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**Atmospheric Effects
Assessment Program:**
Ionospheric Sounding

R. A. Sprague

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**Atmospheric Effects Assessment
Program:**
Ionospheric Sounding

R. A. Sprague

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INTRODUCTION

The main goals of this effort are to study the short-term variability of the ionosphere and to measure the effects of this variability on skywave field strength. Data suitable for accomplishing these goals are being collected in two ways. First, the Naval Command, Control and Ocean Surveillance Center, RDT&E Division (NRaD) vertical incidence ionospheric sounder is being used to obtain ionograms in San Diego at 5-minute intervals throughout the fiscal year. A similar sounder, located in Logan, UT, and owned by Utah State University, is also collecting data at 5-minute intervals for studies of correlation of ionospheric variability over the approximately 1000-km separation distance between the two sounders.

To study the effects of short-term ionospheric variability on high-frequency (HF) communications, a circuit is being established to measure the variability of the received HF signal strength. The chosen circuit will have the transmitter located in Montana and the receiver will be in Imperial Beach, CA, approximately 20 miles from NRaD.

IONOSPHERIC SOUNDING

The first of these goals requires long-term, high-resolution sounding of the ionosphere. This sounding is being accomplished both in San Diego and Logan by continuous vertical incidence sounding of the earth's ionosphere at 5-minute intervals throughout the fiscal year. The ionograms are scaled for the relevant parameters (foF2, hmF2, ymF2, MUF(3000)M3000, etc.), using a method developed by Paul and Mackison (1981). An important advance in the data analysis procedure was achieved early in 1993 with the implementation in San Diego of a realtime ionogram scaling method. With ionograms from two sites to be scaled, the realtime processing in San Diego reduces the time spent preparing the data for analysis. The data from Utah, however, are still largely unscaled and will be a focus area for the FY 94 effort.

The San Diego site has been extremely reliable for the entire year. Two major outages in April (computer failure) and May (backhoe cut the cable to the transmitting antenna) of this year resulted in the loss of approximately 15 days of data. Incidental failures of 1 to 3 days throughout the year led to an additional loss of about 10-15 days. System failures of this type are inevitable and the loss of about 30 mostly noncontiguous days of data is probably to be expected for a data-collection effort of this magnitude.

Conversely, the Utah site has been plagued by continual hardware problems (computer failures, a lightning strike blew out their amplifier) that have severely limited the amount of data collected from that site. The total amount of usable data from Utah for 1993 is still to be determined.

Ionospheric sounding at the two sites is being done at 5-minute intervals. This time interval was chosen to adequately resolve variations produced by locally generated acoustic gravity waves, which transmit their effects collisionally to the ionospheric plasma. These local variations of the ionosphere, called "traveling ionospheric disturbances (TIDs)," have been found to have minimum periods of 15-20 minutes (Paul, 1989). However, larger scale TIDs, which are usually spawned in the high-latitude auroral regions and propagate with little attenuation to lower

latitudes, can have periods of 3 hours or more. Earlier studies have shown that, at mid and low latitudes, the TID spectrum is dominated by the shorter period, locally generated TIDs.

Analysis of the variability is proceeding in several ways. In one effort, the variability data are extracted from daily records of the parameters by low-pass filtering the data with a cutoff period of 3 hours. The filtered data are then subtracted from the original data to produce variability data with periods shorter than 3 hours. An example of this process is shown in figures 1, 2, and 3. Figure 1 shows the foF2 derived from ionograms taken every 5 minutes on 6 October 1993. Note the unusually dramatic presunset rise of foF2 on this day. Figure 2 shows the filtered data derived from the data of figure 1. Finally, figure 3 shows the extracted variability data for the foF2 that are the object of study for this effort.

An example of the analysis done on the variability data is shown in figure 4. This figure shows the autocorrelation of the foF2 data in figure 3. Note especially the peak(s) in the autocorrelation at time lags near 50 minutes and the lack of any apparent structure near 20 minutes.

Figure 5 shows the autocorrelation of the MUF(3000) for the same day, 6 October 1993. Earlier studies of ionospheric variability (Paul, 1989) found that the MUF(3000) was a more sensitive indicator of ionospheric variations, presumably because it is a function of both height and density. In fact, it was through analysis of the MUF(3000) in data collected in the early 1980s at Boulder, CO, that the 15–20-minute minimum period was identified. However, figure 5 again shows that the dominant period of the variability lies near 50–60 minutes.

A spectral analysis is also being done on the variability data in order to confirm the above results. The results from the spectral analysis for 6 October 1993 are shown in figure 6. Both the foF2 (top) and MUF(3000) (bottom) in figure 6 show that the dominant frequencies lie near 0.02, with the peak amplitude around 0.16, which corresponds to 60 minutes. In particular, the spectrum near 0.05 (20-minute period) shows no clear peaks and appears noise-like.

