Communications Research Centre

RACE – AN AUTOMATIC HIGH FREQUENCY RADIO TELEPHONE SYSTEM FOR COMMUNICATIONS IN REMOTE AREAS

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S.M. CHOW, G.W. IRVINE AND B. McLARNON

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ABSTRACT

A high frequency (HF) radiotelephone system offering enhanced performance compared to that of existing systems is described. The enhancements include real-time channel evaluation and the capability of interfacing to existing telephone systems without the need for operators. Results of preliminary on-the-air field trials indicate that the new system is reliable and exceptionally easy to use.

1. INTRODUCTION

This report describes a radiotelephone system known as RACE (Radiotelephone with Automatic Channel Evaluation), which has been designed to provide reliable economical communications to residents of remote areas of Canada. The Department of Communications (DOC) initiated this project in response to a Cabinet directive which called for the improvement of services available to residents of remote areas.

System parameters such as capacity, reliability, and cost were based on information obtained in a series of interviews involving DOC engineers, potential users and common carriers serving the remote areas. These interviews were instigated by DOC to ensure that features needed to satisfy the special requirements of the Canadian North were incorporated.

It was determined early on in the program that HF radio had an important part to play in this system because of its capability to span long distances and its low cost. It was also recognized that the HF portion of the system must be capable of coping with the inherent variability of the ionosphere which made selection of appropriate frequencies difficult even with a skilled operator.

The result of this development is an HF radiotelephone system which can be connected to a switched telephone system at one or both ends on a fully automatic basis; no operator is required. Reliability is greatly enhanced by automatic real-time channel evaluation, implemented with microprocessors, to select the best available frequency.

The developments described were initially intended for application in remote communities of Northern Canada and shipping in Canada's coastal waters. However, there appear to be many similar requirements in the rural areas of developing countries[1]. In a related development, a new voice processing system has resulted from efforts to improve the voice quality obtainable on an HF/SSB circuit. This system, called Syncompex, is a linked compandor implemented using digital techniques, and was designed to be a less expensive alternative to the well-known Lincompex system[2]. Although it plays an important role in the new radiotelephone system, the Syncompex system is a separate entity and could be added to existing HF links. This development is described more fully in a companion report[3].

An experimental three-station HF network has been constructed and has undergone field trials in eastern Canada. No interconnection to existing telephone networks was available for these trials. Upon completion of this phase, the system will be deployed in British Columbia. Interconnection to the Trans Canada System will then be carried out and evaluated.

2. BACKGROUND

High Frequency radio has been used for decades to provide long distance telecommunications via ionospheric modes of propagation. However, the variability of the ionosphere and high levels of background radio noise have made HF radio less than satisfactory as an adjunct of a telephone system. Experience in northern Canada has shown that skilled operators are required to achieve circuit reliabilities approaching 70 percent. The ionosphere is dynamic in nature, requiring the operator to effect frequency changes to accommodate the predictable components of ionospheric variation (diurnal and seasonal) as well as the unpredictable variations due to solar activity. This is frequently beyond the ability of radio operators. In areas in which skilled operators are not available, the level of success may be considerably less than 70 percent. In some systems where HF radio is interconnected with the telephone system, operators have been required to operate transmit/receive switches according to the content of the users' conversation, which the operators had to monitor. The circuit interconnection itself is often a manual process because of difficulties in accommodating conventional telephone dialling and supervisory signalling over the HF radio path. Equipment reliability has frequently been less than satisfactory because of the dependence on obsolete technology to obtain the kilowatt power levels sometimes considered necessary to overcome poor propagation conditions. The combined effect of these and other difficulties has resulted in the general abandonment of efforts to improve HF radio performance in favour of newer communications techniques such as satellite radio relay.

Although techniques for solving many of the problems associated with HF radio systems have been known for many years, the expense involved in their implementation and maintenance has generally precluded their use. The advent of modern integrated circuit technology, however, has changed this situation considerably; the result is the system described below.

3. SYSTEM CHARACTERISTICS

As indicated above, the thrust of the DOC sponsored development project is to produce an improved HF radiotelephone system that can be directly and automatically interconnected with the domestic telephone system. Specific characteristics that the new system offers are:

a) a probability of circuit availability exceeding 90%.

b) a high level of equipment reliability to minimize the need for preventive maintenance or spare installations.

c) automated operation to eliminate the need for highly skilled operators.

d) direct dial access to and from conventional telephone systems.

e) noise reduction and improved speech quality.

f) relatively low cost for civilian users.

