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A METHOD OF MEASURING AND RECORDING THE IMPULSE RESPONSE OF THE IONOSPHERIC CHANNEL

by

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ABSTRACT

This report describes a simple method by which the propagation modes of an ionospheric communication channels can be measured and recorded. Experimental results are included as illustration of the technique.

1. INTRODUCTION

This report describes a simple technique which has been successfully used to examine and record the impulse response of an ionospheric channel. This technique has been used to determine the instantaneous condition of the ionospheric channel during a communications experiment.

High frequency (HF) radio signals propagate by reflecting from ionospheric layers. The performance of high frequency communications is greatly influenced by the height, number, electron density and relative motion of these layers.

Each of these parameters is a variable which has both predictable and non-predictable elements. Transmission of digital data over HF circuits is sensitive to these parameters because they can cause intersymbol interference, selective fading and excessive differential group delay. While ionospheric features in general terms can be predicted, the parameters which have major impact on system performance cannot. It is therefore useful to at least record these parameters during an HF communications experiment, as valuable insight can be gained by correlating the path characteristics with the measure of success achieved in communication. Additionally, it is often valuable to evaluate these parameters in real time to assist in the selection of optimum frequencies for communications.

In that regard it is useful if common radio and antenna equipment is used both for evaluation and communication, since the contribution of that equipment to the measured impulse response will then be applicable to the communication element of the system.

Oblique incidence ionospheric sounders have in fact been used for many years to measure and record ionospheric path characteristics as an aid to better HF communications. Unfortunately, most of these sounding equipments are relatively elaborate and expensive.

The technique described in this report uses a pulse compression technique to allow the modes of propagation to be resolved without requiring excessive amounts of peak transmitter power. Recent advances in digital technology permit a simple implementation of the technique to be realized. The additional equipment required is connected to the audio interface of the communications equipment and can be constructed using standard integrated circuits.

2. PRINICPLE OF OPERATION

Pulse compression techniques usually require transmission of a special coded sequence and reception using a matched filter. If the sequence used is suitably selected, the output of the matched filter will consist of a series of pulses, each pulse representing a particular propagation mode. The relative amplitude of the pulses corresponds to the relative intensity of the signal arriving via each mode and the time of occurrence of the pulses corresponds to the difference in the mode path delays, (Ref. 1).

The equipment described in this report called for the transmitter to emit continuously for several minutes a periodic sequence of 31 bits with each bit occupying 0.5 milliseconds. The circuit used to process the received signal is a type known as a "sliding correlator", (Ref. 2). This circuit has found wide application in echo ranging systems because it is easy to implement and can yield the same information as the more complicated classical matched filters under certain conditions. In essence, the sliding correlator uses as the correlation reference, a replica of the transmitted sequence time-scaled by a small amount. This results in the two sequence periods to form a beat. For the equipment described in this report, the PN sequence periods used were 15.5 milliseconds in the transmitter and 15.34147 milliseconds at the receiver. When observed on an oscilloscope, the input sequence appears to slide past the correlation reference (hence the name, "sliding correlator"). When the two sequences are in step, the output of the correlator forms a peak. For a composite input signal consisting of several sequences displaced in time, the sliding correlator output forms several peaks, corresponding to the time at which the reference is in step with one of the constituent sequences.

The period of the transmitted sequence limits the maximum spread of the multipath that can be observed with the equipment. The period of the sequence used in the experimental equipment was 15.5 milliseconds, which was much greater than the multipath spread expected. This ensured that the output accurately represented the multipath encountered.

The delay resolution capability of a system is inversely proportional to the system RF bandwidth. For the experimental equipment the RF bandwidth was about 2400 Hz giving the system a time resolution of about 0.4 milliseconds. This meant that two modes with delay difference of less than 0.4 milliseconds could not be resolved.

One advantage of this system is its ability to use a low powered transmitter to observe the detail of the ionosphere. This ability is due to the processing gain of the system which is related to the beat rate of the reference sequence with respect to the input sequence. For the described system the gain achieved was about 100 giving a processing gain of 20 dB. This means that the 20 watt transmitter used in the experiment had the same resolution as a pulse sounder of equivalent bandwidth with 2K watt peak power emitting a single pulse for each measurement. The method by which the processing gain is calculated is described in section 3.