Figure 7 shows the autocorrelation of foF2 (top) and MUF(3000) (bottom) for 25 January 1993, a day of extreme variability. The extraction of the variability data from which these plots are derived proceeded in exactly the same way as shown in figures 1–3. Figure 7 shows similar results as above for the MUF(3000), with dominant periods near 50–60 minutes. However, the foF2 on this day shows the presence of more variations of several periods, including an indication of some variations near 15–20 minutes and less than 50–60 minutes.

Figure 8 shows the results of the spectral analysis for 25 January 1993. Consistent with figure 7, the MUF(3000) spectrum shows little indication of significant content near 0.05 frequencies (20 minutes), most of the spectral content being at frequencies near 0.02 and below. However, the foF2 spectrum shows considerable spectral amplitudes at higher frequencies, including frequencies above 0.05. These higher frequency lines appear to be approximately equally spaced above 0.05 and may be due to wave mixing between multiple TIDs. These results indicate that the variations observed on 25 January were predominantly due to changes in electron density caused by expansion and compression produced by TIDs propagating near the F2 layer peak rather than changes in the layer height. Analysis also shows that there is little dependence on season in the results obtained to date.

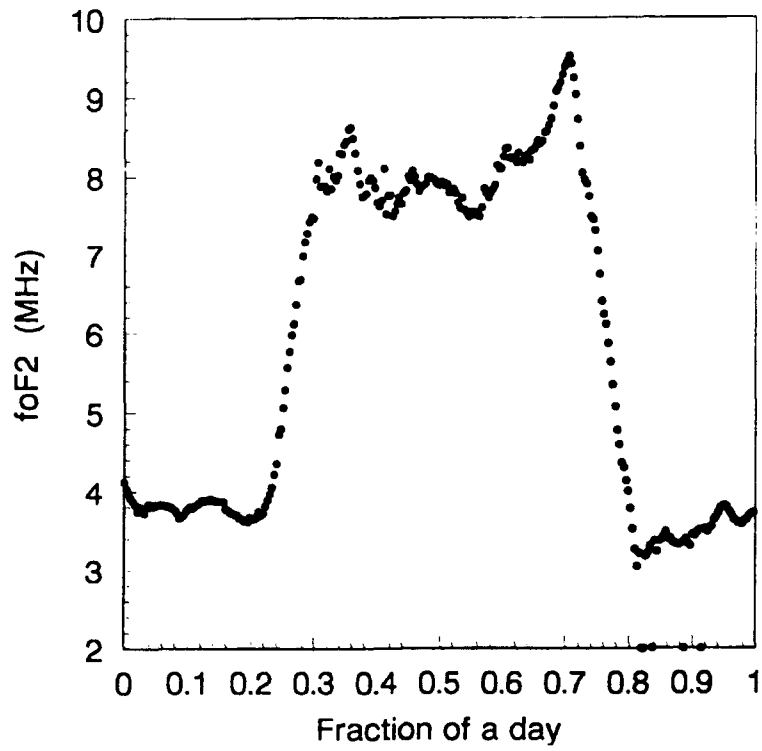


Figure 1. foF2 for 6 October 1993.

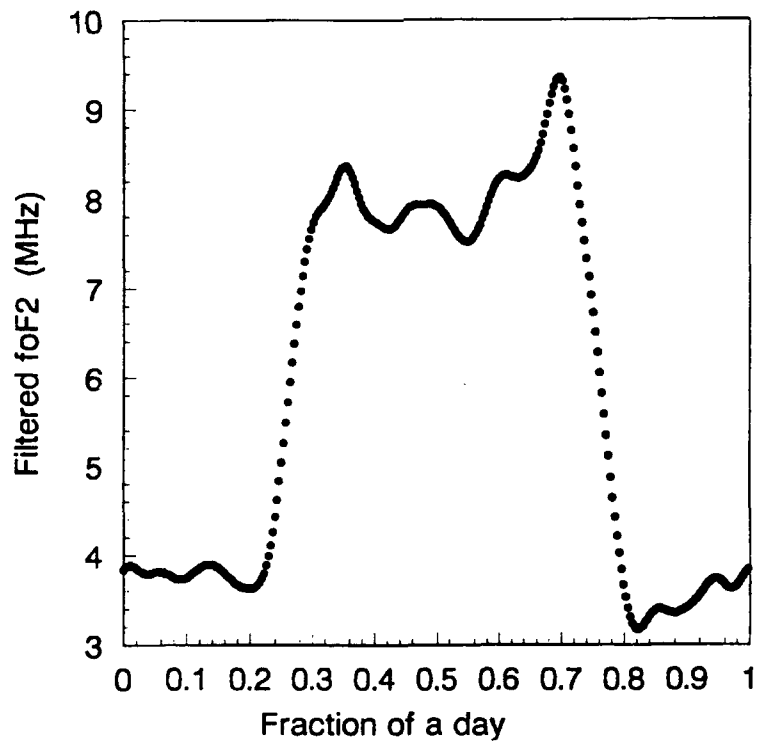


Figure 2. Filtered foF2 data from 6 October 1993. Variations with periods less than 3 hours removed.