Circuit availability is maximised through the proven concept of real-time channel evaluation. This is achieved through use of frequency agile transceivers coupled to wide band antennas, and rapid testing of the radio circuit on each of the available frequencies to ensure that the best one is chosen for the subsequent call. Microprocessor control of the channel evaluation process permits fully automatic operation, thereby eliminating the need for an operator and facilitating automatic interconnection with a telephone system. Real-time channel evaluation represents a step beyond frequency prediction programs because prediction cannot account for factors such as ionospheric disturbances and interference from distant stations. These factors have a strong influence on the selection of a frequency channel.

Noise reduction and speech quality improvement are provided by the Syncompex system, referred to earlier. All of these features together greatly facilitate the problem of interconnecting an HF/SSB simplex radio link to a conventional telephone circuit. The Syncompex system has been tested as a separate entity up to now, but will be incorporated in the HF system at a later date.

4. SYSTEM OPERATION

The three-station experimental system deployed in eastern Canada during the spring of 1980 is depicted in Figure 1. Two types of remote station are shown, one having a single telephone, and the other interconnected to a small PABX switch in order to serve a larger community. Since the master station would normally be located in a larger community, it was also provided with a PABX switch. This switch could be eliminated if not required to service subscribers in the vicinity of the master station; its presence is not required in order to interface the HF radiotelephone to the switched network. In order to demonstrate the capability of extending access to an HF terminal by means other than metallic conductors, a low power 450 MHz voice link was connected to one port of the switch. A VHF or UHF carrier system such as this could just as easily be connected to a remote station for extended area coverage.

All subscribers in the system are assigned seven digit numbers according to the standard numbering plan; however, abbreviated (three digit) dialling is used for calls within the HF network. An access digit is used to differentiate these calls from those destined for the DDD network.

When no calls are taking place in the system, the master station continuously cycles through the assigned channels (eight in the experimental system), transmitting a short digital message on each one. The remote stations synchronize themselves to the master station and maintain short-term statistics on the quality of the channels, derived from an examination of the integrity of the received data. The quality assessment is partly based upon detection of bit errors by means of error detection coding in the data. In addition, a "pseudo-error" measurement technique[4] is used to refine the selection process when several channels have similar error rates.

When a subscriber dials a number requiring the HF network, the master station and the appropriate remote station begin a "handshaking" procedure and jump to the channel selected by the channel evaluation algorithm. If the procedure is successful, the voice paths are enabled and the usual telephone call progress tones are transmitted to the calling party. If the HF network is unavailable or the call setup procedure fails for some reason, a recorder tone is returned to the calling party as an indication that he should redial. When one party goes onhook at the end of a call, the HF station to which he is connected begins transmitting a digital "disconnect" message. This results in another brief "handshake" and the system is returned to the idle state.

In the case of a call from one remote station to another, the procedure begins as above, but the master station then stands by as the calling remote initiates a handshake with the called remote. When the call setup is complete, the master station returns to idle state and is available for other calls (the channel in use by the remotes is automatically busied out until that call is completed). The remote stations therefore communicate directly with one another during the call; this not only frees the master for other calls, but avoids the problems associated with operating two HF links in tandem.

