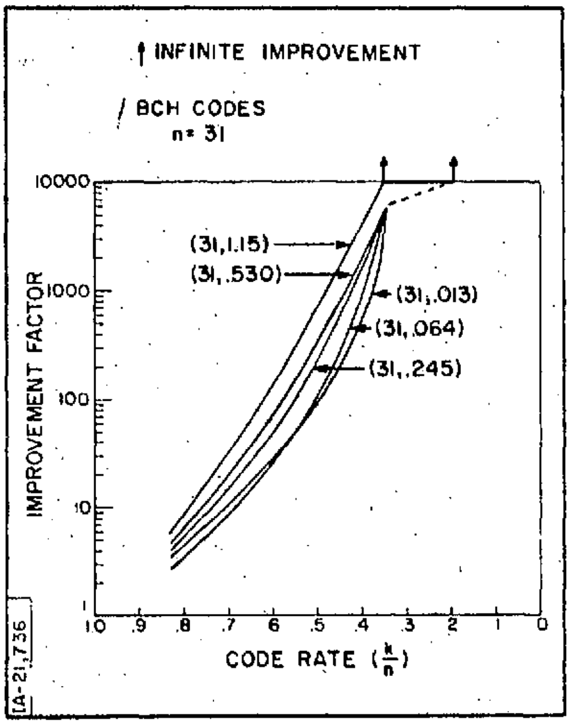

Figure 1b. BCH Code Performance, Test Run 12, n = 31

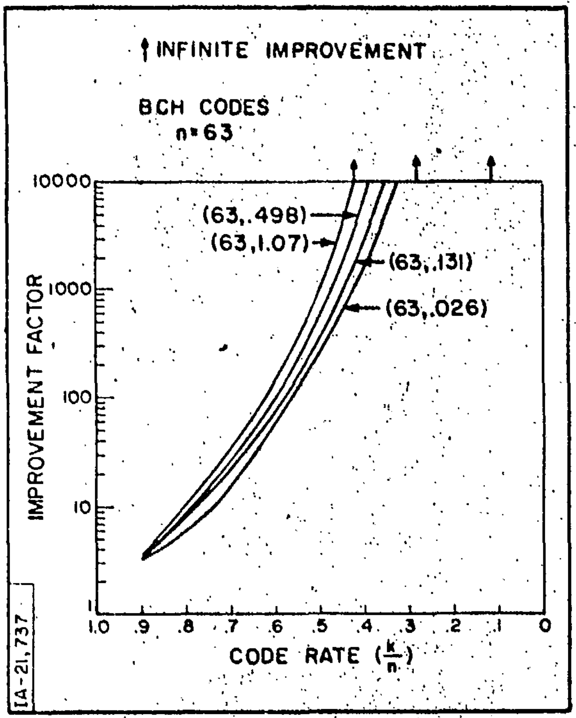

Figure 1c. BCH Code Performance, Test Run 12, n = 63

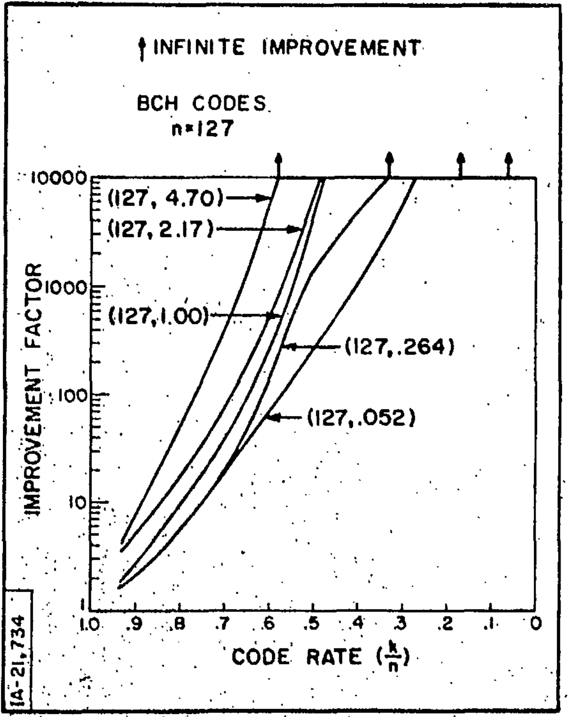

Figure 1d. BCH Code Performance, Test Run 12, n = 127

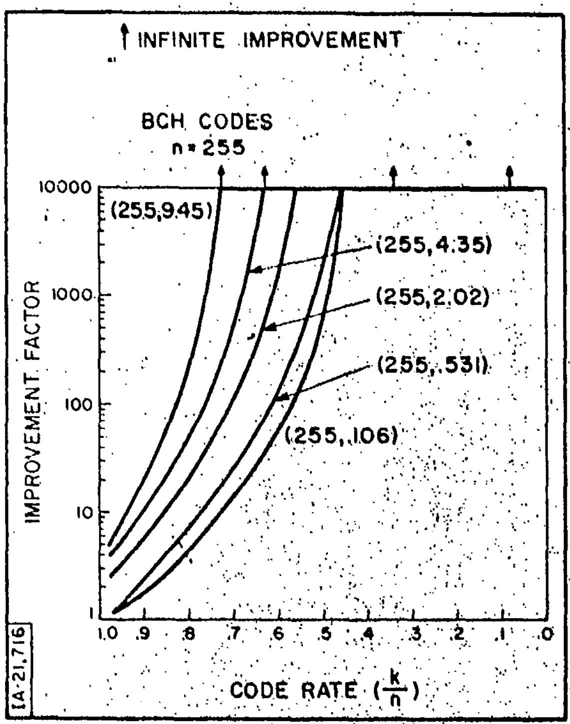

Figure 1e. BCH Code Performance, Test Run 12, n = 255

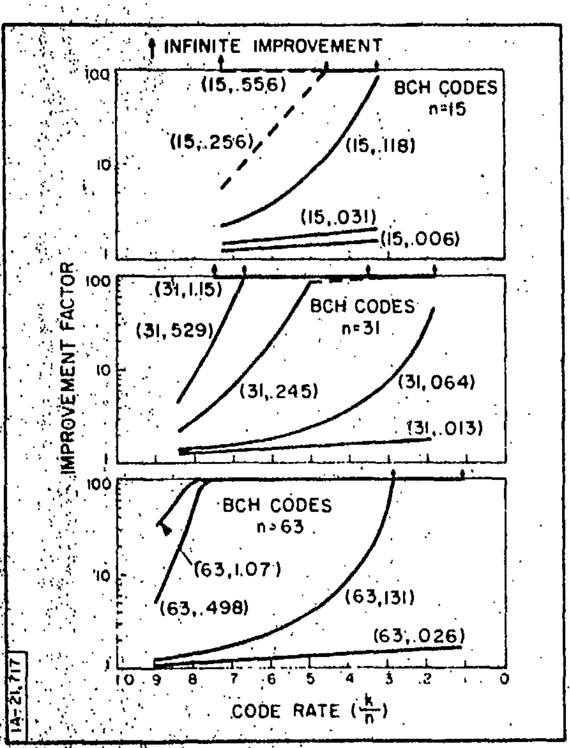

Figure 2a. BCH Code Performance, Test Run 24, n = 15; 31; 63

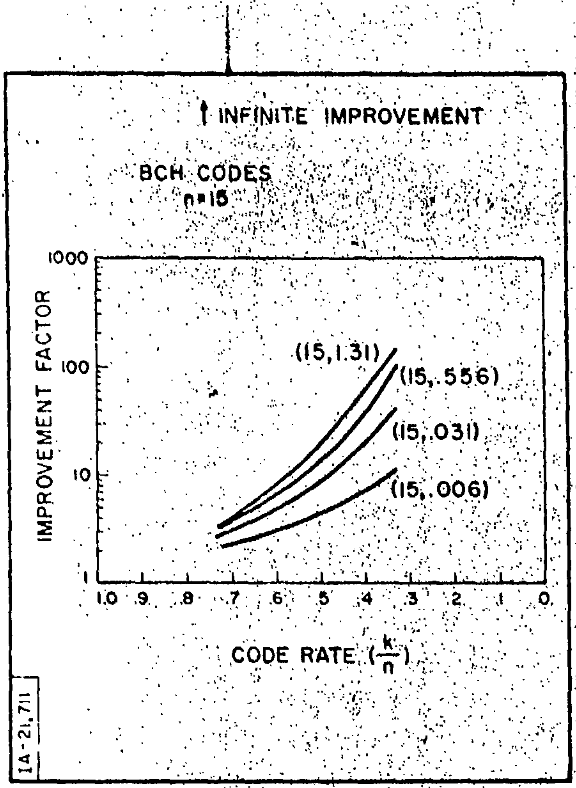

Figure 4a. BCH Code Performance, Test Run 339, n = 15

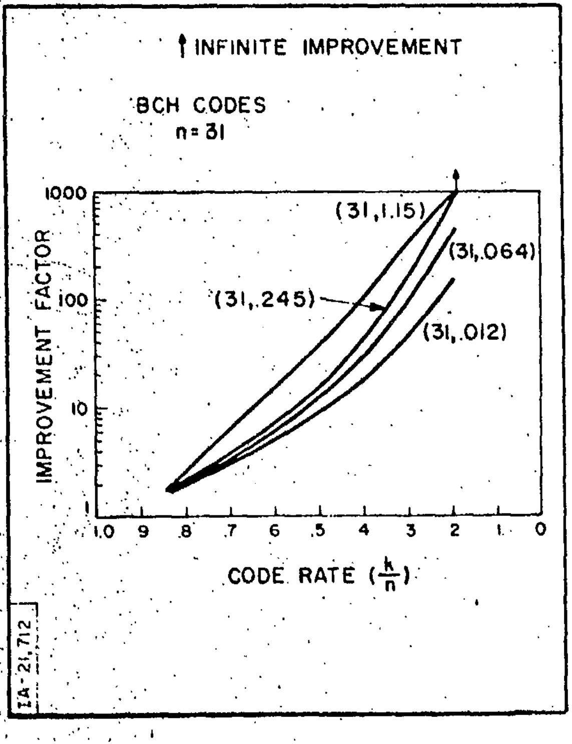

Figure 4b. BCH Code Performance, Test Run 339, n = 31

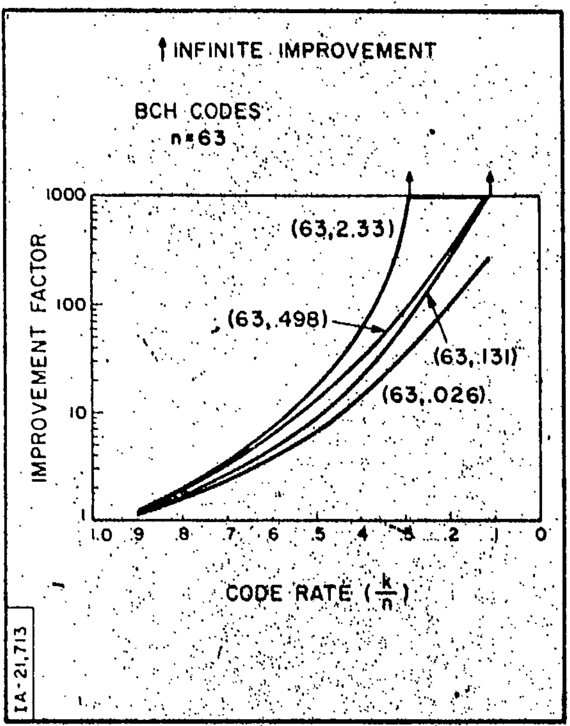

Figure 4c. BCH Code Performance, Test Run 339, n = 63

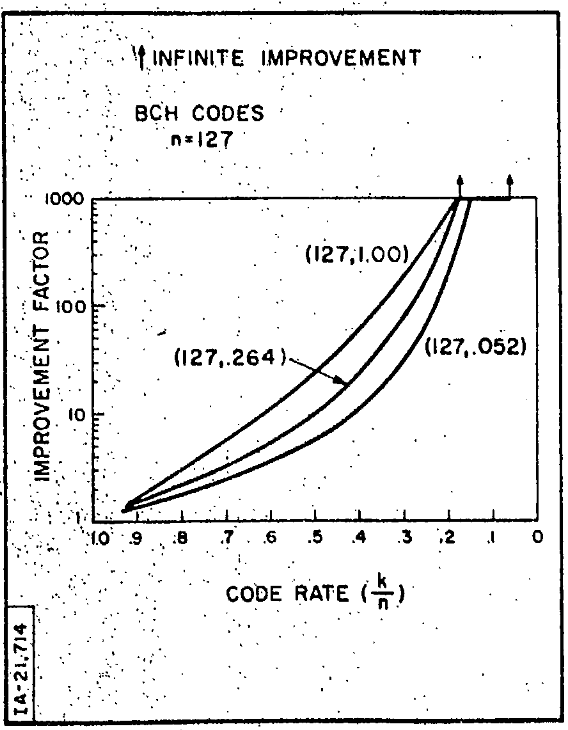

Figure 4d. BCH Code Performance, Test Run 339, n = 127

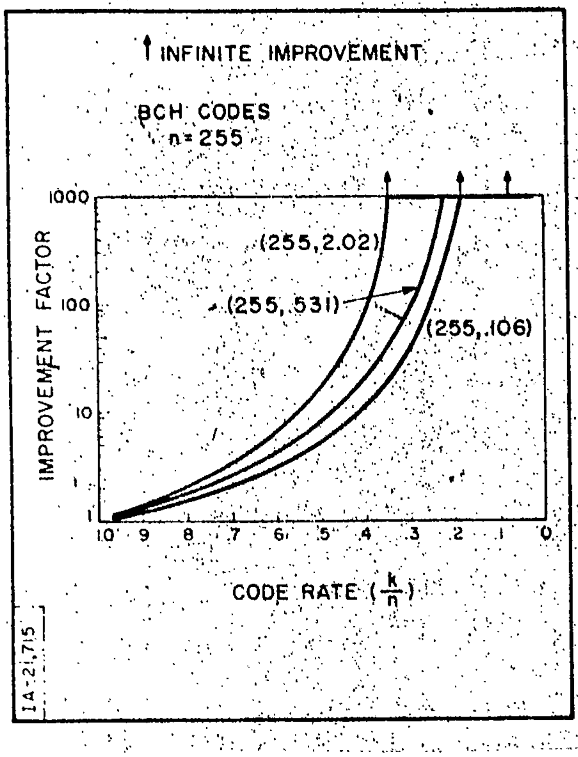

Figure 4e. BCH Code Performance, Test Run 339, n = 255

Considering the set of curves for any one test run, it is interesting to note that for the same delay all codes are approximately equal in performance. On test run 309 the performance for n = 127 at a delay of 2.17 (m-41) is almost identical to that for n = 255 at a delay of 2.02 (m=19). Thus it can be concluded that performance is a function of the product mn and not of m or n individually, if delay is considered the common ground upon which two or more codes are compared. The values of m used are 1, 5, 19, 41, and 89, although in some cases the upper values are not presented owing to lack of significant improvement in performance. In all cases it is possible to get 100 percent correction if the code rate is sufficiently reduced (i.e., an increasing portion of the channel is allocated to parity). It can be concluded that, at a reasonable penalty in delay, the error rate in HF digital communication can be substantially reduced by the interleaved BCH code technique.