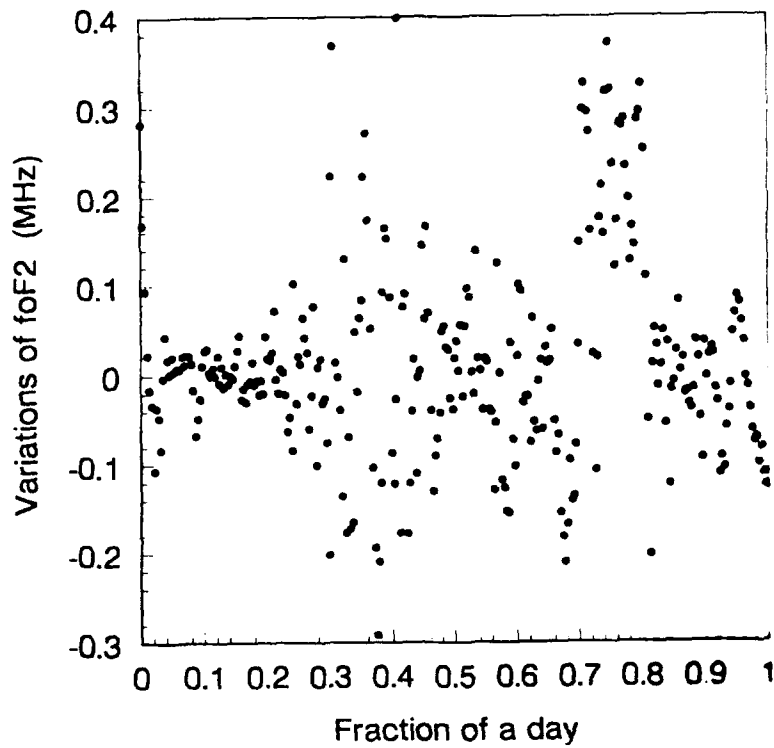


Figure 3. Variability data for foF2 on 6 October 1993. Data obtained by subtracting data of figure 2 from data of figure 1.

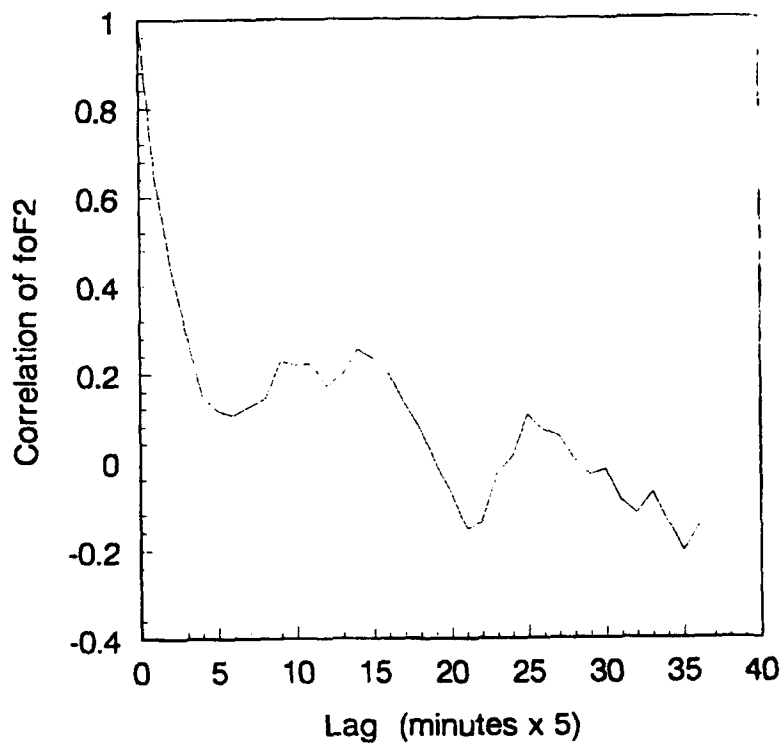


Figure 4. Autocorrelation of variability data shown in figure 3.