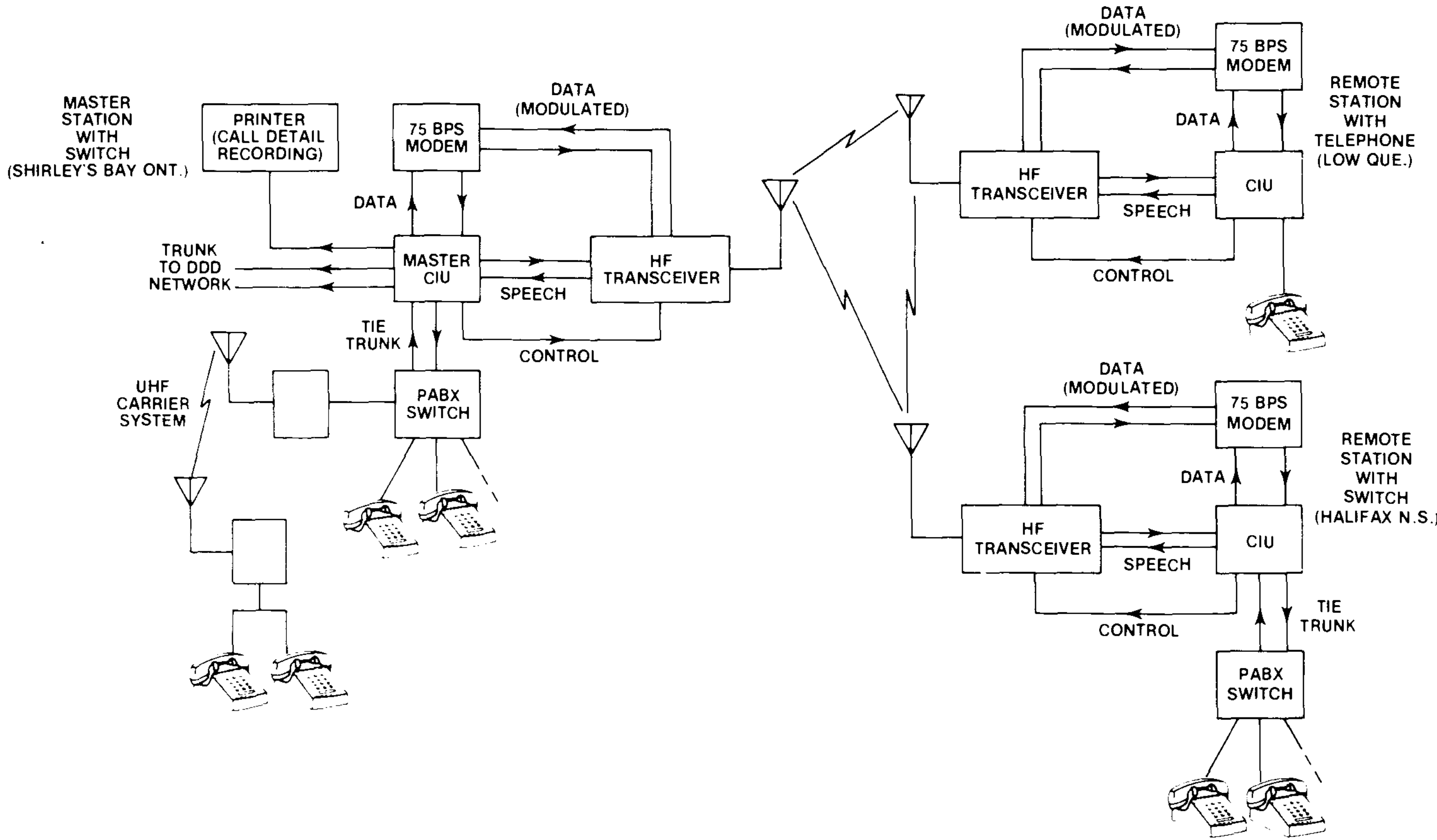

Figure 1. Block Diagram of Experimental System Deployment

5. SUB-SYSTEM CHARACTERISTICS

The experimental automatic HF station consists of an all-solid-state 100 watt HF/SSB transceiver, a broadband antenna, a 75 bps modem, and a controller/interface unit which provides the automatic functions and necessary interface characteristics for telephone compatibility. These system components will be described in detail in the remainder of this section.

5.1 THE HF/SSB TRANSCEIVER

A 100 watt HF/SSB transceiver has been developed for this project which has the capability of being controlled remotely by a microprocessor to operate in one of eight preselected frequency channels. Since that development, we have noted that several types of commercial transceivers can be easily modified to operate in the system. It is important to note that the reliability of the system is largely dependent upon the transceiver and that selection of an expensive but more reliable transceiver will often prove to be more cost-effective in the long run. Emergency service calls to rectify equipment failures in remote areas can be very expensive and involve long delays.

