Communications Research Centre

IONOSPHERIC SOUNDING AS AN AID TO HF COMMUNICATIONS

by

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ABSTRACT

A review of sounding systems that could be used to improve HF communications is presented. Systems that are outlined are the sophisticated CURTS, which was developed for the U.S. Defence Communications Systems; CHEC and Channelsonde which were designed to aid Canadian military operations; and the integrated system that was proposed as a solution to communications problems in the Canadian north. From a consideration of these systems, it is apparent that the technology exists for developing sounding systems for a wide variety of applications.

1. INTRODUCTION

Most of the techniques used to improve the quality of HF communications are concerned with upgrading the system's performance under poor channel conditions. Methods generally employed are of the following types: improved antenna design, increased transmitter power, 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 the level that might be obtained, largely because of the problem of choosing a usable channel on which to operate. It has been demonstrated in several of the references quoted that communications can be improved substantially with the aid of ionospheric sounding in the selection of channels.

The problem of usable frequencies (or channels) has two aspects, namely, frequency assignment and frequency selection. The present system of frequency assignment does not make efficient use of the radio spectrum. Frequencies are assigned to a specific agency for a specific circuit or group of circuits to the exclusion of all other users. If a frequency is not used or even usable for the service assigned, it is generally not available to another agency lacking an appropriate frequency. Most users are restricted to a limited number of frequencies, both by assigning and by equipment limitations. If enough frequencies were pooled, sounding could aid in better spectrum management by providing information for assigning frequencies as and when required.

Sounding can also be very effective as an aid to selection of usable channels. 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 of maximum usable frequencies about the median and, to make most effective use of the ionosphere as a 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 by sampling the signal and interference and noise on a channel and then rating performance on a signal-to-noise basis. Such systems should be 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. 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 of 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]. In addition backscatter systems will be limited in use by the high powers required which result in costly installations and excessive interference.

1.1.3 Oblique Sounding[1,2]

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 with varying degrees of complexity have been proposed and developed to aid in real-time frequency selection. The information of prime importance that can be provided is the signal strength of radio waves on frequencies that can be supported on that circuit at a given time. A knowledge of the noise and interference levels 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 intelligence e.g., fading, and time and frequency dispersion. 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 feasible and economically attractive 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 with the intention of indicating the potential use of sounding systems and the present stage of development.

2. 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.

The basis of the CURTS system is a network of oblique ionospheric sounders with a transmitter at each major node 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 sounded 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 history tape and then added to that tape for use on following days at the same time. Measurements were also made of the time dispersion (multipath delay), frequency dispersion, and the background noise and interference on each of the assigned frequencies. The computer then evaluated each assigned frequency for possible interchannel interference. The computer logic also made use of ionospheric predictions, and forecasts of disturbances in assessing the frequencies. A quality figure based on the binary error rate (BER) was assigned to each frequency by the computer which then ranked the frequencies in descending order of quality figures, and transmitted them via teletype to the stations to aid in frequency selection.

From the test network the feasibility of the CURTS system was confirmed and several advantages were demonstrated. The system was shown to be capable of choosing the best frequencies in environments of poor propagation, high interference or both. Various measures of the degree of improvement have been given and, as an example, 98 per cent of the frequency changes resulted in immediately acceptable traffic compared with 70 per cent 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 extent 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 identified.

The conclusion was drawn that with the CURTS system 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. It was also concluded that forward error correction techniques could possibly be used to advantage when a poor quality channel had to be used but would not further reduce the error rate when the frequencies were selected by the CURTS system.

Over 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. 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[15] 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 proposed 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 effectiveness of sounding has been verified. Some systems which have been tested, as well as a system which has been proposed specifically for the Canadian north, will be described briefly.

3.1 THE CHEC SYSTEM[16,17]

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 and encoding the ground interference levels which were transmitted via the stepped-frequency sounding transmitter. Both air and ground units were maintained in time and frequency synchronism by internal, crystal-controlled clocks.

The system was evaluated during a series of flights over the North Atlantic by 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 two minutes. In the sounding process, the interference level at the receiving site (GIL) on a specific frequency was first 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 preset level. To improve the system, 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 further 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 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 encoded 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 2800 km 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. High circuit reliability was attained. Over a six-weeks trial, the average circuit performance achieved with sounding-aided operations was 94.6 per cent compared with a potential performance of 98.6 per cent. The discrepancy was mainly due to time required for frequency changes and equipment malfunctions. The results of this test demonstrated that the performance of an HF circuit can be very good if it is properly designed and operated.

3.2 CHANNELSONDE

Another patented system,[19] 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.

4. ADVANTAGES OF SOUNDING

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 may be recognized as such and thus equipment failures 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.