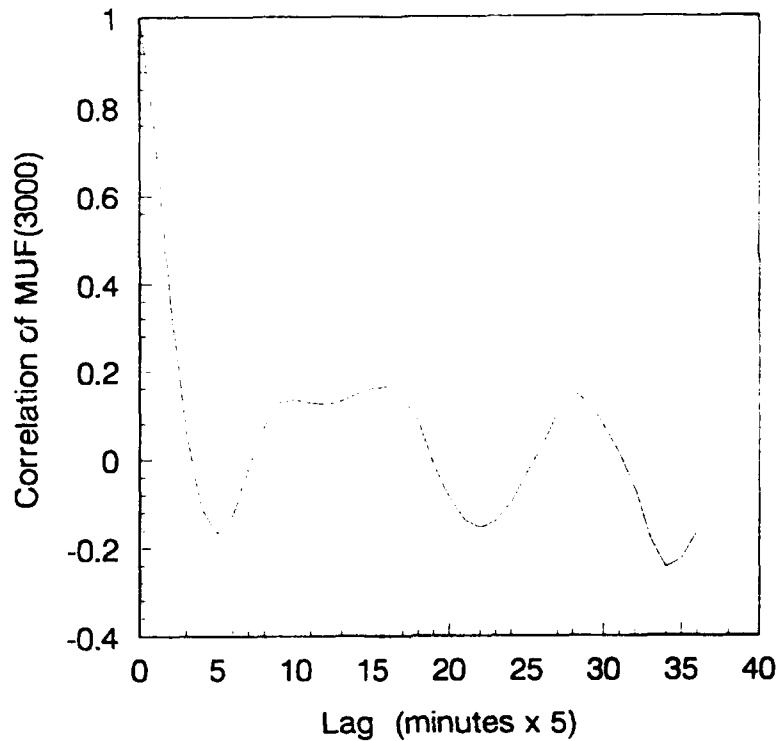


Figure 5. Autocorrelation of MUF(3000) variability data for 6 October 1993.

The reason for the apparent disagreement regarding dominant variability modes between San Diego and other mid-latitude sites is unknown. It is possible that high altitude winds along the coastal region of San Diego are the source of TIDs with properties that differ significantly from other mid-latitude regions. These questions will be investigated next year by comparing the San Diego results with results from a similar analysis of the Utah data.

The correlation analysis described above was presented in a paper given by the principal investigator at the 1993 Ionospheric Effects Symposium in Washington, DC in May 1993 (Sprague and Paul, 1993). A paper on this topic will be submitted, probably to *Radio Science*, once the analysis of the Utah data is complete.

The variability data are also being analyzed to determine the correlation of the variability with magnetic disturbances. In this effort, the mean and standard deviation of scaled parameters for each day will be correlated with several magnetic indices (k_p , k , A) to determine the predictive potential of these indices for ionospheric variability.

Most of the models for HF propagation developed over the years have been monthly median in nature. This includes models developed at NRaD. More recently, there has been an effort to produce models that include information relating to the day-to-day variability of relevant ionospheric parameters. In particular, circuit reliability models use measured median and decile values of transmission loss, maximum usable frequency (MUF), and atmospheric noise to predict the number of days in the month that, for a given hour, frequency, and transmitted power,