5.2 BROADBAND ANTENNA

Since the HF system changes frequencies quite rapidly (every two seconds at present) while in the idle state, the antenna must be capable of providing a good impedance match at each frequency without requiring a significant amount of time or operator intervention for returning. The frequency coverage required is quite large, typically three octaves. In addition, the antenna should provide, in many cases, approximately omni-directional coverage. The most satisfactory means of meeting this requirement is generally a broadband dipole or monopole type of antenna. Three different antennas falling into this category have been used in our field trials and have provided good results. In some cases, however, as in shipboard installations, space limitations preclude the use of such an antenna. It then becomes necessary to use a narrowband type of antenna (such as a vertical whip) together with a matching unit which has presettable tuning and rapid switching. We hope to evaluate the latter approach in future trials of the system.

5.3 MODEM

Interprocessor communication for control of the HF network is carried on by means of 75 bps modems at each station. The modems are standard asynchronous FSK units which have been modified for synchronous operation. In-band frequency diversity is used in order to improve the performance under selective fading conditions. When the Syncompex voice processor is included in the system, this modem can be eliminated, since the modem contained within the Syncompex unit can also be used for network control.

5.4 CONTROLLER/INTERFACE UNIT

The controller/interface unit (CIU) is a microprocessor-based system which provides the link between the telephone network and the HF radio network. The function of this unit include:

a) Generation and control of call progress tones.

b) Generation and reception of dialled digits (via DTMF signalling for individual telephones or PABX switches, and MF signalling for the trunk connection to the switched network).

c) Timekeeping and call detail recording.

d) Interface to HF modem for interstation communication on the HF network.

e) Control of HF radios: transmit/receive switching, channel selection, and mode (voice or data).

f) Two wire/four wire conversion for voice frequency paths.

g) HF channel evaluation.

The CIU is modular in nature, and is housed in a 7 1/2" x 19" rack-mount enclosure. The complement of circuit cards in a given unit depends upon the type of station (master or remote) and the type of telephone equipments to be interfaced. The CIU also contains a keypad and display to facilitate modifications and troubleshooting in the field.

6. TESTS AND EVALUATION

Tests of the experimental system were carried out using sites at Ottawa, Ontario; Low, Quebec and Hammonds Plains, Nova Scotia. These sites were selected because they include a short skywave path of about 60 kilometers and a medium range path of about 1000 kilometers. Eight frequencies between 3 and 21 MHz were chosen as a suitable complement of frequencies.

During the initial part of the experiment, all sites were manned for several test periods and calls were made at five minute intervals around the clock. Well over one thousand calls were completed, and it became apparent that the objective of 90% or better availability was achievable. In order to gather more accurate figures on system performance, a lengthy period of continuous operation was then begun. This operation took place during April, May and June of 1980. Since it was not feasible to man the stations for this length of time, printers were installed at the remote stations to log the data on the quality of the channel sounding transmissions received from the master station. From these data it was possible to deduce whether a call could have been completed at a given time, and to make an estimate of the quality of ensuing voice transmissions. It is also of interest to note how many of the eight channels are actually useful on each of the paths as a function of time.

In analyzing the channel quality data, two levels of performance were distinguished. The first, which we shall refer to as level 1, is reached when the bit error rate on the channel is sufficiently low that virtually all digital messages were received without errors. Such a channel generally offers very good voice communications. The criterion for level 2, on the other hand, is that approximately one-third or more of the messages are received without error. This level was arrived at empirically and corresponds roughly to the lower limit at which voice communications can be carried on without major difficulties. Several dialling attempts will often be required when the channel quality is near this lower limit.

The results of the on-the-air tests were as follows: level 1 quality on at least one channel was attained for 84.2% of the test period on the 60 km path, and 77.7% of the period on the 1000 km path; for level 2 quality, the figures were 99.9% and 98.3% respectively. In other words, one or more useable channels were available on both paths for virtually the entire test period.

Several comments on these statistics are in order. First, although disturbed propagation conditions were encountered several times during the test period, including geomagnetic storms on at least two occasions, it is obvious that sustained blackout conditions were not encountered. Such blackouts are very rare events; however, their occasional appearance would tend to lower the long-term availability figures slightly.

On the other hand, the figures tend to be pessimistic, since they have not been weighted according to normal traffic patterns. The most difficult time for HF propagation is usually in the early morning hours prior to sunrise, which coincides with a period of very low traffic density. Thus a weighted availability figure would tend to be greater than the unweighted figure.