The pulse coding used was a pseudo-noise sequence (PN). This type of sequence was chosen because of the shape of its auto-correlation function which approximates a delta function. Such sequences are often used because they are easy to implement. The experimental system required use of a 5 bit shift register and a half adder to generate a periodic pattern of 31 pulses (Ref. 3). Such a circuit can be implemented using only two IC's.

3. DESCRIPTION OF THE EQUIPMENT

The equipment used consists of two subsystems, one associated with the transmitter and one associated with the receiver (see Figure 1). The equipment at the transmitter end consisted of a pattern generator producing an audio signal to be transmitted by the radio transmitter. The pattern was a 31 bit PN sequence. The rate at which the sequence generator was driven in this case was 2 KHz. The period of the sequence was 31/2000 = 15.5 milliseconds. The binary sequence phase modulated a 1.5 KHz sinusoid by means of a mixer. The mixer output was bandpassed by a filter to confine it to a bandwidth suitable for transmission through the available radio. During the experiment the transmitter was required to emit the above described signals for several minutes.

The signal from the receiver was multiplied by means of a balanced mixer with a replica sequence obtained from a PN generator driven by an oscillator at a rate slightly different from 2 KHz. The output of the mixer which functioned as a phase modulator was bandpassed by a filter eliminating all components more than 50 Hz from the 1500 Hz centre frequency. The mixer-bandpass filter combination formed the correlator which gave an output consisting of a carrier pulses of varying amplitude. The correlator output was detected by means of a diode and a low pass filter forming an envelope detector. The detector output was used as the recorder input.

The rate at which the replica generator at the receiving end is driven determines the rate at which the ionospheric conditions are measured. For example in the system described, the replica generator in the correlator was driven at a rate which caused the two sequences to "beat" at the rate of 1.5 seconds. This means that the replica generator received 31 pulses more (or