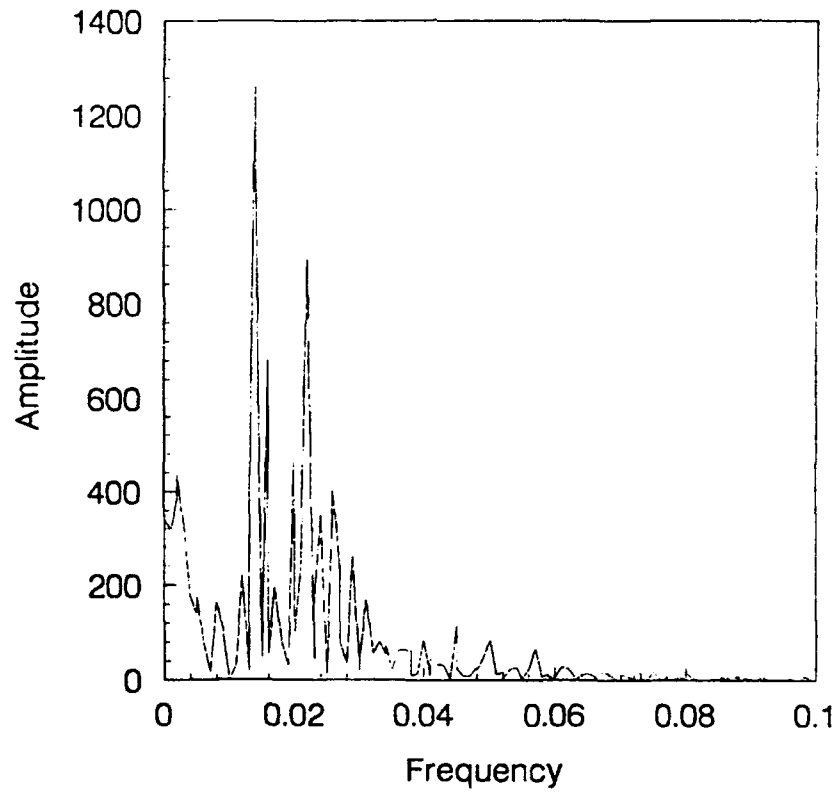
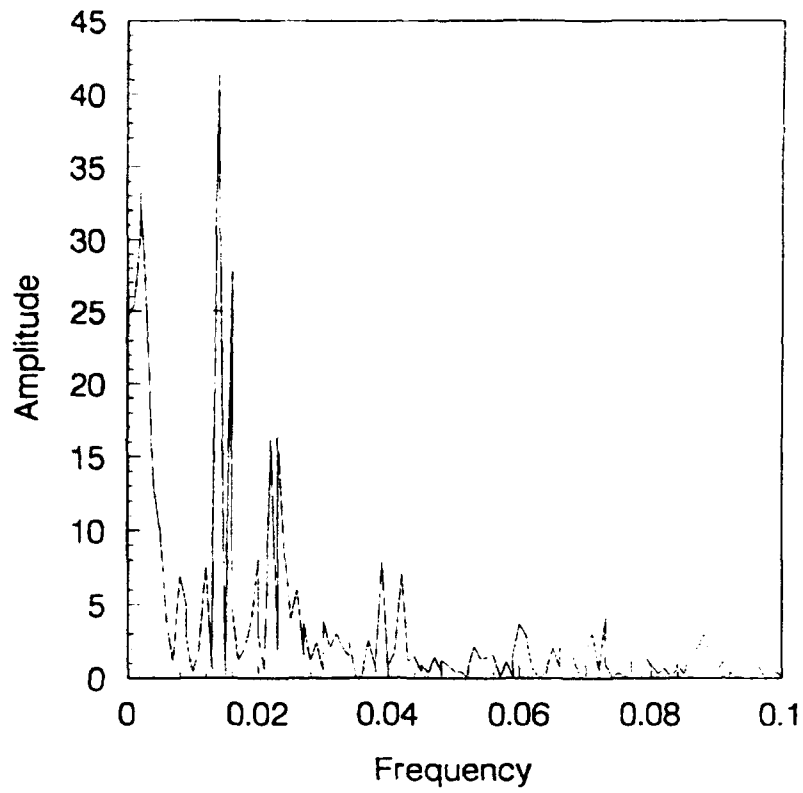


Figure 6. Spectral amplitudes for foF2 (top) and MUF(3000) (bottom) for 6 October 1993.

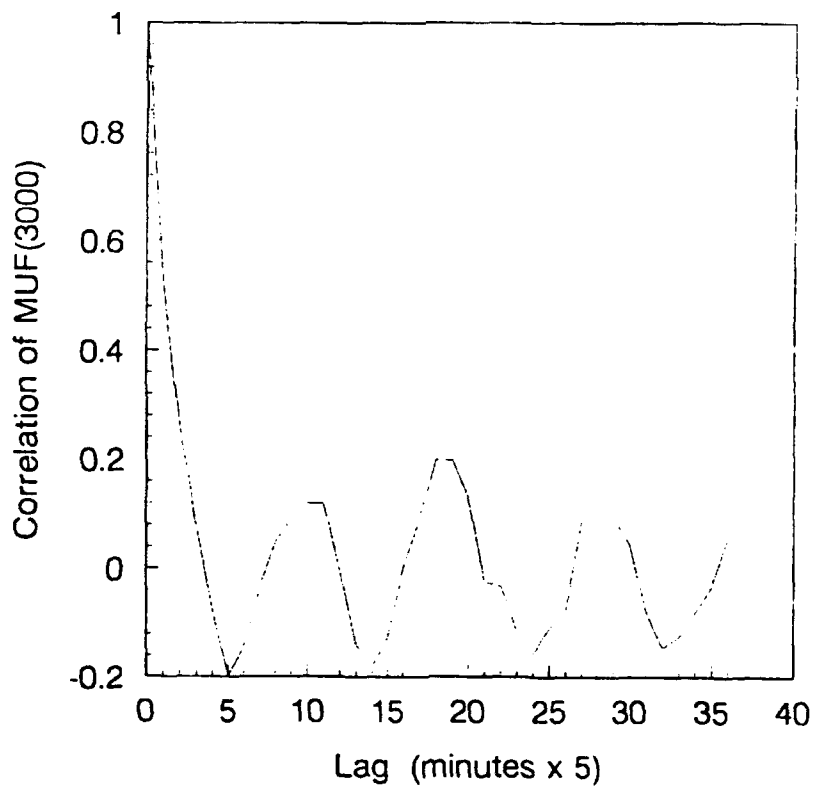
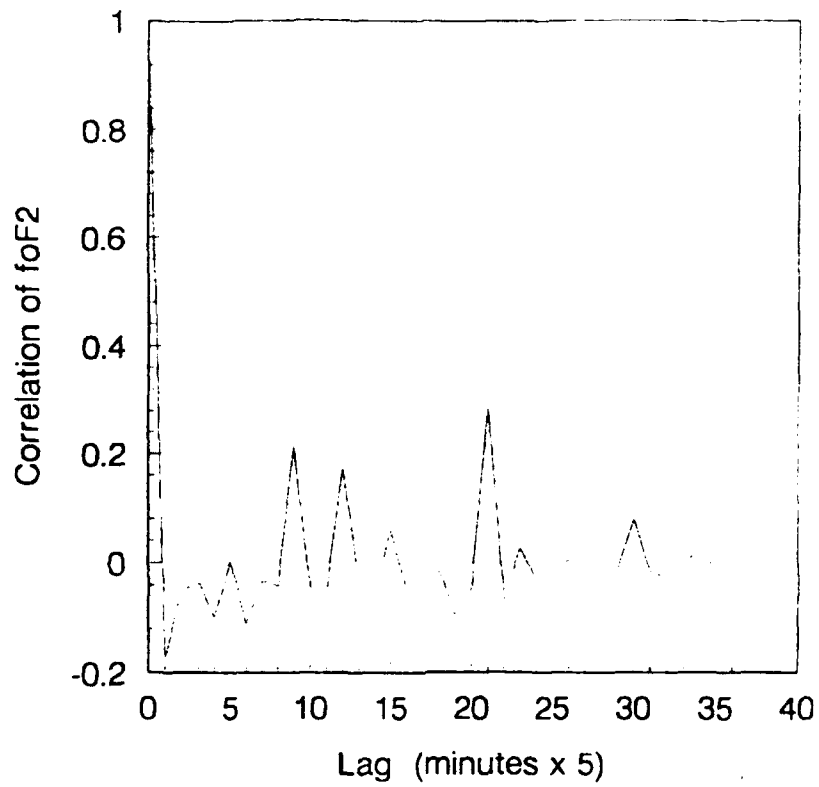