As shown in Figure 2, the test results demonstrated that there was nearly always more than one useable channel available for a given path; in fact, there were at least four channels available in the majority of instances. Moreover, the set of useable channels for two different paths at a given time is often quite different, particularly if the path lengths differ considerably. One conclusion that might be drawn from these observations is that the availability of a suitable channel for setting up a call tends to remain relatively high even if several of the total set of channels are busy. There is also a strong indication that fewer than eight channels would provide good service; however, it is difficult to generalize from the results of a trial whose duration was only a few months. It is worth noting at this point that one of the channels (channel #8, 20.5 MHz) was useful so seldom during the trials that it could have been omitted entirely with negligible effect on the availability figures.

Finally, the results of the on-the-air tests clearly demonstrated the value of real-time channel evaluation. Many instances of propagation well above the predicted maximum useable frequency (MUF) were encountered. On the 60 km path, for example, channels at 13.7 MHz and 20.5 MHz were useable on a number of occasions when the predicted MUF was in the 5-7 MHz range. Interference from distant stations sharing the same channel, another unpredictable element in HF communications, was also found to be a very important factor in determining the best channel to use. Figure 3 provides a graphic illustration of the unpredictable nature of HF channels and the utility of the real-time channel evaluation. The best channel, as determined by the channel evaluation algorithm, at the same time of day on successive days was recorded for each path. The percentage of days during the test period that a given channel was best at that time is shown by the histogram. The approximate frequencies of the channels numbered 1 through 8 were 3.2, 5.3, 6.8, 7.6, 9.4, 11.6, 13.7, and 20.5 MHz respectively. At 0000 local time, for example, one would normally expect the lower-frequency channels to propagate best; it can be seen, however, that the higher-frequency channels were best for a significant proportion of the time.

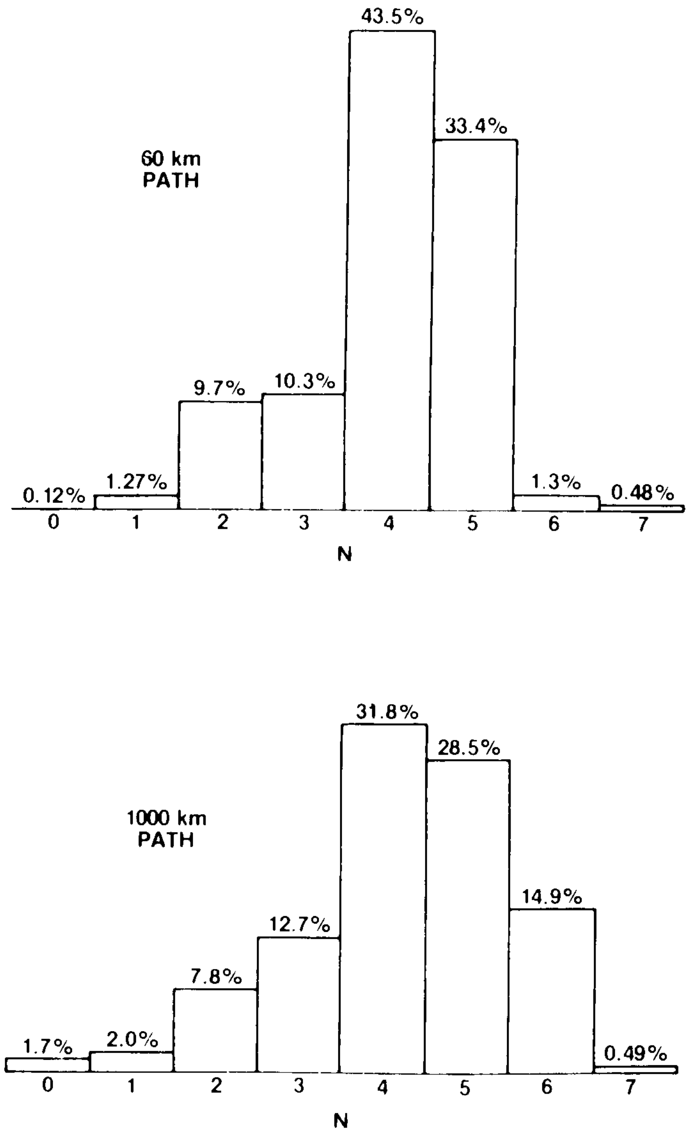

Figure 2. Percentage of Test Period for which N Channels Exceeded Level 2 Quality