1. A. Kohlenberg and G.D. Forney, Jr., "Convolutional Coding for Channels with Memory", IEEE Transactions on Information Theory, Sept. 1968 vol. IT-14 No. 5, p 618.

2. D.L. Cohn, A.H. Levesque, J.H. Meyn and A.W. Pierce, "Performance of Selected Block and Convolutional Codes on a Fading HF Channel", IEEE Trans. on Information Theory, Sept. 1968, vol. IT-14, No. 5, p 627.

3. J.L. Ramsey, "On the Effectiveness of Coding for HF AUTODIN", IEEE Trans. on Information Theory, Sept. 1968, vol. IT-14, No. 5, p 759.

4. H.J. Crowley, "A Field Test of Error Control Systems", IEEE Trans. on Communications Technology, Oct. 1969.

FULL DUPLEX HF CIRCUITS

USING A TIME SHARING TECHNIQUE

by

O. S. ROSCOE

Full Duplex HF Circuits using a Time Sharing Technique

Introduction -

Full Duplex circuits are of interest where voice is the information carrying modulation and fully interactive communications are desired. This is true regardless of the means by which the circuits are established, be they wire or radio frequency circuits. Duplex operation is normally provided by separate wire or radio frequency carriers. At HF frequencies full duplex operation has been very difficult, if not virtually impossible for other than fixed services because of the difficulty of operating a transmitter and receiver at frequencies in close proximity, necessary for reciprocal propagation. For connection to trunk telephone circuits, however, full duplex operation is a requirement. Following is a proposal for operating a full duplex circuit at HF on one frequency by applying time sharing for transmitting and receiving.

Principle of Operation -

The basic principle is that of synchronously time-sharing one frequency for transmitting and receiving by two communicating stations. This requires that the speech signal be broken up into short segments, compressed in time to less than half, transmitted as a burst, expanded in time and reconstituted as a continuous signal at the receiving station. Both stations would perform identical functions, one transmitting while the other is receiving, and vice versa, so that the circuit appears as if two continuous paths existed. Frame time for the speech segments could be of the order of 20 to 40 milliseconds, so that there would be no noticeable delay in the speech signal. The time compression would produce a proportional bandwidth expansion of the signal, necessitating a greater r.f. channel bandwidth than a normal two-way push-to-talk circuit.

The time compression can be easily accomplished by several techniques. One possible method, using off-the-shelf components, is by using a pcm technique. The analogue voice signal can be passed through an A/D converter and stored in a memory such as a long shift register. Clock rate for the conversion would, of course, be high enough to preserve the full voice quality in the normal 3kHz bandwidth. When the shift register becomes filled, the data can then be passed through a D/A converter at somewhat in excess of twice the read-in rate, thereby effecting the time compression. The resulting analogue signal would modulate the transmitter. While the shift register store is being read-out, a second shift register would be in the process of being filled by the A/D converter, and alternate switching carried out as required. A sped-up analogue signal would be transmitted rather than a pcm signal to conserve bandwidth.

A time compression of greater than 2 is required to provide a

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guard time for transmit-receive switching, transmission delay variations, inaccuracies in synchronism, etc. These factors require study, but cursory examination indicates that a compression factor greater than 3 would not be necessary. This means that a bandwidth of up to 9kHz may be required.

Some of the problems experienced with HF propagation can be alleviated by the use of active infinite companding. The delay inherent in the time-sharing principle of operation makes it relatively simple to operate actively controlled expanders on the basis of information on the amount of compression, in a method analogous to that used in the LINCOMPEX system, without having to pay the high cost of the components required for the LINCOMPEX system. All of the advantages of active companding would accrue, such as use of full transmitter power for the entire voice signal regardless of modulation intensity of the speech with the resulting increase in average signal-to-noise ratio, receiver quieting in inter-syllabic pauses resulting in suppression of interference, and a marked over-all improvement in the subjective quality of the voice signal.

The need for synchronous operation of the two stations requires the establishment of a timing reference. Again there are numerous ways to accomplish this, with the following being one possible method. Station A would initiate a call to station B by sending tone bursts of normal frame time duration on the correct frequency, operating in the normal transmit-receive time sharing mode. B would monitor a sufficient number of the tone bursts to establish a timing reference. Once established, B would switch to the time sharing mode and transmit confirmation tone bursts. After this confirmation has been established, A would transmit a termination tone burst upon which the two stations would switch to voice modulation.

For more accurate reconstruction of the continuous voice signal, additional timing information can be carried with each transmitted burst as a preamble to the voice signal and used for fine timing adjustments. Information about the amount of voice compression can also be carried as preamble and postamble to each voice signal segment. The postamble signal can be information about the amount of compression for the first portion of the next voice burst, which had already been processed and stored at the transmitter before completion of the current burst transmission. The preamble compression information can be data about the compression of the latter portion of the current burst.

Envelope shaping can also be applied to each burst to prevent transient disturbances in both the transmit and receive circuitry and to

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reduce distortion.

Circuit Implementation -

A configuration of the system described above is shown in Figure 1. The transceiver may be a modification of an existing developed equipment. Most of the circuitry in the other major blocks may be developed from readily available and inexpensive off-the-shelf integrated circuits. Perhaps one of the most crucial elements are the memories. Up to 1024 bits may be required. These are available now in 256 bit units as shift registers or random access IC memories in one dual-in-line package. The 256 bit shift registers are priced at $25. A 512 bit shift register has been announced as being available shortly. Custom implementation of the entire digital portion in LSI technology is a practical possibility in the near future.

Summary -

A system for providing full duplex voice operation on HF radio circuits on one frequency has been described. The system looks like a four-wire system at its terminals and may be readily connected to four-wire telephone circuits. An additional feature of the system is that active infinite companding may be easily included resulting in a marked improvement in circuit performance.

CHAPTER II

LOW FREQUENCY RADIO SYSTEMS

LOW FREQUENCY (LF) COMMUNICATIONS
IN THE NORTH

by

JOHN S. BELROSE

Low Frequency (LF) Communication in the North

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1. Introduction

Radio communications began at low frequencies, and if it were not for the limited bandwidth available, the intensity of atmospheric noise at these frequencies (particularly at low geographic latitudes), as well as certain practical limitations, further discussed below, much more extensive use would be made today of frequencies below about 300 kHz.

Because of the stability of propagation frequencies in this range are useful not only for communications, but also for standard frequency and time broadcasts, as well as navigation systems employing pulse (Loran C at 100 kHz) or CW (Decca 70-130 kHz) or Omega (10 - 14 kHz), phase comparison or direction-finding techniques. In particular, it has been found that the stability of transmission permits frequency comparison to within a few parts in 10^{12} which is some four orders of magnitude better than is possible at high frequencies; thus making possible long range radio navigation utilizing phase comparison between spaced atomic frequency controlled or phase-locked transmissions. At frequencies above about 100 kHz, where it becomes practical to isolate, in some circumstances, the ground-and-sky waves by pulse and sampling techniques, highly accurate time systems can be devised. Marine communications use low and very low frequencies, which are also used for point-to-point communications at times of severe ionospheric disturbances (particularly at high latitudes) that disrupt high frequency circuits. Communication to points under the sea, beneath the ground, or below the polar ice cap can be achieved on these frequencies.

VLF frequencies ($<$ 30 kHz) are normally employed for very long distance (world-wide) communications, and communication to submarines, and LF (frequencies $<$ 300 kHz down to a lower frequency limit of about 60 kHz) are most useful for transmission to distances $<$ 3000 km or so. The frequency range 30 - 60 kHz is useful for distances between these two extremes, but little current use is made of this frequency band.

The principal use of low frequencies (70 - 350 kHz) in Canada is for reliable communications in the Canadian North (in particular by the Department of Transport (a list of circuits in present use is given in Appendix A), for communication between shore-and-ship, for communication between ground-to-airborne equipment (for routine weather information and back up to high frequency

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circuits), and for radio navigation (in particular systems employing simple radio direction location methods for air navigation in the north). The many radio beacons in the Canadian North are, in an increasing number, being used as well for radio teletype transmissions over medium range links, which provide primary or back up service. A number of these circuits use error correction techniques, which improve tremendously the reliability of the transmission (noise at LF is impulsive in nature since individual lightning strokes propagate to the receiver with small frequency dispersion). Frequencies up to at least 350 kHz are not adversely affected at times of severe auroral or polar cap disturbances, in fact the signal strength is often enhanced at times of particularly intense daytime disturbances, disturbances that completely disrupt HF radio communication (black out). The atmospheric noise level is also very low in the Canadian North.

Frequencies below about 70 kHz are not used to any extent by Canadian communicators; this author knows of no Canadian based transmitters operating in the VLF frequency range.

A useful summary of low and very low frequency propagation has been given (Belrose, 1968); and some details concerning the engineering of communications systems for low and very low frequencies is given by Belrose, et al. (1959) and Watt (1967).

2. Some practical considerations of LF communications

Radio operators avoid using low radio frequencies if they can. The antenna systems employed are either of such large physical size that construction and maintenance costs are high; or they are so short with respect to the wavelength that radiation efficiencies are low, and the input impedance is very reactive (capacitive) with such low resistance that the bandwidth of the antenna system is small, and the voltages on the antenna large for even moderate transmitter powers. A large tuning coil and a fairly extensive ground system must be employed. Changing weather condition results in some detuning of the antenna; in the extreme, freezing rain prevents operation entirely unless antenna sleet and ice melting circuitry is available. Automatic antenna tuning circuitry should be employed in a sophisticated system operating on more than one frequency; the retuning of an LF antenna is a tedious time-consuming task. While such equipments are available the author has not seen one in use in Canada. Appendix B describes, as an example, the LF transmitting system employed at CRC for propagation studies.

The receiving equipment should comprise a small electrostatically shielded loop antenna, 1-metre diameter, which should be located in an open field several hundred feet from the building housing the receiver and terminal equipment. The receiver should

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be transistorized, temperature stable, and should employ optimum bandwidth for the particular mode of operation. The receiver should employ impulse noise suppression before the bandwidth is narrowed. Minimum shift FSK is the most efficient mode of operation at these frequencies, employing simplex or time-division multiplex, and error detection codes.

A closed loop error correction system should be employed, particularly for the southern end of a north-south link because of the higher levels at the more southerly location of atmospheric and man-made noise.

Detailed propagation considerations are beyond the scope of this brief report, but a few general comments follow. In general the longer the circuit the lower should be the operating frequency. The antennas should be so sited that sky wave is launched (and received) over sea water or ground of good conductivity, this is near grazing incidence. For example at 100 kHz over a 1500 km circuit that radiated (and received) field strength for a given transmitter power for the cases where the antenna foreground is sea water, rocky soil, arctic land and glacial ice would be reduced by factors of 0.86, 0.52, 0.3 and 0.09 over that for transmission (and reception) over a perfectly conducting flat earth. Since these factors apply at both the transmitter and receiver combined effect on the received field strength is the product of the antenna factors; i.e. in the above example a circuit where the antenna foreground is arctic land would require a transmitter power about 20 db greater than a circuit where the antenna foreground is sea water, for the same received field strength.

The poorly conducting terrain of the Canadian North also affects the phase of the wave, and hence the positional accuracy of a radio navigation system which depends on the phase of the received wave (Bourne, et al. 1968).

3. Present and future use of LF in Northern Canada

The use of LF communications in Canada has been briefly mentioned in the introduction of this report. These are:

a) Radio beacons (200 - 350 kHz)
b) Communications (FSK, CW) over medium to long distances, either as primary or back up circuits.
c) Reception of time and frequency broadcast signals
d) Long range navigation (Omega system 10 - 14 kHz)
e) Short to medium range navigation (and time) (Decca (70 - 130 kHz) and Loran C (100 kHz)).

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The many radio beacons in the Canadian north are in an increasing number being adapted as well for LF communications (i.e. combining (a) and (b) above). The present use of LF by the Department of Transport, the principal user of LF in Canada, is given in Appendix A. This use of LF is likely to continue, and to expand as the north is developed, even with the advent of communication satellites, and with the addition of new microwave links and land lines.

LF radio waves are not extensively used for navigation in the Canadian north, although the DOT has some experience in the use of the Omega navigation system, but with the increasing need for reliable navigation systems (requirements for example to oversee Canadian sovereignity in Arctic waters and oil tankers using the Northwest passage), there is an increasing need for navigation systems. The installation and maintenance of such systems as Loran C in the Canadian North would be very high. The most practical method for navigation in the Arctic would seem to utilize the Omega (10 - 14 kHz) radio navigation system of the US Navy. The accuracy of Omega navigation systems is not very high, being 1 - 3 miles under ideal propagation conditions; probably much worse in Arctic regions due in part to more frequent radio disturbances, and in part because of the poor conductivity of the land. An adaptation of the Omega system, not yet tried (at least insofar as the author of this report knows) is Differential-Omega which would certainly work. In this method Omega monitor receivers would be located at all sites of the Department of Transport where HF and preferably LF communication is available, and updated corrections would be broadcast by radio to users of the system. The differential-Omega navigation method is being considered by the DOT.

