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SU-SEL-68-014

Received Polarization of Ionospherically Propagated Waves as a Function of Time and Frequency

by

M. R. Epstein and O. G. Villard, Jr.

January 1968

Technical Report No. 145

Prepared under
Office of Naval Research Contract
Nonr-225(64), NR 088 019, and
Advanced Research Projects Agency ARPA Order 196

RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

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RECEIVED POLARIZATION OF IONOSPHERICALLY PROPAGATED WAVES AS A FUNCTION OF TIME AND FREQUENCY

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ABSTRACT

The incoming wave polarization of sweep-frequency CW radio transmissions was measured as a function of HF frequency and time of day for one-hop F-layer propagation over 1300 km N-S and 1900 km E-W temperate-latitude paths. Daytime rates of polarization rotation with frequency (at an instant of time) average 1 turn/MHz (equivalent to a null-to-null spacing of 250 MHz) over the N-S path, and 0.25 turn/MHz over the E-W path. These values are in good agreement with predictions that were made using computer raytracing techniques. Higher rates of polarization rotation with frequency are observed at 0.7 and 0.9 MOF_o than at 0.8 MOF_o. The rates are higher at night by about a factor of 2. Typical daytime rates of polarization rotation with time (at a given frequency) average 0.25 turn/min (equivalent to 0.5 signal strength null/min). These rates do not appear to vary either with path azimuth or transmitted radio frequency. Near-zero rates of polarization rotation with time occur for much of the nighttime period. Large fluctuations in the polarization variations occur with both time and frequency throughout the day.

Polarization measurements made with signals that were reflected from nighttime sporadic E layers indicate that, for these layers, circumstances other than polarization effects determine much of the observed signal strength variations with frequency and time.

The results suggest that for round-the-clock propagation when linearly polarized antennas are employed, envelope distortion of broadband signals--due to variation in the incoming polarization with frequency--begins when signal bandwidths exceed approximately 100 kHz for N-S paths and 400 kHz for E-W paths. The effects of such distortion may be reduced either by operating near 0.8 MOF_o or by the use of circularly polarized antennas.

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LIST OF ILLUSTRATIONS

ACNOWLEDGMENT

The authors wish to thank Roger Flanagan, Victor Frank, John Lynch, and Fred Marshall for operating the sounding equipment; and James Lomasney and Ralph Wanner for aiding in the data reduction.

I. INTRODUCTION

The purpose of this report is to describe round-the-clock measurements of HF wave polarization after ionospheric passage. The results of these measurements provide insight into the mechanism of oblique-path CW amplitude variations due to polarization, and broadband signal waveform distortion due to the variation of incoming polarization with frequency. The numerical data are useful to the communications circuit designer in evaluating the advantages of erecting certain specially polarized antennas against the increased cost.

Measurements of received one-hop lower ray F-layer signal strength were made as a function of transmitted frequency for two and one-half days per path over both east-west (E-W) and north-south (N-S) paths using FM-CW sounding equipment. Polarization measurements were also made with signals that were reflected from nighttime sporadic E layers. The experimental equipment and data reduction methods employed in the experiments are described in Section II; the results of the data reduction are presented in Section III and discussed in Section IV.

II. EXPERIMENTAL EQUIPMENT AND DATA REDUCTION

A. Experimental Arrangements

1. FM-CW Sounding System

Sweep-frequency FM-CW sounding equipment was employed for the polarization measurements [1]. This equipment consists of two similarly modified frequency synthesizers, one for use as a transmitter exciter and the other to generate the receiver first mixer injection signal. A close approximation to a CW signal having a linearly increasing frequency is generated by rapidly and phase coherently switching the synthesizer frequency. Operation of the sounding system proceeds as follows: The transmitted frequency sweep arrives at the receiver with each frequency component of the signal phase shifted and attenuated according to the characteristics of the ionospheric channel. The received signal is mixed with a replica of the transmitted waveform which has been translated up in frequency (by 18 MHz) to produce an IF signal. The IF signal is processed by a communications receiver employing product detection to produce an audio signal which may be recorded on magnetic tape. Since a linear frequency sweep is employed, calibration marks on the tape that indicate the beginning of the sweep allow the transmitted frequency to be determined.