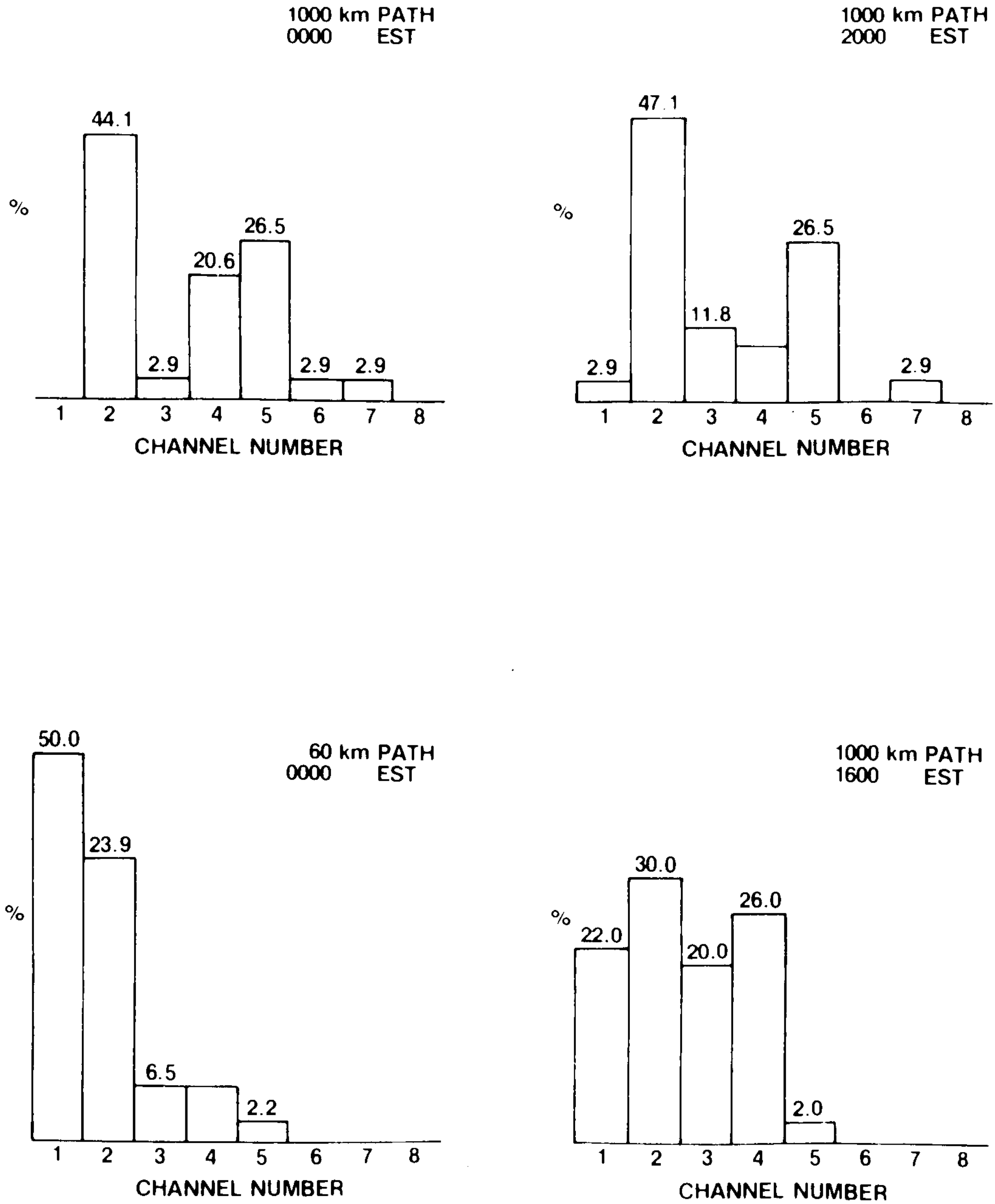

Figure 3. Distribution of Best Channels at Various Times of Day

7. CONCLUDING REMARKS

Results of the first series of tests of the RACE system have been extremely encouraging, and the system has thus far met its design objectives. Judging from comments made by various parties who have observed the system in operation, the RACE concept may find a wider area of application than originally envisaged. The next phase of yield trials, involving interconnection to the switched telephone network, is scheduled to be completed in early 1981. The results of these trials will be described in a later report.

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