The development of transistors and integrated circuits has resulted in considerable improvement in the reliability of communication equipments, particularly in regards to receivers and associated terminal equipment. Solid state LF transmitters have been developed commercially, and CRC has developed a solid state LF transceiver (500 watts) for reliable LF communications over short distances, distances of the order of 250 miles, employing frequencies in the 100 - 200 kHz band. The feasibility of communicating over these distances in the Canadian north, employing an easily erected horizontal half-wave dipole antenna (about 2000 feet tip-to-tip) laid on the surface of the ground (or preferably suspended a few feet off the ground) has been demonstrated, (Evans, 1970), which makes possible reliable communication from temporary or semi-permanent locations. The requirement for a LF communication system is uncertain at the present time, but such a communication system could meet military and government needs where reliability is a principal requirement.

In conclusion LF radio communication has been and is being used for reliable communication in the north; and, even with the

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advent of sophisticated satellite communication systems, with the installation of microwave links and land lines, LF radio is likely to continue to be used; either as a back up for these other systems, or a back up to HF radio at places where other reliable communication systems are not available.

APPENDIX A

Canadian Department of Transport LF Circuits

Circuit	Remarks
Cambridge Bay to Copper Mine	157 kHz CW
Cambridge Bay (245 kHz) to Resolute Bay	Radio beacon transmissions FSK with error correction.
Ft. Smith to Norman Wells and Inuvik	Backup circuit for land line 134.9, 139.8 or 172 kHz FSK
Inuvik (172 kHz) to Sac Harbour (179 kHz)	FZK Primary circuit.
Resolute Bay (170.5kHz) to Mol Bay Isachsen, Eureka (all on 138.05 kHz) and to Alert (relay via 178 kHz at Eureka)	FSK
Churchill (151 kHz) to Coral Harbour (362 kHz)	FSK Error correction.
Churchill (197 kHz) to Trout Lake (187 kHz) Baker Lake (187 kHz), Poste-de-la-Balline (371 kHz) and Inoucdjouac (Port Harrison) (396 kHz)	FSK Churchill may change to 305 kHz.
Frobisher Bay to Nitchequon, Fort Chimo, and Schefferville (Knob Lake)	153 kHz CW changing to FSK. Possibly new frequencies.
Schefferville (203 kHz) to Ft. Chimo (153 kHz) Border (239 kHz), Lake Ion (227 kHz), and Nitchequon (364 kHz)	New circuit FSK.
Trout Lake (187 kHz) to Baker Lake (251 kHz)	New circuit.

Appendix B

The LF Transmitter Installation at the CRC

The antenna employed is a 250 foot umbrella top loaded vertical radiator. The top hat comprises 24 active guys, which are attached to the top of the radiator and to guy anchors equally spaced around a 350 foot radius circule about the base of the mast. The design is for maximum top loading to permit operation on very low frequencies. The active portion of the umbrella guys, the top 308 ft, is insulated from the bottom portion by 30 foot fiberglas insulators, each fitted with a corona ring, and the active guys are connected to each other at their bottom ends by a wire skirt. The (estimated*) radiation efficiencies, bandwidth and antenna voltage for 5,000 watts input power at 32.8, 80, and 198.5 kHz are: 2.5, 14 and 30%; 90 Hz 520 Hz and 25 kHz; and 33, 13 and 0.9 KV respectively. The resonant frequency of the antenna is of the order of 200 kHz, and it is clear that the radiation parameters change rapidly with decrease in frequency below the fundamental resonant frequency.

The ground screen consists of 120 radial wires 1,000 ft. long, buries a few feet in the top soil; and connected at their mid-point and ends by a ground rod.

The transmitter is a TMC Model GPT-10KLF low frequency transmitter, which provides 5,000 watts of CW power over the frequency range 5 - 500 kHz. The output transformer is a broadband network requiring no tuning over the frequency range of the transmitter.

The purchase of an automatic antenna tuning unit is under consideration. A suitable equipment is manufactured by Amplidan A/S, Denmark. The tuning is fully automatic, the servo-control signal is derived from the reflected power in the transmission line, and the antenna is tuned for minimum reflected power.

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* the antenna is presently being modified.

References:

Belrose, J.S, Radiowave Propagation, Pt.IV, Low and very low frequency radio propagation, AGARD Lecture Series XXIX, Tech. Editing and Reproduction Ltd., London, July, 1968.

Belrose, J.S., W.L. Hatton, C.A. McKerrow and R.S. Thain. The engineering of communication systems at low frequencies, Proc. I.R.E., 47, 661, 1959.

Bourne, I.A., B.Segal and D.B. Ross. An investigation into some problems associated with the Decca "Hi-Fix" navigation system in the Canadian Artic, DRTE Report 1196, DRB, July 1968.

Evans, W.M., A transportable LF communication system, CRC Report, in preparation, 1970.

Watt, A.D., VLF Radio Engineering, Int. Monographs in Electromagnetic Waves, Vol.14, Pergamon Press, 1967.

CHAPTER III

RADIO RELAY LINE-OF-SIGHT SYSTEMS

COMMUNICATIONS IN THE
CANADIAN NORTH
RADIO RELAY SYSTEMS

Prepared by:

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INDEX

1. INTRODUCTION

This section describes the role that point-to-point radio systems have, and will have, in the development of Communications to the North and in the North.

1.1 Requirements

1.1.1 Quality

The quality of a circuit is completely defined by two things:

- how much does it garble the message (fidelity)
- how often is it available (reliability).

Ultimately, there is no difference between the transmission requirements for the Northern part of Canada, and the Southern part. Psychologically the Vancouver businessman will soon become intolerant of noisy and unreliable calls to Frobisher Bay; and the eskimo will quickly recognize that the Prime Minister's face is not magenta. Technically, and possibly more important though, will be the enormous quantities of data that must go rapidly and accurately between the small "on site" computer of a northern mining operation and the main computer, snugly housed in its rarified, air-conditioned room at the company's headquarters. Psychologically or technically, Northern circuits carry information in the same form and at the same rate as Southern circuits and, ultimately, have the same quality requirements.

The word "ultimately" keeps cropping up because there is a catch to all of this. The better and more reliable a circuit is, the more it costs. Somebody has to pay.

1.1.2 Quantity

Here's where the big difference comes. The more circuits between any two places, the less each circuit costs. If Pond Inlet, and every other small, northern community, had a real economic requirement for a thousand circuits, or even a few hundred, there would be no point in wiring this report. Heavy route microwave and complex satellite systems would today bind together the north into one massive communications web, and north-south communications would be as reliable and inexpensive as southern ones.

1. INTRODUCTION (Cont'd)

1.1.2 Quantity (Cont'd)

Pond Inlet, however, does not have a real economic requirement for a thousand circuits. In fact, as a typical, small, isolated, northern community it can not economically justify even one circuit of a quality equal to those of the south. (Whether or not it should have one, good quality, circuit is not discussed in this section). At the moment, Pond Inlet has a single voice communication link that is operational about eighty percent of the time and requires frequency repetition of messages. This represents the low end of the communication spectrum, both in terms of quality and cost, and follows the philosophy that 'any communication is better than none at all'.

1.1.3 Summary

Thus, development of Northern communications involves the combining and balancing of two fundamentally contradictory requirements:

- good fidelity, reliable circuits, but
- relatively few to any geographical point.

1.2 Present Situation

Historically, and in order of importance. Northern communications have developed using three main types of radio:

1. High Frequency (HF) radio
2. Troposcatter radio
3. Point-to-point radio.

1.2.1 HF Radio

High Frequency radio was and is still almost always the first form of communication to a northern community. HF radio requires high power, is fairly unreliable, and carries a maximum of one or two poor quality circuits. On the other hand, HF radio can span thousands of miles in one jump and is inexpensive both to buy and maintain. Such systems have had, and will continue to have, an important role in Northern communications, and are discussed under the appropriate section.

1. INTRODUCTION (Cont'd)

1.2.2 Troposcatter Radio

Troposcatter radio systems provide reasonably good quality circuits with cross-sections to 120 voice channels or more. They are much superior to HF circuits, but fall short of the standards normally associated with communications in the South. They are also much more expensive and are usually heavily supported by large government contracts. Nevertheless, when reasonable communication facilities were required in the North, troposcatter systems were, and in many cases still are, the only method of achieving them.

1.2.3 Point-to-Point

Point-to-Point systems, up until now, provided the ultimate in good quality, long distance communications, and still carry the majority of east - west traffic. (Coaxial cable systems are just now becoming a reasonable supplement). However, such systems require a repeater about every 30 to 40 miles and, therefore, were prohibitively expensive to install and maintain in areas where there are no transportation facilities. For this reason, northern use of point-to-point radio has been almost entirely restricted to the north-west.

1.3 Future Trends

In order of importance:

1. Satellite) alone or in combination
2. Point-to-point)
3. Troposcatter
4. HF Radio

1.3.1 HF Radio

Satellite systems are similar to HF systems in that they can cover thousands of miles in one jump (to the satellite and back). It is expected too that they will be comparably priced. There the similarity ends, for it is expected that satellite systems will provide circuit quality equivalent to that available in the southern part of Canada. With a few exceptions, therefore, satellite communications will probably eclipse HF radio where the northern point of contact is geographically fixed.

1. INTRODUCTION (cont'd)

1.3.2 Troposcatter

The same holds true for Troposcatter systems as they are presently used, i.e. very high power, brute force equipment. The 'scatter' mode of propogation, however, will likely still be used but in a more elegant and less expensive way.

1.3.3 Satellite

Satellite communication, as it is now envisaged, seems to be one very promising way of achieving good quality circuits without paying too high a price for them. Although, ultimately, the satellite will probably be used for as few as one or two channels to a community, it should initially start as a group of channels (say 24) beamed to some central northern community, with ground facilities radiating from there to the smaller communities. A few years ago, these ground links would have been served by HF radio or conventional Troposcatter, despite the inherent problems of high powers and low reliability. Even now, HF radio will often be the most practical way of providing this form of communication.

1.3.4 Point-to-Point

As mentioned earlier, conventional point-to-point systems require good transportation facilities. The newer, fully solid-state equipment has changed all that. Now it is possible to enclose ultra-reliable radio equipment, together with ultra-reliable, low-cost power equipment, in a single weather-proof container that can be transported bodily to just about any place in Canada. Strings of these repeaters can be used to join smaller centres to the satellite ground stations or, in some cases, avoid the need for a ground station and supply interconnection direct to the southern part of the country. This second application may be used for economic reasons, or as an alternative to using the limited spectrum available to a satellite. It is the purpose of this section to describe the factors involved in the design of light and medium capacity using such isolated repeaters.

2. SYSTEM DESIGN CONSIDERATIONS

2.1 General Considerations

The key factor in developing this Isolated Repeater System approach is based upon a significant reduction in the installation and operating costs of the radio relay repeaters.

2.1.1 Housings

Repeater housings must be inexpensive yet suitable to provide acceptable internal environmental control.

2.1.2 Power

Where commercial power is not available, power sources, such as air depolarized batteries, thermal generators, thermoelectric converters, etc., are integrated into the basic housing design.

2.1.3 Installation

In the majority of cases, equipment installation is completed at a central location in transportable repeater housings prior to the installation of the unit in the field. This greatly reduces the high engineering and installation charges often associated with radio repeaters.

2.1.4 Maintenance

Reliability and stability of the complete isolated repeater allows operation for long periods of time without interruption of service and requires only one or, at the most, two scheduled maintenance visits per year. The exact timing of these visits is not critical.

2.1.5 Site Selection

The design engineer has almost complete freedom in selecting his sites. In topographical areas characterized by low, rolling hills or flat plains, repeater sites tend to be relatively closely spaced but use short towers and may be located close to the means of transportation, such as existing roads or winter roads, lakes or river chains, or any suitable point where site access is as economical as possible. In mountainous areas, through the use of helicopters, repeaters can be located in extremely high and remote locations. In this way, repeater spacing can be greatly increased with a subsequent decrease in overall system cost.

2. SYSTEM DESIGN CONSIDERATIONS (Cont'd)

2.2 Transmission Design

2.2.1 Radio Frequency Bands and Propagation

Repeater spacing is directly dependent upon the propagation characteristics of the radio frequency band utilized. Since frequency congestion is generally not a problem in the North, it is practical to take advantage of the radio propagation characteristics of the lower frequency bands to either extend repeater spacing or minimize tower heights.

2.2.1.1 Frequency Band 138.0 - 143.6, 150.05 - 147.0 MHz

Propagation in this frequency band is best suited to operate over the more heavily obstructed paths. Considering all factors, this frequency band is recommended for two types of application.

a) Narrow Band Systems

One or two channel capacity systems provided by low performance narrow band, low power equipment. Systems are normally engineered with a minimum RF signal and can be expected to provide a median voice frequency channel performance better than 38 dBaO, or 25 dBaO when channels are compandored. Noise over one or two hops of such a system is audible as a background hiss, but is not objectionable.

b) Medium Capacity Systems

Six to twelve channel capacity systems provided by higher performance and broader band equipment with high RF output powers. (Up to a kilowatt is commercially available). Unfortunately, these higher powers are usually derived only from tube equipment. Such equipment, although quite reliable, requires some sort of primary power and is not suited to the completely isolated approach. Nevertheless, with a fairly minimal received signal (-65dBm) such systems will provide VF circuits with a per-hop performance of about 25 dBaO.

2. SYSTEM DESIGN CONSIDERATIONS (Cont'd)

Since this frequency band is susceptible to man-made interference, such as ignition noise, some care is required in engineering RF receive input levels and site locations to minimize this problem.

Care must also be used to avoid mutual interference between point-to-point systems and mobile systems which can share this band in relatively built-up areas. This pretty well restricts the use of this band to more remote areas.

2.2.1.2 Frequency Band 410-420, 450-470

The propagation characteristics of the 450 MHz band allow it to operate satisfactorily over obstructed hops by careful selection of transmitter output power, antenna gains and site selection.

Reliable systems having capacities from six to sixty channels can normally be fitted into this band, and they can be engineered to provide VF circuits with median per-hop noise between 20 dBaO and 30 dBaO depending upon the RF input signal. In general, systems are engineered with average RF signals adequate to provide the noise performance required with about a 30 dB fade margin to threshold to assure adequate overall reliability.