Figure 7. Autocorrelation of foF2 (top) and MUF(3000) (bottom) for 25 January 1993.

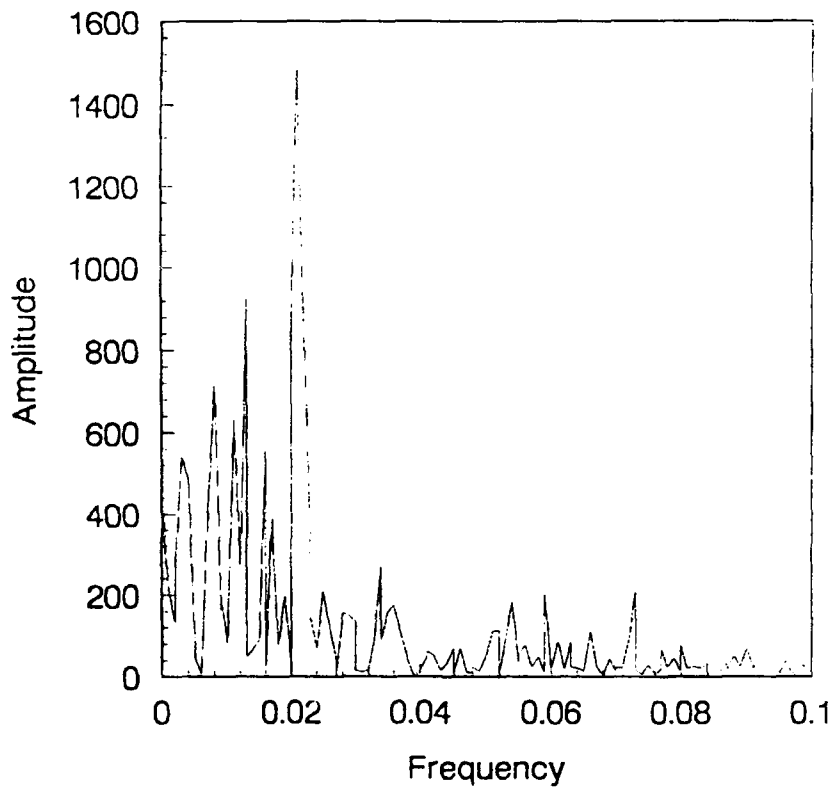
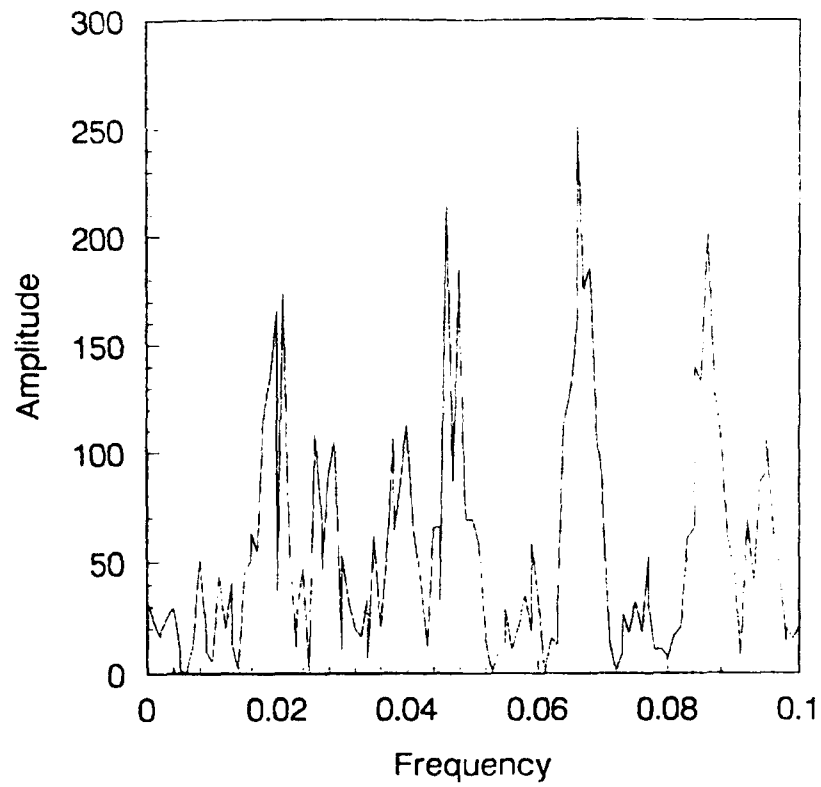