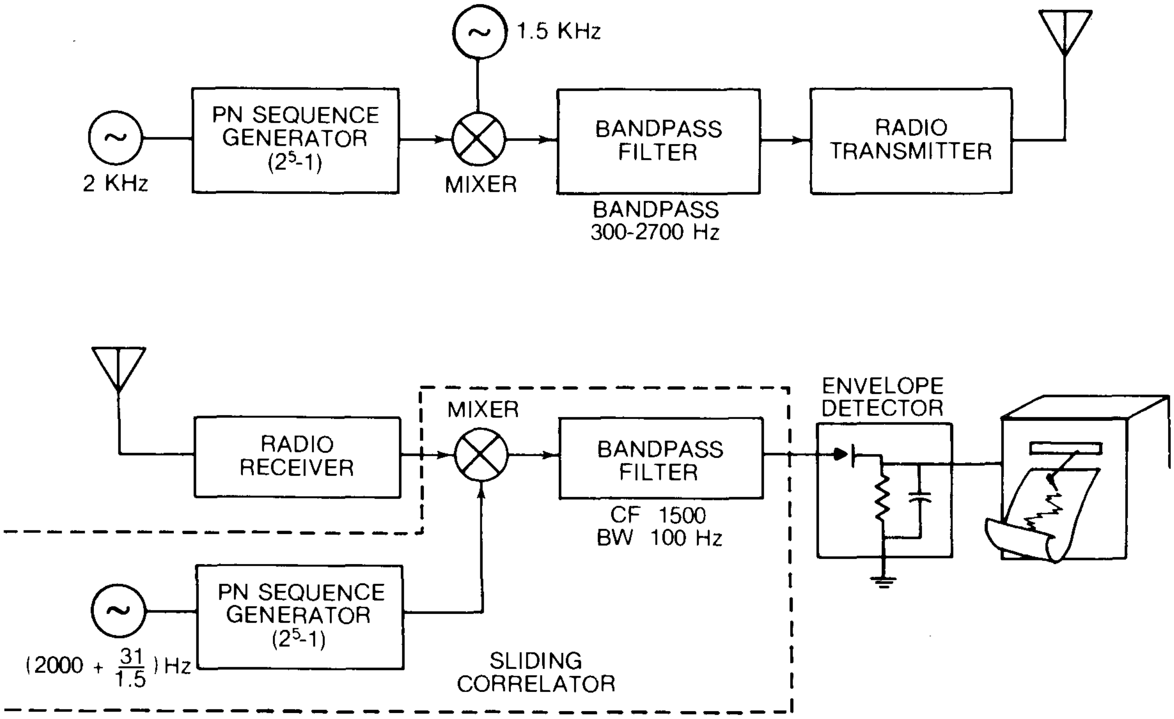

Figure 1. Ionospheric Probe Block Diagram

less) than the generator in the transmit side every 1.5 seconds. i.e., the replica generator must have been driven at a rate of (2000 ± 31/1.5) Hz. The sign of frequency difference determined the order in which the constituent path was examined. For the plus sign, the longer path appeared at the correlator output first.

The processing gain is given by the ratio of T_c/T_r where T_c is the time period in which the two sequences are in step and T_r is the period of one bit of the PN sequence, (1/2000 seconds). Since the two sequences are in step once every 1.5 seconds, and that each period of the PN sequence consists of 31 bits; $T_c = 1.5/31$.

$$\text{Processing gain} = 10 \log (1.5/31) / (1/2000)$$

$$= 20 \text{ dB.}$$

The impulse response of an ionospheric channel is complex. That is, it has a phase as well as a magnitude component. The envelope detector used in the experiment was only capable of giving the magnitude. A coherent detector using in-phase and quadrature channels could be used to detect and record both magnitude and phase information. This would be appropriate if the phase information of the impulse response is important for a given application

It should be noted that the signal-to-noise ratio achieved for a measurement is inversely proportional to the number of measurements taken per second. This trade-off allows the experimenter to design the experiment to suit the ionospheric conditions and his requirements. For example, when the ionospheric conditions are varying rapidly with time, it might be desirable to increase the measurement rate to allow the dynamics of the variation to be examined. However, the corresponding decrease in signal-to-noise ratio may cause some of the less pronounced modes to be obscured by noise.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 2 is a strip chart recording of data obtained in an experiment over a 400 Km path between Toronto and Ottawa at 5.28 MHz. The time of the transmission was local noon, August 4, 1978. It is apparent that 3 modes of propagation were involved. These modes were identified by examining a vertical ionogram obtained independently but at the same time in Ottawa. An oblique ionogram for a 400 km path was generated based on data from the vertical ionogram by applying method given in Ref. 4. The oblique ionogram identified the three modes involved as the one hop-E, one-hop F and the two-hop F with virtual heights of about 100, 300 and 600 Km respectively, (see Figure 3). Because 5.28 MHz was near the critical frequencies of the modes, the signal strength of the modes associated with each layer could be expected to vary rapidly. This was confirmed by the record which indicated significant variation in amplitude between samples obtained in 1.5 second intervals.

The delay between the one-hop E and one-hop F mode for the virtual heights of 100 and 300 Km was calculated to be .9 milliseconds and the delay between the E and the two-hop F mode was calculated to be about 2.7 milliseconds. These values roughly match the results obtained by examining the recording shown in Figure 2. It can also be seen that the one-hop E and F modes often became merged because of the finite width of the reflecting layers and the resolution capability of the system.

A propagation path resulting in several distinct modes will cause the transmitted signal to suffer non-uniform attenuation across the signal spectrum. An r second multipath will cause nulls to appear 1/r Hz apart. The depth of the nulls will be a function of the relative signal strength of each mode. Deep nulls correspond to a complete cancellation of a signal caused by the existence of two paths of equal strength but opposite in phase. The photographs of Figure 4 show spectra of a PN sequence after transmission over a HF path. Deep nulls can be observed across the spectrum. These nulls were observed to be moving at various rates across the spectrum of the received signal indicating the ionosphere layers are in motion during the measurement period. This phenomena is called selective fading. Figure 4C was obtained from the same transmission as the strip chart recording shown in Figure 2. The nulls with spacing of 370 Hz corresponding to a 2.7 millisecond multipath can be readily seen. The photographs of Figure 4 illustrate the typical selective fading characteristics observed during a series of experiments carried out over a 300-750 Km path during August 1978 using frequencies of 5.28 and 6.8 MHz.