As in the 150 MHz band, the 450 MHz band is shared with mobile equipment and therefore is also susceptible to intersystem interference. Too, the band is susceptible to man-made interference, but at a reduced level. so care is normally exercised in the system design to handle this situation.

2.2.1.3 Frequency Band 890.0 - 942, 942 - 960 MHz

The transmission characteristics of this frequency band make it ideally suited for multichannel light route systems. Paths can be engineered at grazing or with slight obstructions through careful choice of antenna heights, gains and site locations. There is sufficient bandwidth available to design systems with capacities up to 120 channels and still allow a per-hop noise performance of about 15dBaO. Once again, systems are normally engineered utilizing RF signal levels adequate to provide the noise performance required and with at least 30 dB fade margin, to handle the types of fading encountered.

Man-made interference noises, such as car ignition, have almost no effect in this band, so it can also be used in locations where this type of interference is normally encountered. The use of these frequencies is shared with industrial, scientific and medical equipment and the possibility of interference from this equipment has, for a number of years, discouraged the use of 900 MHz equipment. Studies are presently being carried out on the degree of ISM interference that can be expected on multi-channel systems. Although the amount of radiation from the ISM type equipment is not controlled by D.O.C. regulations, the design must meet health requirements for protection against microwave radiation. It is presently felt that, if equipment meets these health regulations, the radiation level will be sufficiently low to eliminate the possibility of interference with operating multi-channel systems. No interference, therefore, is anticipated in the remote areas, and the possibility in populated areas is slight.

2.2.1.4 Frequency Band 1429-1525 MHz

This band is under study by D.O.C. for possible use by narrow band radio relay stations. This band would be useful for multichannel systems. However, at this time, it would not appear to have any appreciable advantage over the 890-960 MHz band.

2.2.1.5 Frequency Band 1710-1900 MHz

This band is suited for systems occupying the normal RF bandwidth of 300 channels with 200 KHz RMS deviation. Propagation characteristics allow operation over diffracted paths especially for systems providing less than 300 channels with high deviation (see Section 2.2.2.4). Overall median per-hop noise performance runs about 15 dBaO.

2. SYSTEM DESIGN CONSIDERATIONS (Cont'd)

2.2.1.6 Frequency Band 1900-2290 MHz

This band is to be used for high performance systems (better than 3 pW/KM) requiring large expansion capabilities for both voice and TV circuits.

This is the lowest frequency band that can be utilized to provide these capacities and will provide a more economical arrangement than the utilization of higher radio frequencies.

2.2.1.7 Frequency Band 3540 MHz and Higher

For economic reasons, it is expected that most of the point-to-point light and medium capacity systems in the North will be developed in the frequency bands below 2300 MHz. When frequency congestion or other factors are encountered, normal available multi-channel frequency bands operating above 3540 MHz can be utilized.

2.2.2 Radio System Design Parameters

2.2.2.1 Reliability RF Received Signal

The amount of signal arriving at a receiver depends upon the

- power generated by the transmitter, the
- focusing of this power by the antenna, the
- propagation losses between the TX and RX, the
- focusing power of the RX antenna, and the
- miscellaneous transmission line and filter losses.

2.2.2.1 Reliability RF Received Signal (Cont'd)

With the exception of propagation losses, all of the above factors are either stable gains or stable losses. The amount of signal reaching the receiver, therefore, will have an average mean value which will fade from time to time during periods of bad propagation. A faded signal gives a noisy or unreliable communication channel. When it becomes so noisy that it is no longer suitable for transmission, it is considered to be unavailable, or down. The reliability of a system (particularly one using ultra reliable equipment) is almost solely dependent upon the probability of fading. Tables are available that relate atmospheric conditions to probability, so that in this way the probability or reliability of an RF received signal can be predicted with reasonable accuracy. Charts 1 and 2 show examples of this relationship for a design near Fort Smith, N.W.T.

2.2.2.2 RF Received Signal and Performance

Once the relationship between reliability and RF received signal has been established, it is necessary to relate RF received signal to performance. This is most easily done using a Receiver Noise curve, which relates directly the channel noise to the RF RX signal. Figure 1 shows such a curve.

2.2.2.3 Performance and Equipment Parameters

The receiver noise curve can be seen to be a composite of three separate lines, as shown in Figure 2.

Curve A is the basic or inherent equipment noise due to the amplifiers, demodulators, oscillators, etc., and is independent of RF RX signal.

Curve B is normally called the thermal curve. When plotted on a dB scale, as shown, its slope is always 45°. Its position, however, depends upon

- the position (frequency) of the voice channel in the baseband
- the emphasis characteristics used

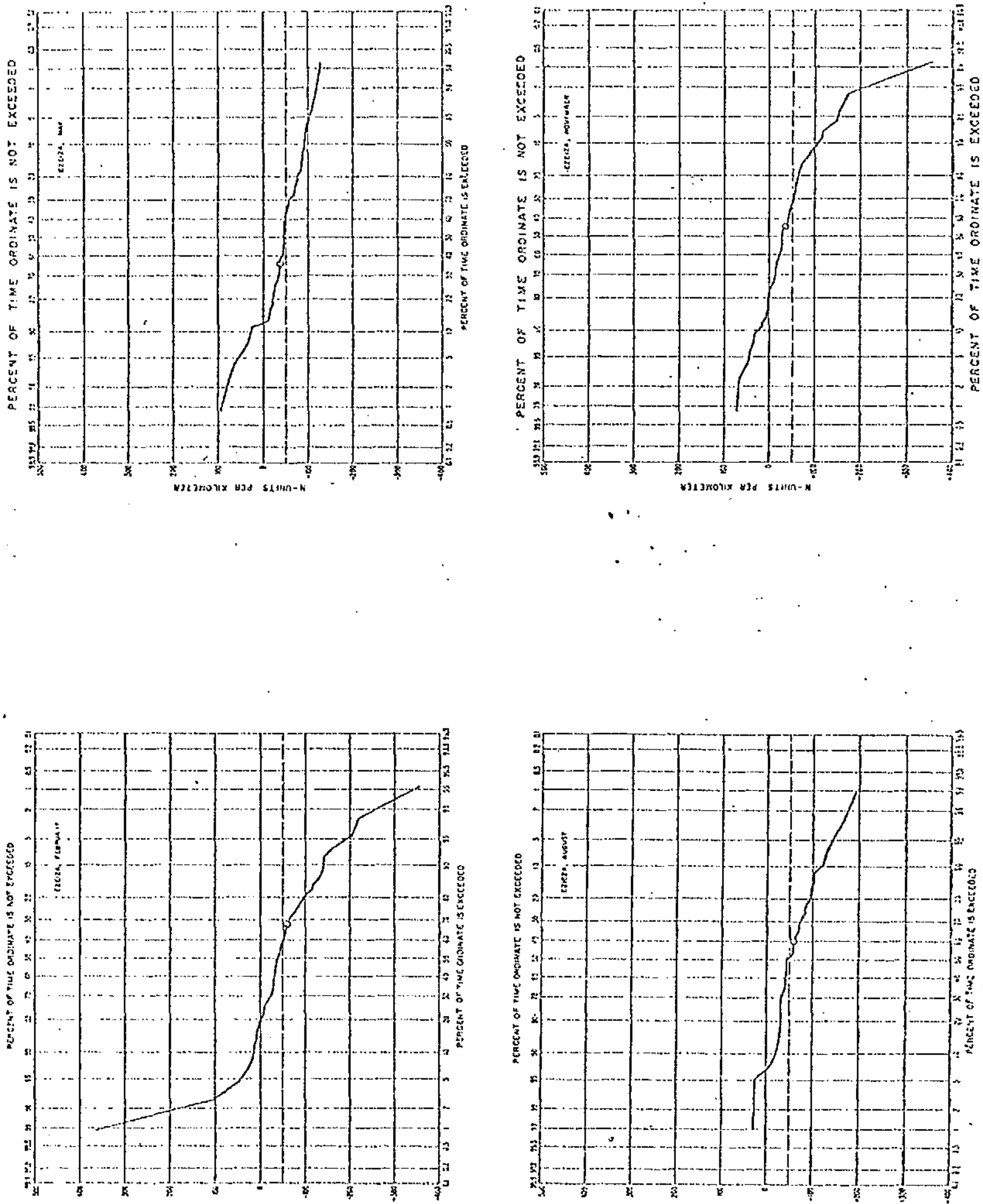


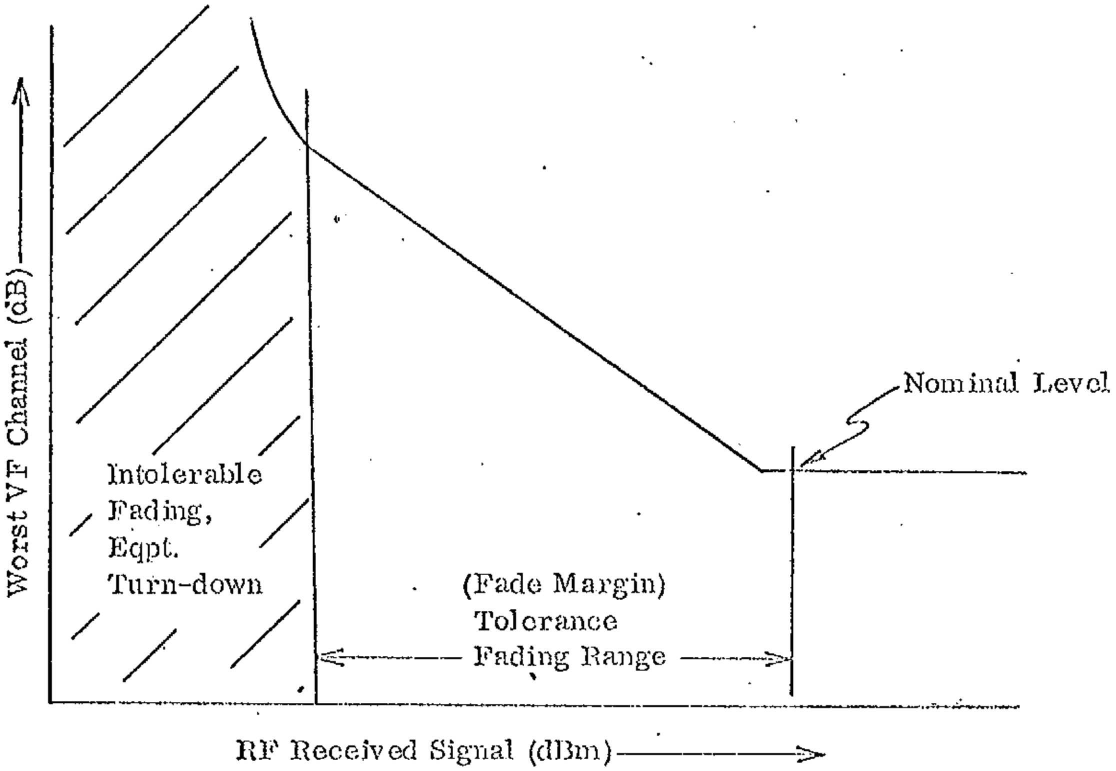
FIGURE C-64. *Cumulative probability distributions of dN/dh for ground-based 100-m layer: Ezeiza, Argentina.*

Chart 1

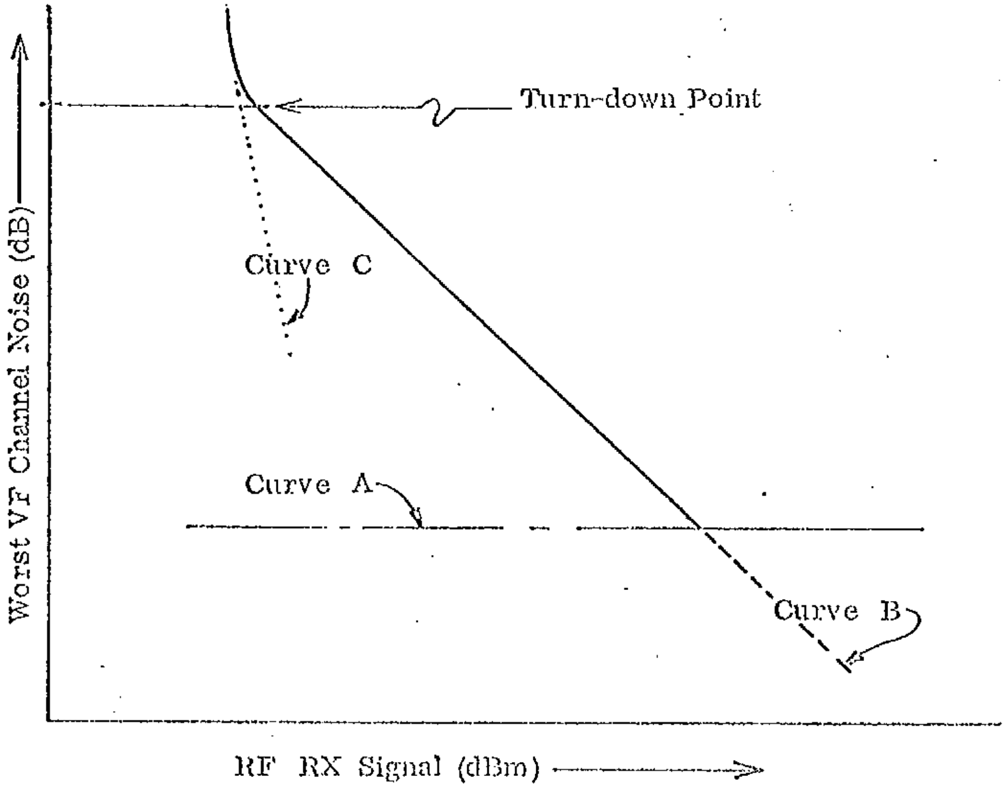
Chart 2

```
A.GENERAL-SLIGHTLY ROLLING PLAINS
 1.TERRAIN IRREGULARITY =  125. FEET
 2.GROUND CONDUCTIVITY = 0.008 MHOS/METER
 3.GROUND DIELECTRIC CONSTANT = 80. ELECTROSTATIC UNITS
 4.SURFACE REFRACTIVE INDEX = 320.
B.PARTICULAR
 5.PATH LENGTH =  50.0 MILES
 6.EFFECTIVE TOWER HEIGHTS =  300. AND  280. FEET

FREE SPACE LOSS (IN DB) = A114.1/B123.6/C129.6/D135.7/

      ATTENUATION BELOW FREE SPACE(IN DB)------>
      0         15        30        45        60        75        90
     II . . . . I . . . . I . . . . I . . . . I . . . . I . . . . I
     I
 0.36           .         .         .         A B C D   .         I 280.
     I
 0.38           .         .         .        A. B C D   .         I 260.
     I
 0.40           .         .         .       A .B C D    .         I 240.
     I
 0.42           .         .         .     A   .BC D     .         I 220.
     I
 0.44           .         .         .    A    B C D     .         I 200.
     I
 0.47           .         .         .  A     B.C D      .         I 180.
     I
 0.50           .         .         .A      B C  D      .         I 160.
     I
 0.53           .         .        A.     B  C. D       .         I 140.
     I
 0.57           .         .       A .   B    C.D        .         I 120.
     I
 0.61           .         .     A   .B    C   D         .         I 100.
     I
 0.66           .         .   A    B. C    D .         .         I  80.
     I
 0.72           .         .  A  B  C.   D     .         .         I  60.
     I
 0.80           .         .A B  C  D.         .         .         I  40.
     I
 0.89           .        AB C  D    .         .         .         I  20.
     I
 1.00           .      ABCD         .         .         .         I   0.
     I
 1.15           .    CD   .         .         .         .         I -20.
     I
 1.34           .DBA      .         .         .         .         I -40.
     I
 1.62      D CB .A        .         .         .         .         I -60.
     I
 2.04 DC  B    A.         .         .         .         .         I -80.
     I
 2.75 D     A   .         .         .         .         .         I-100.
     I
 4.24 D   A     .         .         .         .         .         I-120.
     I
 9.22 D A       .         .         .         .         .         I-140.
     II . . . . I . . . . I . . . . I . . . . I . . . . I . . . . I
 ↑     A= 150./B= 450./C= 900./D=1800./  MHZ                            ↑
EARTH RADIUS                                                GRADIENT OF
FACTOR(K)               HOR. POLARITY                REFRACTIVITY DN/DH
```