Sounding should be particularly advantageous for mid- and northern Canada where communications are carried on under conditions of a very irregular ionosphere. Difficulties in communications 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. PROPOSED SYSTEM FOR NORTHERN CANADA

From current surveys of the requirements for communications in the remote areas of Canada, it would appear that a satisfactory solution could be an HF system that could 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[20]. Details of the whole system will not be included here, only a brief account of the HF operation.

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.

5.1 SYSTEMS OPERATION

In the proposed system the north of Canada would be divided into communication zones approximately 500 miles in diameter with a centralized control in each zone. A complement of frequencies would be assigned to each region and would then be selected for use by a computer at the control centre on the basis of information derived from vertical incidence sounding and both noise and interference measurements. The control centre would be connected with national trunk systems and local exchanges. As far as the user is concerned, the system would operate with a simple procedure little different from that of a standard telephone.

Communications within the HF system is illustrated by referring to Figure 1. Any subscriber can call any other subscriber by direct dialing. Suppose a subscriber A at terminal 231 wishes to call B at terminal 242. Subscriber A picks up the handset, listens for a dial tone and dials 242. When he has finished dialing, local HF station 23 automatically sends a signal to control centre R2 with the information that 231 is calling 242. This signal is sent successively on each of about four 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. Station 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. Station 24 changes to f_c to receive the call. Stations 23 and 24 make local connections to 231 and 242. When subscriber 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.

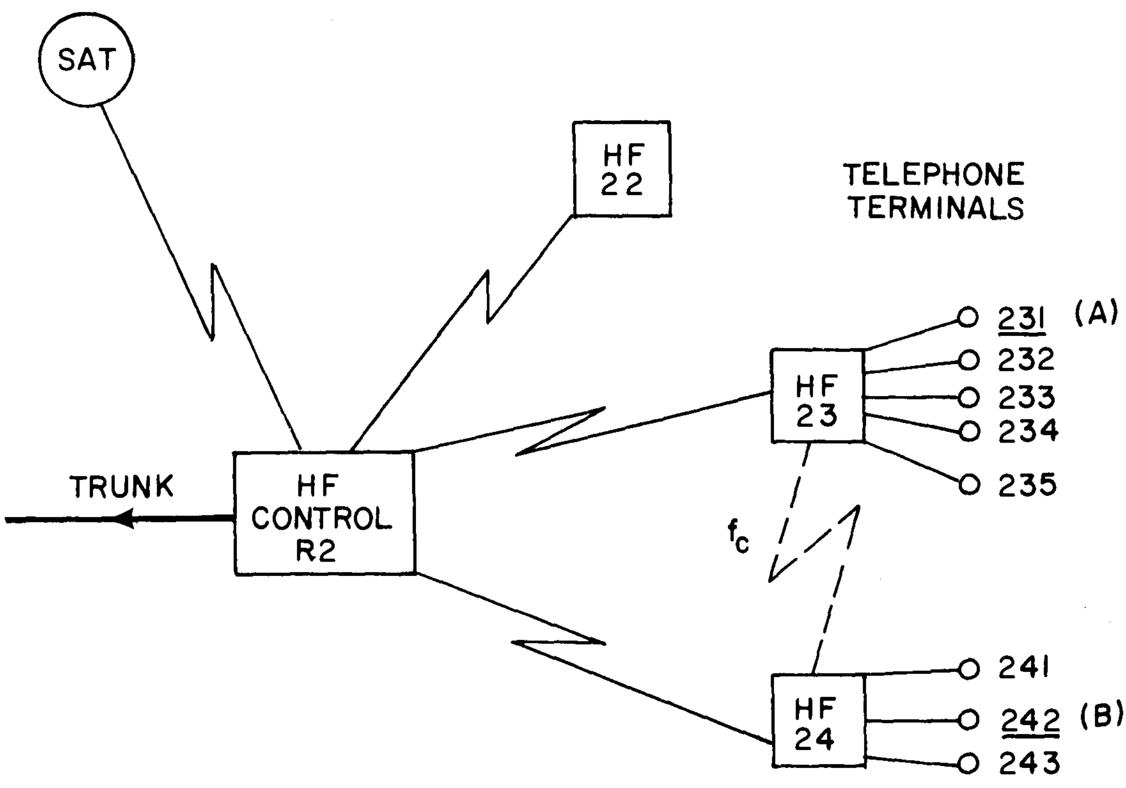

FIGURE 1

5.2 ADVANTAGES

Advantages of this particular system are considered to be:

(a) All the advantages of prediction and sounding techniques (see Section 4).

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

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

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

6. SUMMARY

In this report, several schemes have been outlined for the utilization of sounding as an aid to HF communications. Each system was designed for a specific application. They varied in complexity from the relatively simple channelsonde to the sophisticated CURTS system. Using the technology that has already been developed, reliable systems could be designed for a wide variety of applications.

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