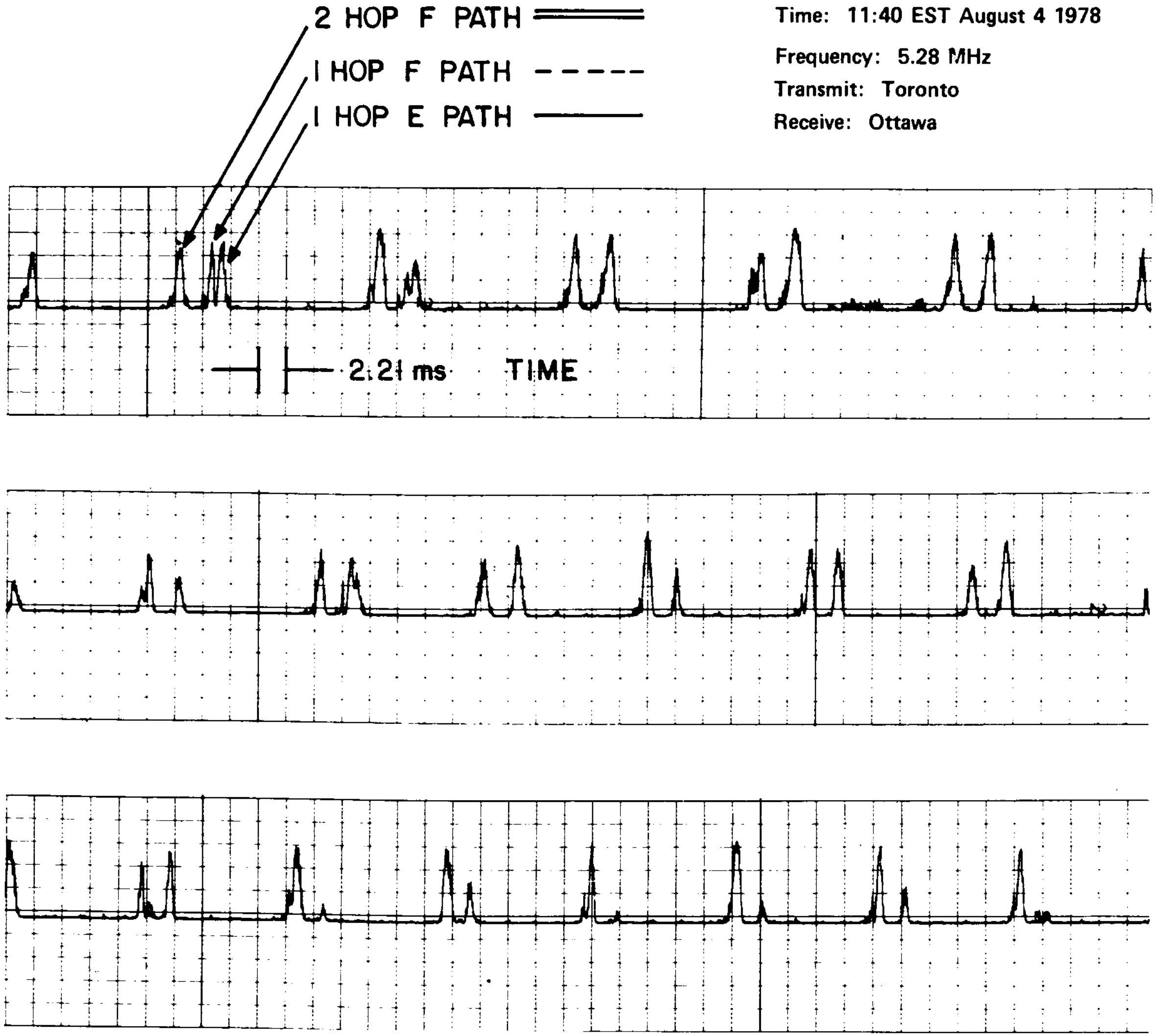

Figure 2. Impulse Response of the Ionosphere

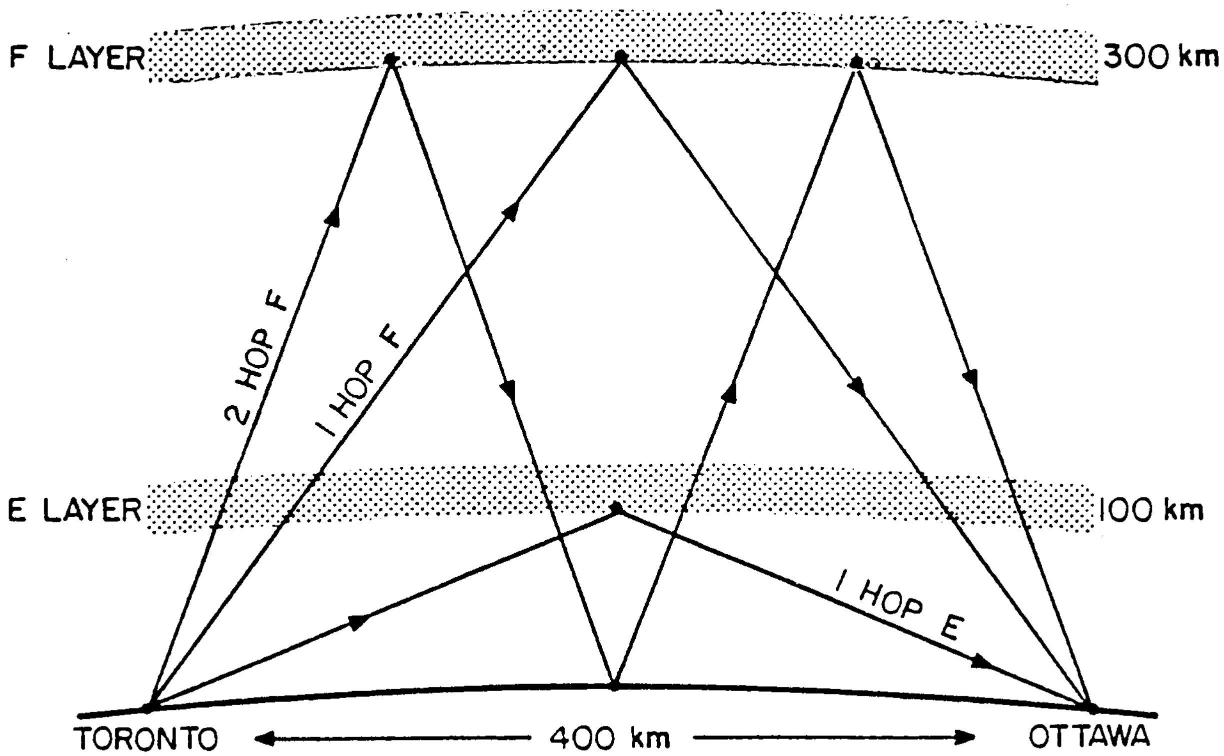

Figure 3. Modes of Propagation

5. SUMMARY AND CONCLUSION

A simple technique for recording the impulse response of an ionospheric channel has been described. Such recordings are crucial to an interpretation of experimental results because the impulse response of the ionosphere can indicate amplitude and pulse distortions imposed on the transmitted signal by the transmission media. This technique is especially relevant to digital systems because these systems are known to be sensitive to selective fading and intersymbol interference; phenomena closely associated with multi-mode propagation in the ionosphere.

Many modern HF systems use special modulation, coding and frequency diversity in various combinations in order to achieve good performance under multi-mode conditions. It is impossible to judge the effectiveness of these systems against multipath unless the ionospheric conditions under which they are tested are documented along with the test results. The system described is one means of providing such document.