2. SYSTEM DESIGN CONSIDERATIONS (Cont'd)



RECEIVER NOISE CURVE FIGURE 1



RECEIVER NOISE CURVE FIGURE 2

2. SYSTEM DESIGN CONSIDERATIONS (Cont'd)

2.2.2.3 Performance and Equipment Parameters (Cont'd)

Curve B(cont'd)

- the per-channel deviation
- the noise figure of the receiver
- the VF channel bandwidth

With the exception of per-channel deviation, all of the above parameters are a function of the particular equipment being used. Per-channel deviation, however, is a very important variable, and is discussed under the next heading.

Curve C is called the threshold curve, and defines the point at which any further increase in fading causes a sharp increase in noise. In a well designed system the 'knee' formed by the combination of curves B and C will be the turn-down point of the communication link. The percent probability of the RF signal being greater than this value is the reliability of that hop. The combined reliability of all the hops gives the reliability of the system. (There are a number of diversity techniques that are often used to improve this reliability.)

2.2.2.4 Per-Channel Deviation

Increasing the per-channel deviation is usually no more difficult than turning a gain control. It affects the system in two important ways:

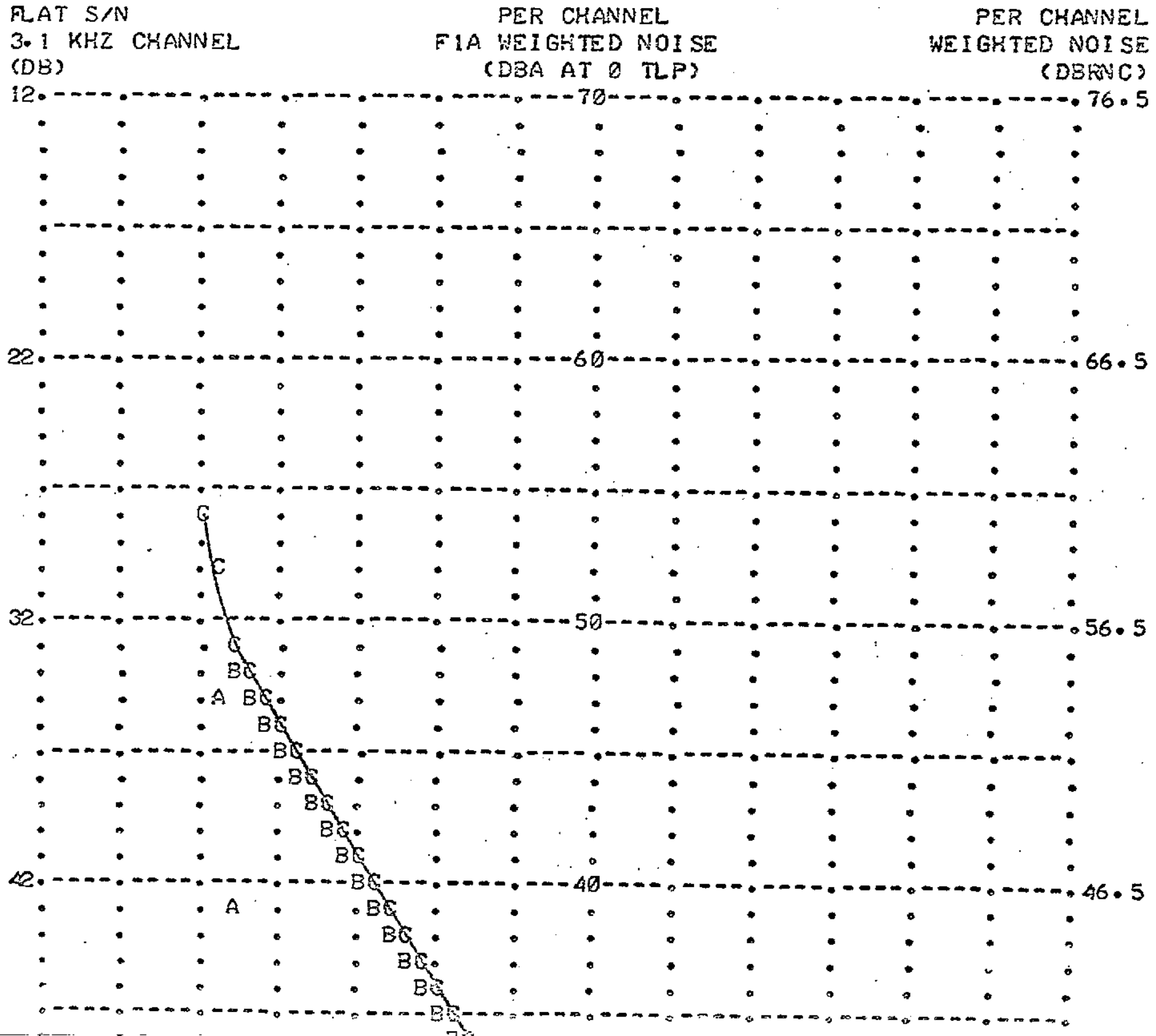
- it increases the necessary bandwidth
- it lowers Curve B on the receiver noise curve.

In other words, increasing the per-channel deviation improves the fidelity of the system at the expense of RF spectrum. In areas where large amounts of RF spectrum are available, the technique of increasing per-channel deviation can be safely employed to markedly improve the fidelity of the communication channel.

2.2.2.4 Per-Channel Deviation (Cont'd)

Charts 3 and 4 show the change in the receiver noise curve for a fairly typical 60-channel system. Chart 3 shows the curve for three selected channels of a 60-channel system, with ± 50 KHz RMS per channel deviation average. Chart 4 shows the same thing except that the deviation has been increased to ± 800 KHz RMS average.

```
DATA
  1. RECEIVER NOISE FIGURE =  8.0 DB
  2. I.F. BANDWIDTH =  5.0 MHZ
  3. PER CHANNEL DEVIATION =   50. KHZ RMS
  4. EQUIPMENT TOTAL INHERENT NOISE = 15.0 DBA0
  5. NO. OF VOICE CHANS =   60
  6. MAXIMUM FREQUENCY (CCIR EMPHASIS) =  240.KHZ
```