Figure 8. Spectral amplitudes for foF2 (top) and MUF(3000) (bottom) for 25 January 1993.

the received signal will have sufficient signal strength to provide a given level of service. These models use transmission loss and MUF data derived in the 1950s that have never been verified. For the purpose of verification of this day-to-day variability data, the MUF(3000) is being analyzed to extract monthly median and 10% and 90% decile values for each hour.

HF FIELD STRENGTH MEASUREMENTS

The other measurement required to verify the circuit reliability models is transmission loss or received power variability. These measurements are the second goal of this research effort.

For this purpose, a transmission circuit is being established between the Vanada Radar Site operated by the Air Force near Forsythe, MT, and the Naval Radio Receiving Facility in Imperial Beach, CA. This path was chosen in order to take advantage of the location of the vertical incidence sounder at Logan, UT, which lies at the approximate midpoint. The path length is approximately 1770 km and, although a somewhat shorter path would be optimal, it should provide the required propagation characteristics. The design of the experiment is shown in the diagrams of figures 9 (transmitter) and 10 (receiver).

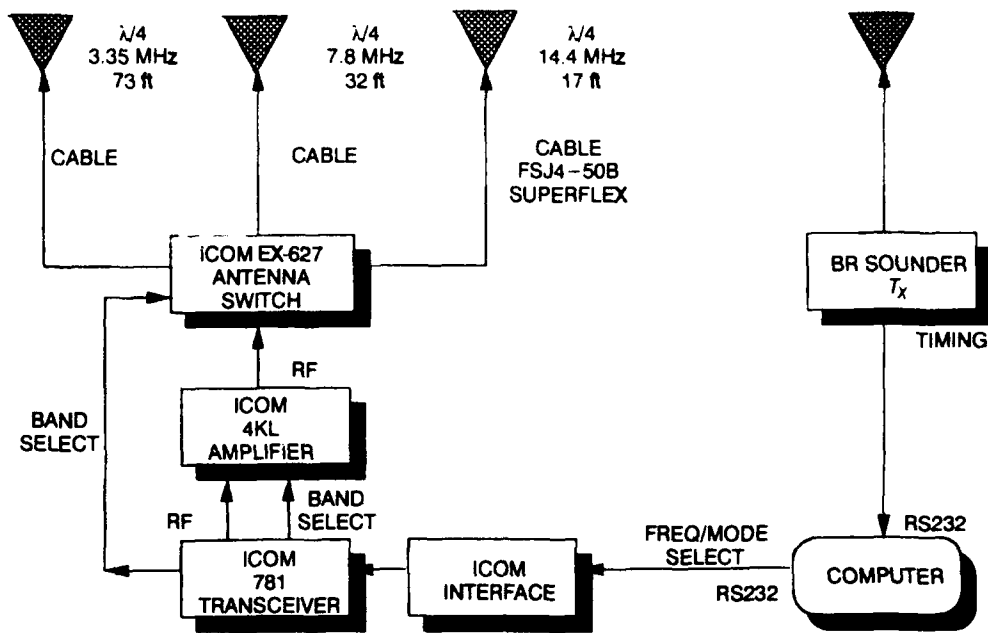
The transmitter system, located in Montana, is computer-controlled through RS232 connections with the oblique sounder transmitter and the ICOM781 transceiver. Timing between the transmission system and the reception system is maintained by the oblique sounder system, which will also be deployed on the circuit. The oblique sounder transmitter and receiver typically maintain synchronism to within 0.5 second, which is adequate for the purposes of these measurements.