This technique could be implemented in operational systems, with measurement of the impulse response of the channel measured in real time providing a means for selecting a suitable frequency for transmission of data.

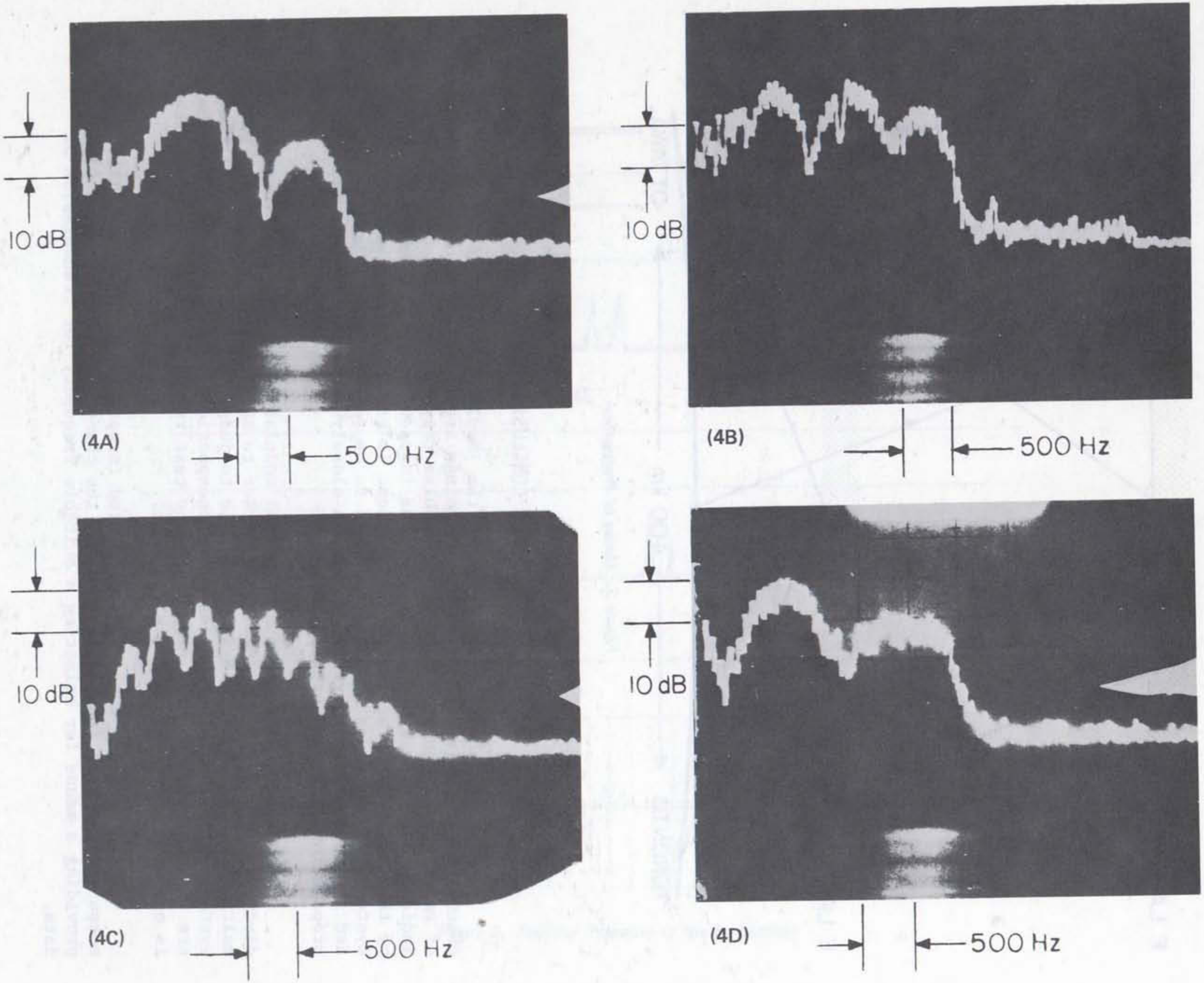

Figure 4. Spectrum of Received Signal

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