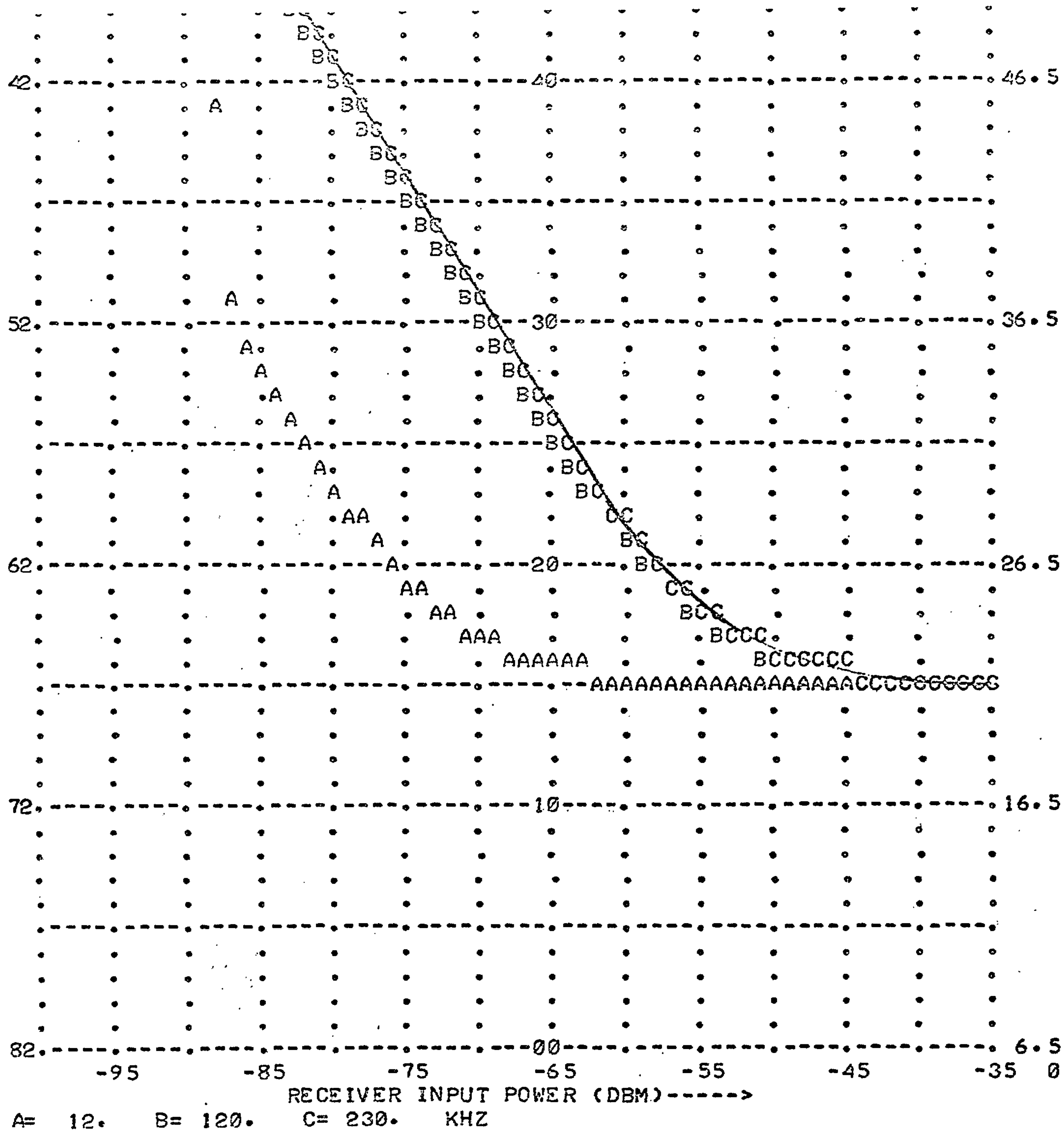
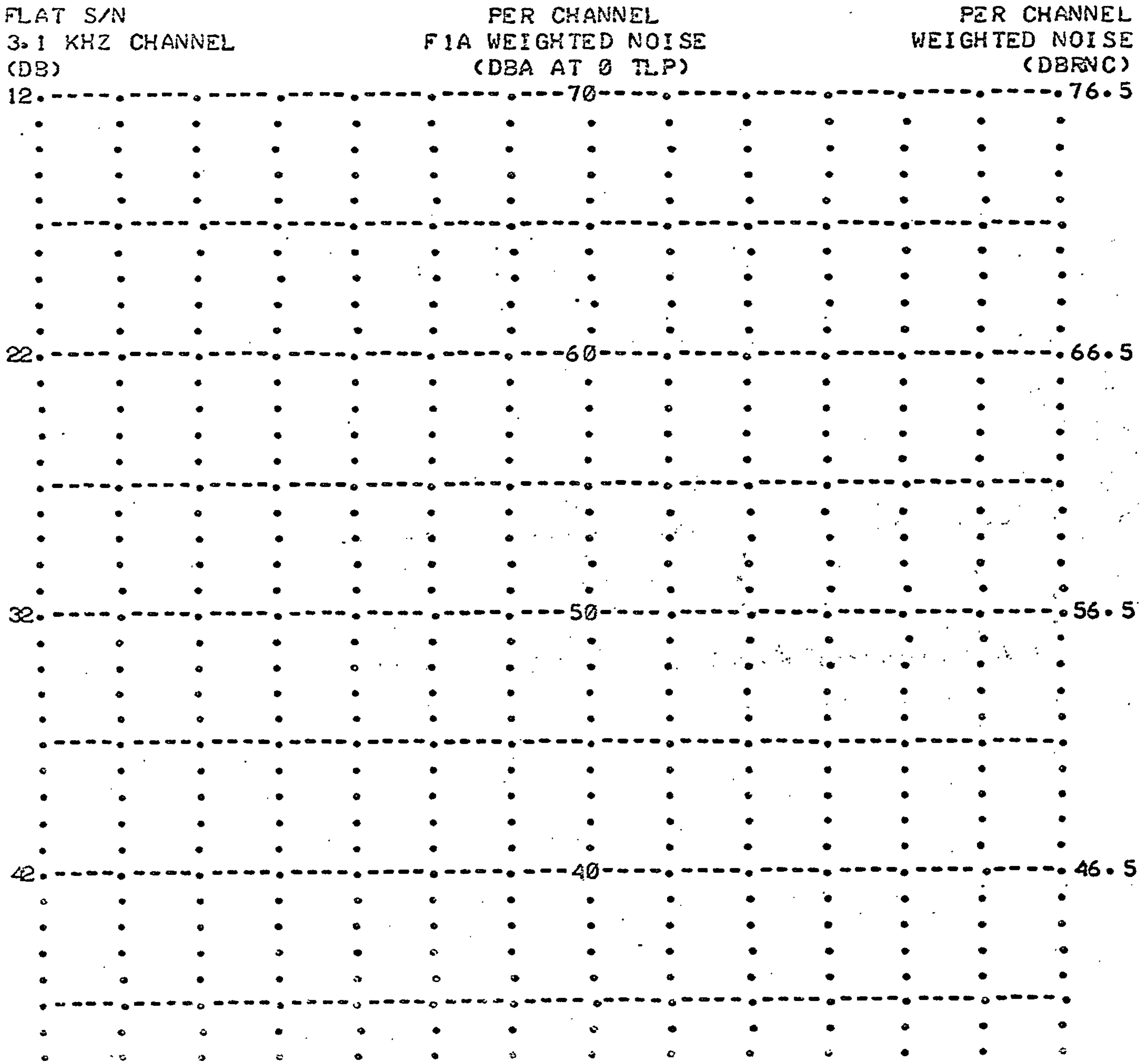
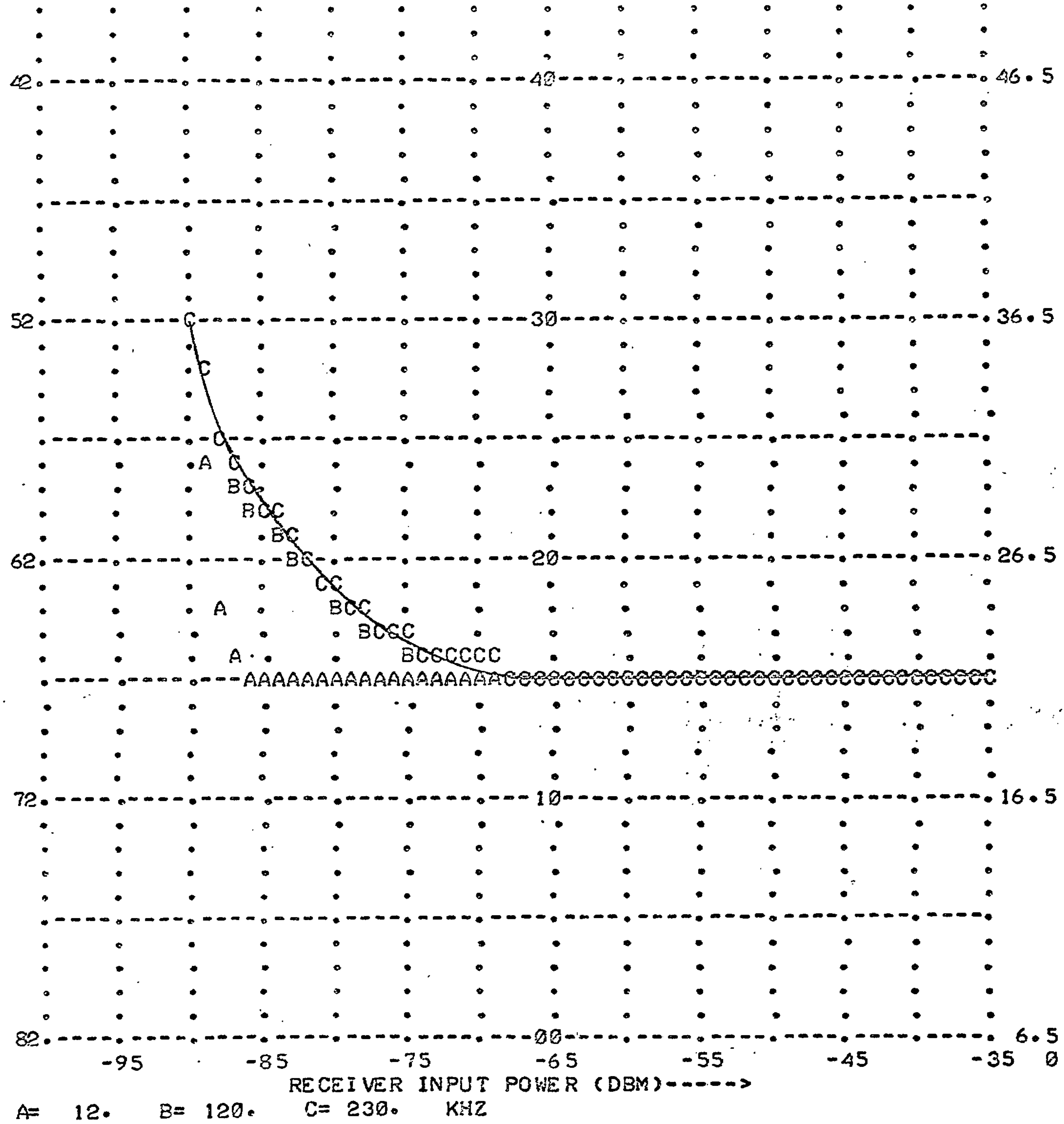

42
52
62
72
82
40
30
20
10
00
46.5
36.5
26.5
16.5
6.5
0
-95
-85
-75
-65
-55
-45
-35
RECEIVER INPUT POWER (DBM)----->
A= 12. B= 120. C= 230. KHZ

Chart 3

```
DATA
  1. RECEIVER NOISE FIGURE =  8.0 DB
  2. I.F. BANDWIDTH =  5.0 MHZ
  3. PER CHANNEL DEVIATION =  800. KHZ RMS
  4. EQUIPMENT TOTAL INHERENT NOISE = 15.0 DBA0
  5. NO. OF VOICE CHANS =   60
  6. MAXIMUM FREQUENCY (CCIR EMPHASIS) =  240.KHZ
```




42
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00
46.5
36.5
26.5
16.5
6.5
0
-95
-85
-75
-65
-55
-45
-35
RECEIVER INPUT POWER (DBM)----->
A
B
C
A= 12. B= 120. C= 230. KHZ

Chart 4

3. CONSTRUCTION AND MAINTENANCE (Cont'd)

3.4 Towers and Antenna (Cont'd)

2. Cost of placing heavy equipment on site.
3. Maintenance facilities for heavy equipment.
4. Temporary living and messing facilities for crews.
5. Large crews for long periods.

There is obviously little advantage in using "state of the art" techniques on buildings, equipment and power plants aiming for, let us say, a three-day installation time if this is to be offset by tower and antenna erection time.

Bearing this in mind, sites should be chosen where possible that:

- have rock base, eliminating concrete or digging
- engineer paths to allow the use of reasonably sized towers and antennae.

Under certain circumstances, a 50 or 100 ft. tower can be assembled and helicopter erected very quickly, whereas gin pole methods are slow and subject to weather delays.

Transportation of a 10 ft. or 12 ft. parabolic antenna is a problem and subject to delays. Work is in progress on a sectionalized 12 ft. antenna, which should make this size of dish easily useable in remote areas.

At present, the use of 20- or 30-foot billboard dishes present heavy costs in transportation, erection and time. There is no reason why, with the use of light alloys, careful design and a colour coded mating system, such antennae should not become feasible for this type of system.

Table A compares antennae which are presently available. The "trouble free" crossover point is a Paraflector at MHz and an 8 ft. Dish at 900 and 2,000 MHz. The choice of larger antennae leads to excessive transportation and tower stressing costs. The breakdown 12 ft. Dish, when available, will eliminate transportation problems but, of course, would still require heavy tower guying which can in turn be a costly problem in remote locations.

TABLE A

ANTENNA COMPARISON

TYPE	GAIN		SHIPPING SIZE	SHIPPING WEIGHT	GENERAL COMMENTS	
450 MHz						
Yagi	10 dBd		3 cu.ft.	6 lbs.	No transportation problems.	
Corner Refl.	7.5 dBd		17 cu.ft.	40 lbs.	Light wind loading allows simple structure	
Paraflector	15 dBd		36 cu.ft.	25 lbs.		
10' Dish	17.2 dBd		340 cu.ft.	800 lbs.	Transportation problems. Heavier tower structure requirements.	
	Note: All above gains referenced to a dipole.					
900 MHz & 2 GHz						
	GAINS dBi 900	2 GHz				Thrust on Tower in 120 MPH Wind
4' Dish	19	-	20 cu.ft.	130 lbs.	No transportation problem	500 lbs.
6' Dish	22	28.5	50 cu.ft.	180 lbs.	No transportation problem	1,500 lbs.
8' Dish	24	31	150 cu.ft.	380 lbs.	Possible transportation problem.	3,000 lbs.
10' Dish	26.1	33	340 cu.ft.	800 lbs.	Transportation problem	5,000 lbs.
12' Dish	27.9	34.5	550 cu.ft.	1200 lbs.	Transportation problem	7,500 lbs.
15' Dish	29.8	36.4	710 cu.ft.	1600 lbs.	Transportation problem	11,500 lbs.
20' Billboard	-	38.6			High on site transportation costs plus heavy erection costs	self-supporting
30' Billboard	-	42.1				

3. CONSTRUCTION AND MAINTENANCE (Cont'd)

3.4 Towers and Antenna (Cont'd)

A further design consideration is the choosing of sites and antennae heights as far as possible to eliminate the need for tower lighting.

Packaged repeaters, as envisioned, call for self-contained "exotic" power supplies engineered for low consumption equipment. The inclusion of normal tower lighting power requirements would increase costs several orders of magnitude.

Where tower lighting is necessary, consideration should be given to the use of strobe lighting or other means to ease the power burden.

3.5 Reliability and Maintenance

Although, initially, six-monthly visits may be planned, the eventual maintenance objective on an isolated repeater site should be a "Hands Off" operation with annual maintenance routines for performance up-grading.

Present "state of the art" Solid State Radio Terminals have component failure MTBF in excess of 15,000 hours. The normal protection of radio and redundancy of active ancillary equipment means that even a unit failure is unlikely to cause circuit outage.

Due to aging of components, etc., system performance can fall off over a period of time. In contemplating a "Hands Off" operation, consideration should be given to this degradation as compared to acceptable standards. With the use of appropriate test techniques and careful commissioning, it is quite in order that after a year's degradation the system will still be within minimum specification. For example, a radio hop designed for a total noise of 12 dBa can be initially commissioned giving figures in the order of 7 to 8 dBa.

The additional costs in making a system "over perform" are minor when compared to the advantages of visit-free operation.

General maintenance checks over an operating year should consist of examining the system "end-to-ens" and recording performance deterioration, if any.

3. CONSTRUCTION AND MAINTENANCE (Cont'd)

3.5 Reliability and Maintenance (Cont'd)

When a radio is placed in service it probably has had about 1,000 hours operation made up as follows:

Bench tuning of units:	3 days
System testing in factory:	14 days
Commissioning time:	21 days

It is unlikely that any further run-in time would be of advantage in stretching MTBF figures.

Heat cycling, however, tends to level out operational performance changes and additional temperature cycling should be considered on equipment intended for remote application.

There are presently in operation multi-hop systems with "end-to-end" testing facilities. Working only from the terminal station the A and B paths can be paralleled; with these operating as independent systems traffic is switched to one freeing the other for testing.

Using such methods, a whole system can be checked out very quickly and site visits for individual hop testing would be done on an annual basis.

In addition to normal design consideration, equipment for isolated repeater systems should meet the additional objectives:

1. Low unit failure rate with complete protection or redundancy.
2. Selected units allowing "over performance" above minimum specification.
3. Additional temperature cycling to level out degradation curves.
4. Remote switching facilities to allow "end-to-end" system checks.
5. Special "Go - No Go" test equipment to allow system checks by unskilled personnel.

3. CONSTRUCTION AND MAINTENANCE (Cont'd)

3.6 Access

In planning the installation of any communication system in the North, major considerations must be given to:

1. Site accessibility.
2. Material transportation.
3. Personnel transportation.
4. Work stoppage or delays due to the above, or environmental conditions.

The vastness of the Canadian Northland provides for a complete range of terrain and environmental conditions. In some instances, even in very northern latitudes, road and motel availability make the undertaking very similar to jobs in normal, habitated areas and few, if any, special techniques are required.

In remote, "unserviced" regions one must differentiate between the problems which will be encountered in the area where work is planned. For instance, there is considerable difference between the eastern Arctic, with its ragged, inhospitable environment, compared to the central area where flying and ground conditions are easier.

With the advent of low power drainage equipment and the concept of isolated repeater stations, the need for roads and year-round maintenance is alleviated.

Access requirements, apart from initial equipment, would be a semi-annual or refuelling and equipment check visit.

As the average repeater package would consist of:

1. Equipment shelter
2. Fuel tanks
3. Tower and antenna

it is perfectly feasible to lift all material on site by use of helicopter. Costs of this operation would vary considerably, depending on how close to the actual site materials could be marshalled using lower cost transportation. In general, however, helicopter costs would be unlikely to exceed even temporary road costs.

3. CONSTRUCTION AND MAINTENANCE (Cont'd)

3.6 Access (Cont'd)

The accompanying Table B compares various methods of equipment transportation. In the initial planning stages, it would be necessary to analyze costs and other considerations to choose a method of placing all materials at a location suitable for helicopter shuttle.

Access to any remote northern site is dependent on weather conditions. Delays caused by blizzards, etc, are common to any mode of transportation. However, with ground transportation, even after the weather clears, there are further delays due to road conditions, drifts, etc.