Three frequencies: 3.35 MHz, 7.8 MHz, and 14.4 MHz, have been chosen for this experiment. Model studies for these frequencies indicate that the low frequency will be available during nighttime hours and the high frequency will only be usable during the day. The middle frequency should be usable both night and day, perhaps on different modes. There is some interest in making measurements on these frequencies as the MUF for the path passes through the frequency. It is hoped that the fall-off of signal strength over the MUF can be determined from these measurements.

As indicated in figure 9, the signals will be transmitted via 1/4-wavelength monopole (whip) antennas with ground planes of slightly more than 1 wavelength in radius. These antennas were chosen because the transmitting characteristics of short whip antennas are well known and do not require measurement of gain characteristics.

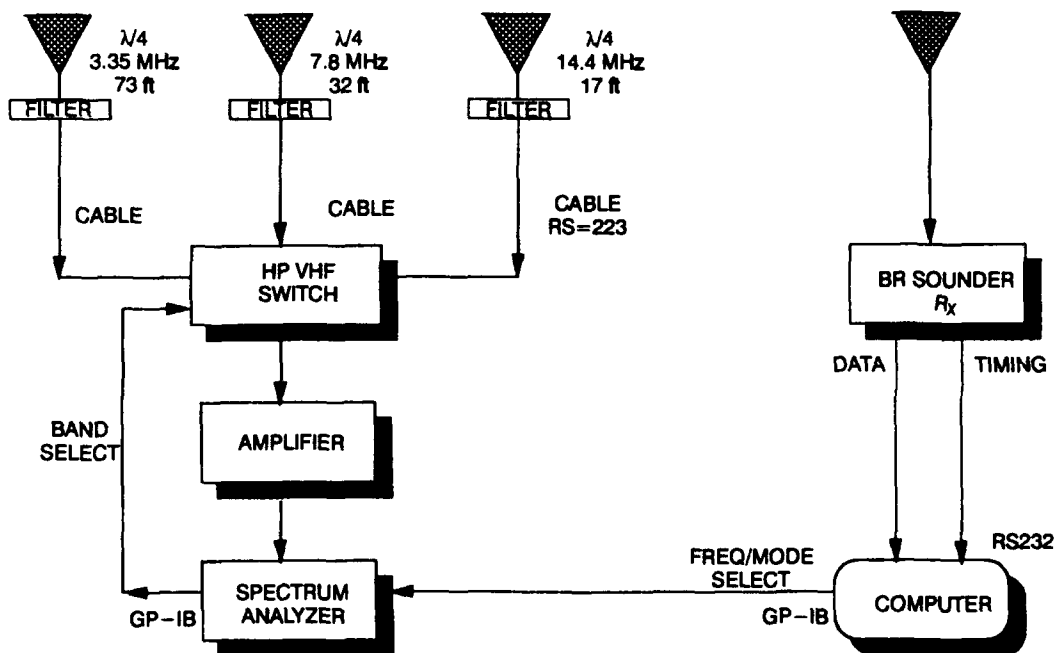
The receive system shown in figure 10 is, in most ways, a mirror of the transmitter system. Here, the oblique sounder receiver is the source of timing for the entire receive system. An HP-8568B spectrum analyzer is being used to measure the HF signal strength with a 300-Hz bandwidth. Control of the spectrum analyzer is through a general purpose-interface bus (GP-IB) board within the computer.

Again on the receive end, the signals will be received by 1/4-wavelength monopole antennas.



SOUNDER CALIBRATION SYSTEM—TRANSMIT

Figure 9. Diagram of transmitter system for field strength measurements.



SOUNDER CALIBRATION SYSTEM—RECEIVE

Figure 10. Diagram of receiver system for field strength measurements.

The oblique sounder, besides providing accurate timing, will provide oblique ionograms before each transmission sequence. These ionograms will be used to identify propagating modes for the assignment of proper antenna gains. The required angles for the gain determination will be obtained by ray-tracing through the ionospheric profile determined by the vertical incidence sounder at the path midpoint. Vertical ionograms will also be available in San Diego to provide a second height profile if required.

All the hardware has been obtained and the software is complete for this experiment. The intention was to deploy the system at the end of FY 93 but insufficient funding made that impossible. Our intention is to field the system as soon as possible in FY 94.

These two efforts comprise the work that has been done for FY 93.

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