Much weather data has been gathered for northern regions over the past decade; proper use of this information should allow elimination of most weather delay costs.

3. CONSTRUCTION AND MAINTENANCE (Cont'd)

TABLE B
TRANSPORTATION COMPARISON

Type	Cost	Advantages	Disadvantages
Boat or barge	Low	1. High Payload.	1. Requires suitable port or beach area. 2. Unloading problems, landing barge or helicopter. 3. Slow. 4. Can only be used in areas near sea or navigable rivers. 5. Navigational delays.
Fixed-wing aircraft	High	1. Medium to good payload 2. Can service most areas. 3. Possible close to sites service if lakes available. 4. Fast.	1. Weather delays. 2. Size limit to material.
Cat. train.	Med/ High	1. Good payload. 2. Possible direct on site service in some regions.	1. Slow. 2. Weather delays. 3. High degree of planning.
Wheeled vehicles Track vehicles	Low	1. Cheap mobility in areas where practical.	1. Poor payload. 2. Basic road requirement. 3. High maintenance. 4. Very limited range. 5. Weather delays.
Helicopter.	High	1. Fast 2. Direct site access. 3. Fast personnel emergency movement 4. Use in erection.	1. Poor payload. 2. Weather delays. 3. Size limit to material.

4. CONCLUSIONS

Radio Relay systems will be utilized in the development of the North, particularly to interconnect location with a significant common interest, and also to extend systems connecting with the southern telecommunications networks. They will be used in combination with HF, Troposcatter and Satellite systems, depending on the relative cost and type of fidelity and reliability required.

Through carefull engineering, light and medium route systems can be designed specifically adapted to the special Northern conditions at substantially reduced initial and operating costs, compared to systems that have been installed in the past.

COMMENTS ON THE PAPER

FROM D.J. HADLEY

on

COMMUNICATIONS IN THE CANADIAN NORTH

RADIO RELAY SYSTEM

by

G. P. LOCKHART

1. Mr. Hadley presents very clearly many of the problems associated with communications in northern areas.

2. In item 1.3.1 i5 is suggested that Satellite systems may be priced comparably with HF systems. This is not our understanding. The budgetary price of a typical two-way Arctic-type earth station is believed to be in excess of $250,000. For this reason we are not proposing to construct earth stations in Northern B.C. to carry telephone traffic. It is our intention to continue to use our HF/VHF network, and to expand our microwave systems as the area develops.

3. B.C. Telephone is also using the portable trailer concept (outlined in sections 2.1 and 3.2) for radio repeaters. This permits radio and power equipment to be installed and tested prior to the package being moved to the site. The concept appears to work well with non-TWT microwave equipment where the power drain is less than 50 watts per Tx-Rx bay. Propane-powered thermocouple units provide the necessary power up to about 350 watts.

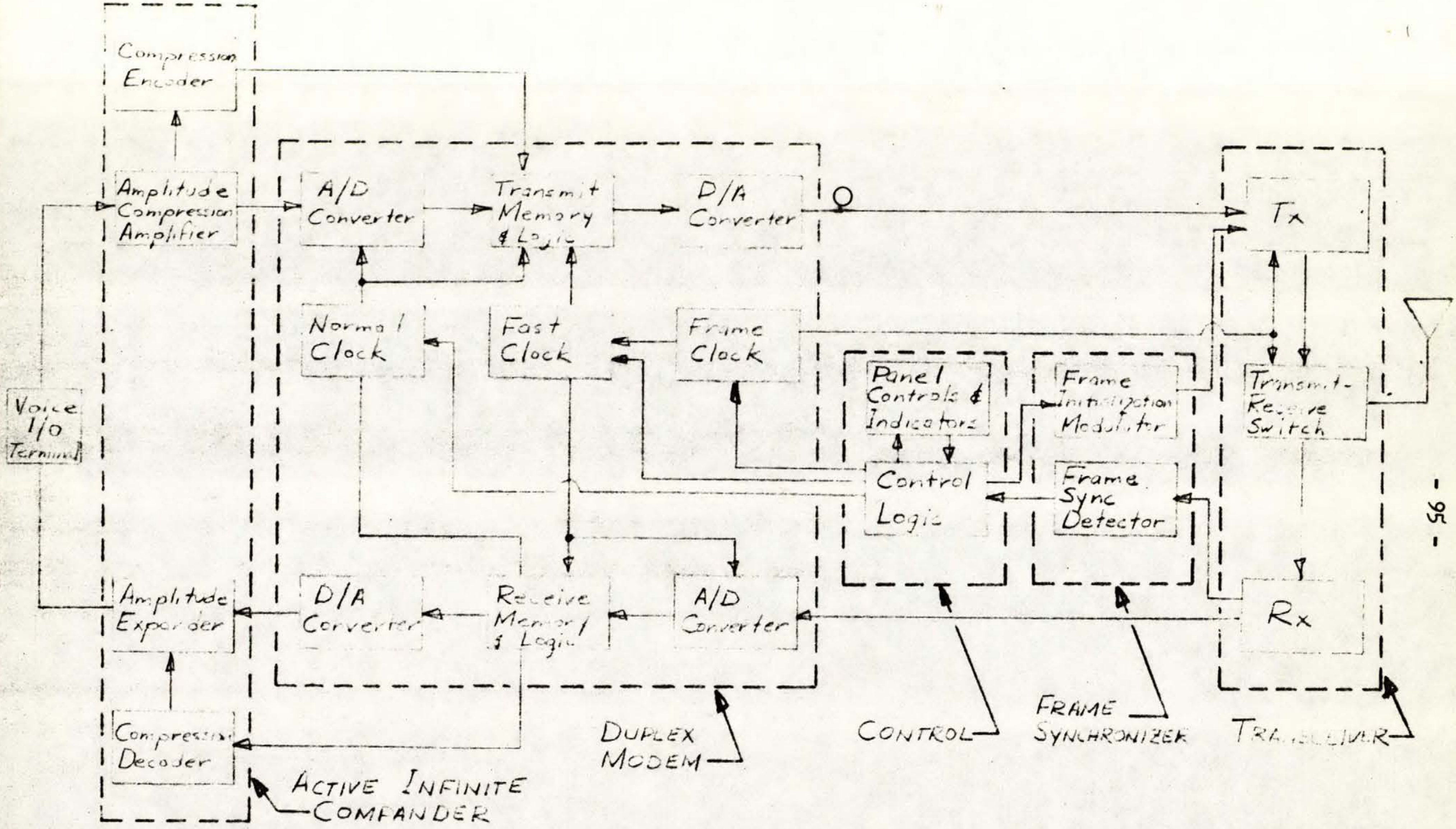
4. It has been our experience that low, rolling hills or flat plains require high towers, rather than the short towers suggested in Section 2.1.5, in order to provide Fresnel Zone clearance and in some cases to avoid near-end reflections. In mountainous areas, extremely high sites present added difficulties of icing, wind, and unreliable access.

5. We agree with the statement that the possibility of ISM interference into the 890-960 MHz band is negligible in remote areas and only slight in populated areas. Probably the major reason for past neglect of this band has been the lack (until recently) of suitable solid-state low power-drain radio equipment.

6. The report suggests in item 2.2.1.5 that in some circumstances systems can be operated in the 1710-1900 MHz band over diffracted paths. BCT engineering practice has always assumed that normal microwave clearance criteria apply down to and including this band. It would be very interesting to obtain any reports or test results on signal strengths and system performance on diffracted paths in this band.

7. The 7125-7725 MHz band should also be considered for point-to-point light and medium capacity systems in the Canadian North. The major advantage of this band is that passive reflectors can be utilized. It is expected that low-cost low power-drain microwave equipment will be developed to meet the DOC's new plan (SRSP 305) for 12-120 channel systems operating in this band.

8. The section on reliability does not consider the effects of frequency-diversity or space-diversity techniques to reduce the effects of multipath fading. B.C. Telephone has found that both methods provide considerable protection against multipath-type fading on two-channel microwave links equipped with 1:1 baseband combiner systems.



BLOCK DIAGRAM OF AN HF TRANSCEIVER PROVIDING A FULL DUPLEX VOICE CIRCUIT AND ACTIVE COMPANDING BY USING A TIME-SHARE TECHNIQUE

FIGURE 1

TROPOSPHERIC RADIO SYSTEMS

by

D. A. Wright

TROPOSPHERIC-SCATTER SYSTEMS

by

D. Wright

1. Introduction

Tropospheric-scatter radio-relay systems operate at carrier frequencies above about 250 Mc/s and make use of the scattering of radio waves by fluctuations in the refractive index of the troposphere. The purpose of this chapter is to outline briefly how the characteristics of this phenomenon influence the design of equipment.

2. Characteristics of tropospheric-scatter propagation

2.1 Basic transmission-loss

The attenuation of a tropospheric-scatter path may be discussed in terms of a basic transmission-loss, defined as the attenuation of signal power between isotropic transmitting and receiving antennae at the locations of the real antennae at the ends of the path.

$$L_b = 10 \log_{10} (P_t/P_a) \quad \text{db}$$

where L_b is the basic transmission-loss,

P_t is the radiated power from the isotropic transmitting antenna.

P_a is the available power from the isotropic receiving antenna.

2.2 Scattering mechanism

The refractive index of air, and its refractive modulus N, is defined by:

$$N = (n-1) \times 10^6$$

where n is the refractive index, which varies with density, temperature and humidity. Air movement and the mixing of air with different temperatures and humidities cause a continually changing pattern of N in the troposphere. When a radio signal of suitable frequency is beamed beyond the horizon, the vertical gradient of N, ΔN, causes the beam to bend towards the earth, and the space and time fluctuations of N cause energy to be scattered out of the beam. If a high gain receiving antenna is directed so that the main lobe of its radiation pattern intersects the transmitted beam it receives a signal characterized by:

- rapid fluctuations in amplitude and phase arising from the scattering process, in effect the received signal consists of the sum of a large number of elementary signals arriving with various and changing phases;
- slower changes in mean power caused by changes in the mean parameters of the troposphere.

The basic transmission-loss thus has a rapidly varying component and the median loss considèred for periods of even a year varies from one period to the next. Calculations of transmission loss predict a long-term median value and the statistics of the variations in median values for shorter periods.

2.3 Median value of transmission loss

Several methods for predicting long-term median values of the transmission loss have been published. The reliability of prediction is generally not better than a few db because the state of the troposphere on any specific path is not known precisely and can be dealt with in terms of only broad averages. Occasionally prediction errors may be as high as 10 to 15 db. Typical tropospheric-scatter links have long-term median path losses in the range 180 - 240 db.

Some of the parameters that influence the long-term median path loss are as follows: (The influence of each parameter depends upon the values of the others - the values given represent only useful approximations).

Distance. The transmission loss is proportional to the cube of the length of the path.

Frequency. The transmission loss is proportional to the cube of the frequency. If the size of the antenna is kept constant, the loss between the feed points of the transmitting and receiving antennae varies approximately linearly with frequency.

Angle of scatter. The angle of intersection of the beams from the transmitting and receiving antennae. The transmission loss is proportional to the fourth to fifth power of the angle of scatter.

Refractive modulus, N. The transmission loss decreases with increasing N and with increasing N. Stratified irregularities in N caused by temperature inversions can cause "ducting" in which the transmission loss can fall almost to the free space value.

Antennae Foreground. The effective height of an antenna depends upon the topography between the antenna and the radio horizon. A reflective foreground can decrease the transmission loss several db relative to that experienced with an absorptive foreground.

2.4 Fading

When the long-term median value of the transmission loss is established, it is convenient to deal with the fluctuations in terms of the fading of a received signal relative to the long-term median value of the signal.

2.4.1 Rapid fading

The rapid component of fading, examined over a period short enough to exclude changes in the mean parameters of the troposphere, has a Rayleigh distribution of amplitdues or at times a Rayleigh distribution plus a constant component. The power spectrum of the fading pattern usually has a quite pronounced peak, which may at times lie anywhere between a small fraction of 1 c/s and several cycles per second, often with low level components extending into the tens of cycles per second. The mean fading rate tends to increase with frequency. The phase angle of the received carrier relative to the transmitted carrier has essentially random fluctuations over many radians at rates similar to the fading rates.

2.4.2 Slow Fading

Hourly median values of signals have an approximately log-normal distribution, that is, the distribution is Gaussian when the signal power is expressed in db relative to an arbitrary reference, with standard deviations ranging from 4 to 12 db. Where the weather or climate has cyclic variations, the received signal has corresponding cyclic components of fading. A diurnal cycle is often noticeable in the fading pattern and, in the temperate zones, the highest monthly median value, usually occurring in late summer may be as much as 10 or more db above the lowest monthly median value, usually occurring in late winter.

Ducting can cause signals to rise to 60 to 70 db above the median value for hours at a time, usually with a reduction of the rapid fluctuations. Where ducting is quite frequent the distribution of hourly medians tends to be skew.

2.4.3 Total fading

The received signal in a tropospheric-scatter path may, during rapid fades, vary from as much as 60 db below the yearly median value of the signal to 60 to 70 db above the yearly median value of the signal during pronounced ducting.

3. Effect on the design of equipment

3.1 General

Tropospheric-scatter equipment is basically similar to line-of-sight radio-relay equipment, but it has some important differences which are necessary to counteract the high median value of the path transmission-loss and the very wide range of received signal powers. Achieving communication over tropospheric-scatter paths is quite close to the practical limit of technique, where the cost per decibel of improvement in performance rises rapidly. Tropospheric-scatter links tend to be designed with little margin and the trend has been to make the equipment flexible, so that it could be adapted to each situation in such a way as to get the required performance at minimum cost.

Tropospheric-scatter equipment is characterized by the use of:

- diversity reception to reduce the effects of rapid fading,
- high antenna gain, high transmitter power and low receiver noise to counteract the high transmission loss,
- threshold reduction techniques to lower the FM threshold and thus to reduce noise "swishes" caused by momentary fading below threshold.

3.2 Diversity

3.2.1 Antenna arrangements

In a plane normal to the direction of reception a scattered signal has large variations in amplitude and phase and these fluctuate rapidly in time. Antennae separated by at least 50 wavelengths between centres in this plane pick up signals with a correlation of rapid fading low enough (less than about 0.4) to give effective diversity reception. The correlation between slow fading patterns is high because the signals are subjected to the same average conditions in the troposphere and diversity is not effective against slow fading. Typical arrangements of antennae for dual and quadruple space diversity are shown in Fig. 1(a) and 1(b).

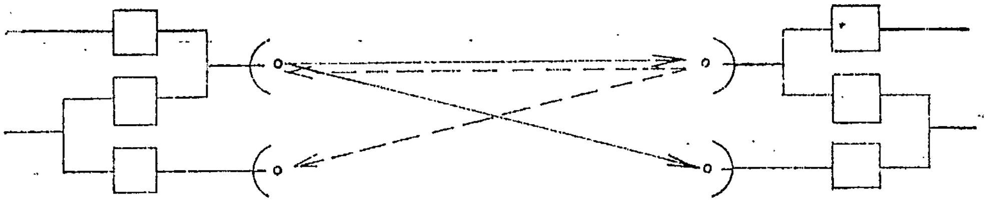


Fig. 1(a) : Dual space-diversity

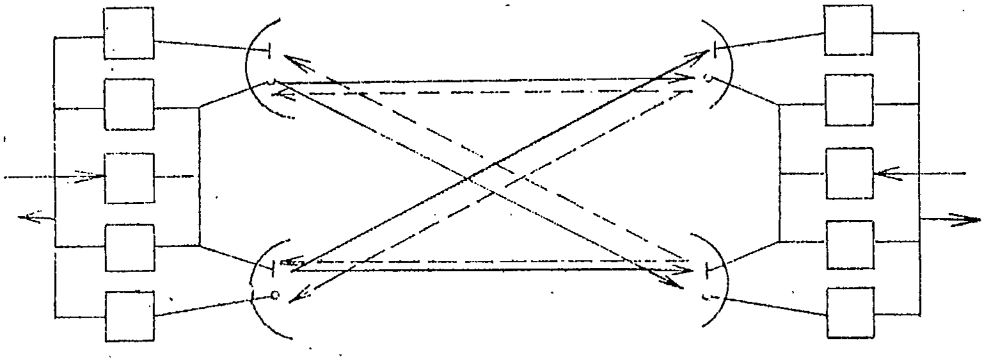


Fig. 1(b) : Quadruple space-diversity

——— : f_1

– – – – : f_2

The correlation between signals of different polarity received by the same antenna from one transmitting antenna is too high for polarization diversity itself to be useful. However, cross-polorization is often used to separate the signals received via different routes through the troposphere as in Fig. 1(b).

Frequency diversity is possible but is generally not used because it represents inefficient use of the spectrum.

Angle diversity is a form of space diversity using several feeds in one reflector to produce main lobes displaced from the reflector axis in different directions. The arrangement for dual angle diversity is shown in Fig. 2.

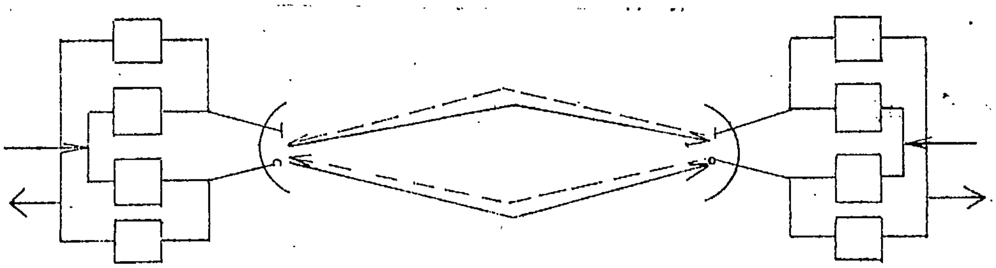


Fig. 2 : Dual angle-diversity

This arrangement saves one reflector at each terminal, but the angles of scatter of the various beams are larger than the angle of scatter would be for beams aligned with the axes of the reflectors.

The reliability of a link using frequency-modulation (FM) is usually taken as the fraction of time the carrier is above the FM threshold. The potential reliability of a link with n-fold diversity is approximately:

$$R_n = 1 - (1-R_1)^n$$

where R_1 is the reliability of any one carrier, and the correlation between fading of the n carriers is sufficiently small. R_n is the probability that at least one carrier will be above the FM threshold.

The potential improvement in reliability due to diversity reception could be obtained by using a switching arrangement to select the signal with the best carrier-to-noise ratio. However, a further improvement in average signal-to-noise ratio can be obtained by combining the diversity signals in a suitable fashion and this is customary.

3.2.2 Combining

It has been shown that the signal-to-noise ratio is a maximum when each diversity signal is multiplied by its signal-to-noise ratio and the resulting signals are added linearly, the so-called "ratio-squared" combining. A slightly less effective, but simpler method, is equal-gain combining, in which the receivers have equal gain, usually controlled by a common automatic gain control, thereby equalizing the noise on the signals before addition.

Combining may be done at intermediate-frequency (pre-detection) or at baseband (post-detection). In combining at intermediate-frequency, the carriers have to be brought into phase alignment before adding them together and this is done by controlling the local oscillator frequencies by the outputs of phase comparators. Usually a common automatic gain control adjusts the gains of the intermediate-frequency amplifiers according to that of the amplifier carrying the strongest signal, giving equal-gain combining.

In combining at baseband the receivers contain circuitry by which their output impedances may be varied, for instance a biassed diode-bridge or a cathode follower, and the outputs of several receivers are connected together. In each receiver, noise is monitored, usually in a band above the occupied part of the baseband. It is rectified, filtered and used to control the output impedance. The combining characteristic may be made close to that of a ratio-squarer by shaping the transfer characteristic of the noise amplifier in conjunction with the control characteristic of the impedance controlling element.

In practice, a high gain stability and freedom from transients in combining tend to be more important than the theoretical advantages and disadvantages of "ratio-squared" as compared with "equal-gain", or "pre-detection" as compared with "post-detection" combining.

3.3 Antenna gain

A scattered signal has fluctuations both in space and time in the plane of the aperture of a receiving antenna. An antenna with an aperture small compared to the scale of the fluctuations will intercept a signal with its components essentially co-phased and will realize approximately its plane wave gain. As the aperture is increased in size the range of the phases of elementary signals that it intercepts and adds at any instant increases and the mean gain falls short of the plane-wave for that size.

This gain defect, sometimes called "aperture-to-medium coupling loss "depends upon the range of delay possible for significant elements of signal. Thus it depends primarily upon the sizes of both the transmitting and receiving antennae, on the frequency and on the angle of scatter.

Theoretical studies of this phenomenon show a mean gain defect increasing monotonically with receiving aperture size, other things being equal. Theoretical estimates of the gain defect in practical links show that it may be as high as 10 to 12 db for a particular transmitting-receiving antenna pair, and it would appear that combined transmitting and receiving antenna gains would seldom exceed 100 db.

However, there is some evidence to suggest that for very large apertures (large relative to the scale of phase fluctuations across its aperture), the loss of gain becomes constant as would be expected when the phases of elementary signals became essentially random across the aperture. It is apparent that further work is needed on this aspect of the prediction of transmission loss.

3.4 Transmitter power

Transmitter power, which was originally limited by the availability of suitable tubes is now limited more by economics and by the technical problems of handling high continuous wave power at SHF. Powers of 50 kW and more have been used at frequencies around 400 Mc/s. At frequencies above 2 Gc/s the problems in handling high power increase rapidly. At 5 Gc/s for instance, burnished copper waveguide can have a temperature rise of 90°C in free air at 8 kW and waveguide components such as filters have to be designed to avoid local "hot spots" which can cause ionization and subsequent arcing. At 6500 Mc/s this problem is considerable at about 4 kW.

Although lives of 30,000 hours are not uncommon for power amplifier tubes, the cost of primary power and of replacement tubes are a substantial portion of the operating cost which is significant in commercial operation.

The need to minimize the interference potential of high radiated power is important but it has not so far been a limitation on the power used.

3.5 Receiver noise

Every decibel of reduction of system-noise produces a corresponding improvement in the output signal-to-noise ratio. It also makes a corresponding reduction in the FM threshold which makes a substantial improvement in reliability when deversity is used.

Tropospheric-scatter receivers are designed to have less front-end noise than line-of-sight receivers. For instance, a typical noise figure for a 5 Gc/s receiver with a mixer input is 9 db including the loss in a five-section input filter. With a parametric amplifier the corresponding noise figure is 4 db. At 1 Gc/s, a typical receiver with a parametric amplifier has a noise figure of about 1.5 db.

Since a tropospheric-scatter antenna is always directed at the horizon it receives noise from the surface of the earth at a temperature of nominally 290°K (N.F. = 0 db), or less if the foreground is reflective. The minimum possible system noise-temperature is somewhat higher because of miscellaneous losses. As the receiver noise figure or noise temperature is reduced the system noise temperature approaches the minimum asymptotically. The receiver noise-temperature or noise figure is usually not reduced below the point at which the cost per decibel of improvement in system noise is similar to the cost of getting the improvement in performance by other means.

3.6 Threshold reduction

In a conventional FM receiver the FM threshold occurs at a carrier-to-noise ratio of approximately 10 db. The noise power and hence the FM threshold level is proportional to the bandwidth of the receiver, which must be great enough to pass the FM signal with low distortion. When the front-end noise has been added to the received carrier the deviation may be reduced by using phase-or frequency-feedback or frequency division. This reduces the phase component of noise in the same ratio as the deviation so the signal-to-noise ratio after demondulation is, to a first approximation, unchanged by the reduction in deviation, provided that the carrier is above the FM threshold. The reduced deviation permits the circuit bandwidth to be reduced, thus reducing the amplitude component of noise at the demodulation input and reducing the FM threshold.

A mathematical treatment of FM threshold under these conditions is extremely difficult. A number of partial analyses have been published and provide valuable design guidance. However, the theory has not yet progressed far enough to provide consistent prediction of threshold reduction and an assured optimization of parameters.

3.7 Other factors

3.7.1 The large disparity between transmitter power and receiver sensitivity, which may be of the order of 170 db, requires about 60 db more noise isolation between transmitter output and receivers in one terminal than is necessary in line-of-sight radio-relay equipment. This is achieved partly by using larger receiver and transmitter filters and partly by using greater frequency separation. It is also sometimes necessary to use additional filtering in the transmitter output to suppress the transmitter noise spectrum at the receive frequency when a transmitter and receiver are duplexed on one antenna feed.

3.7.2 The power disparity also prevents using the same pair of frequencies for a radio-frequency channel in two adjacent links because antenna front-to-back gain ratios are not large enough to prevent over-reach interference. In general the same pair of frequencies can be used in different links of a system only if the separation and orientation of the links preclude the possibility of over-reach interference, allowing for ducting.

3.7.3 When the difference in transmission delay between different signal components is a substantial fraction of a period at the top baseband frequency, the baseband frequency and phase responses will show fluctuations at the upper end. The baseband frequency at which this fluctuation becomes perceptible depends upon the radio-frequency, size of antenna, path length and angle of scatter. In a typical case involving a 215 km path, a frequency of 4700 Mc/s and antennae 10m in diameter with guadruple diversity, baseband amplitude response fluctuations were just perceptible at 1.5 Mc/s and increased to about 6 db at 3.5 Mc/s. This effect limits the baseband capacity of a tropospheric-scatter system for multi-channel telephony. However, the high frequency perturbation was not noticeable in the picture in television in the example cited.

3.7.4 Tropospheric-scatter receivers should have a wide dynamic range. In regions where ducting may occur for a significant fraction of time, the dynamic range should be at least 100 db. Most demodulators will not maintain good performance over a wide range of applied signal level. An effective automatic gain control serves to keep signal powers in various parts of the receivers within the limits for good performance.

CHAPTER IV

TROPOSPHERIC SCATTER NOTE

by

G. Peterkin

TROPOSPHERIC SCATTER NOTE

by

G. Peterkin

Beyond the horizon tropospheric radio has developed over the last fifteen years into a highly successful radio communication system which offers certain advantages not possessed by other types of systems.

Scatter provides a high grade multi-channel service over distances between 70 and 600 miles in a single span, thus reducing the number of stations or terminals required in a line-of-sight system.

With a properly designed system, it will offer a circuit of high propagational reliability on a year round basis.

It can be utilized in rugged or otherwise inhospitable terrain where it is impractical or impossible to provide other means of communication.

It provides a high degree of spectrum utilization while simultaneously minimizing frequency allocation problems incident to radio interference in a high density location.

It offers a relatively high degree of security as compared with other methods of communications.

New techniques permit new tropospheric scatter systems to carry speech, telegraph, high speed digital data (50 KB/S), facsimile, telephotography and other pulse types of information. With a well designed system a total channel capacity can reach 252 channels with a top baseband frequency of 1052 MHz.

Existing systems have a varying degree of usefulness in the Commercial field, due to the design capacity of the system, older types of equipment and few multiplex breakouts. To be financially attractive a system has to have adequate capacity to produce revenues which will provide an adequate return on capital investment, and maintenance funds. Where multiplex breakouts exist and a new spur route, e.g. VHF, is to be added, a capital investment of approximately $100,000 would be required. If a multiplex breakout and a wireline entrance link is to be added, an additional expense of approximately $60,000 would be incurred.

In the years ahead tropo will probably provide links between short range and long range communications in the North. It will probably complement satellite communication rather than compete with this new technology. Numerous feeder systems will be needed where other means are impracticable, and where reliability and security is required.

NOTE: Information taken from Tropospheric Scatter Communications by Frank A. Gunther

EXISTING SYSTEMS

TITLE	No. of Tropo Spans	Total Systems Length	System Freq. Band MHz	Present Voice Chan. Capacity	Ultimate Voice Chan. Capacity
(U.S.A.F.) Dew Line	29	2695	900	24	-
(CNT) Hay River	3	640	2000	26	72
(U.S.A.F.) Pole Vault (North)	5	955	900	108	132
(Bell Canada) Pole Vault (South)	2	325	600	47	48
(Bell Canada) Quebec, Labrador	4	470	900	204	252
(U.S.A.F.) Thule Fox	1	590	400	12	72