The amplitude and phase of the received FM-CW signal correspond to those of the transfer function of the ionosphere. Hence a display of frequency vs time vs amplitude (the latter variable in the Z dimension) corresponds to the group time vs frequency description of the ionospheric channel called an oblique ionogram.

2. Transmission Paths and Antennas

An FM-CW HF sounder transmitted 60 watts power from a Granger Associates Model 747-L wire, horizontally polarized log periodic antenna for two different two and one-half day periods over an E-W and a N-S propagation path. The signals were received at Stanford, California. Transmissions over the 1900 km E-W path from Lubbock, Texas were received (during 20-22 February 1967) with a horizontal rhombic antenna possessing a leg length of 183 ft and a total length of 361 ft. Transmissions over the 1300 km N-S path from Bozeman, Montana were received (during 17-19 October 1967) with vertically and horizontally polarized Hy-Gain LP-13-30 log periodic antennas. The E-W path is very nearly aligned at 90° azimuth, while the N-S path is situated approximately 22° east of geomagnetic north from Stanford (Fig. 1). Both experimental periods were geomagnetically very quiet.

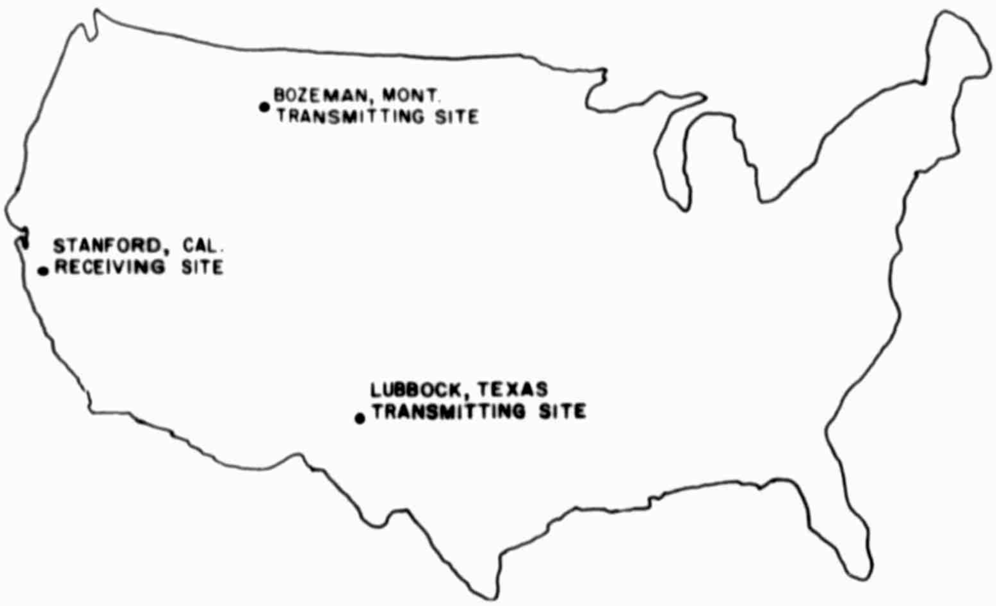


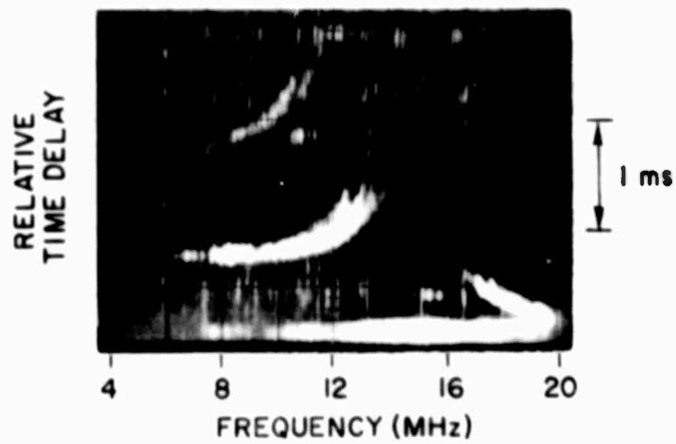
Fig. 1. TRANSMITTING AND RECEIVING SITE LOCATIONS.

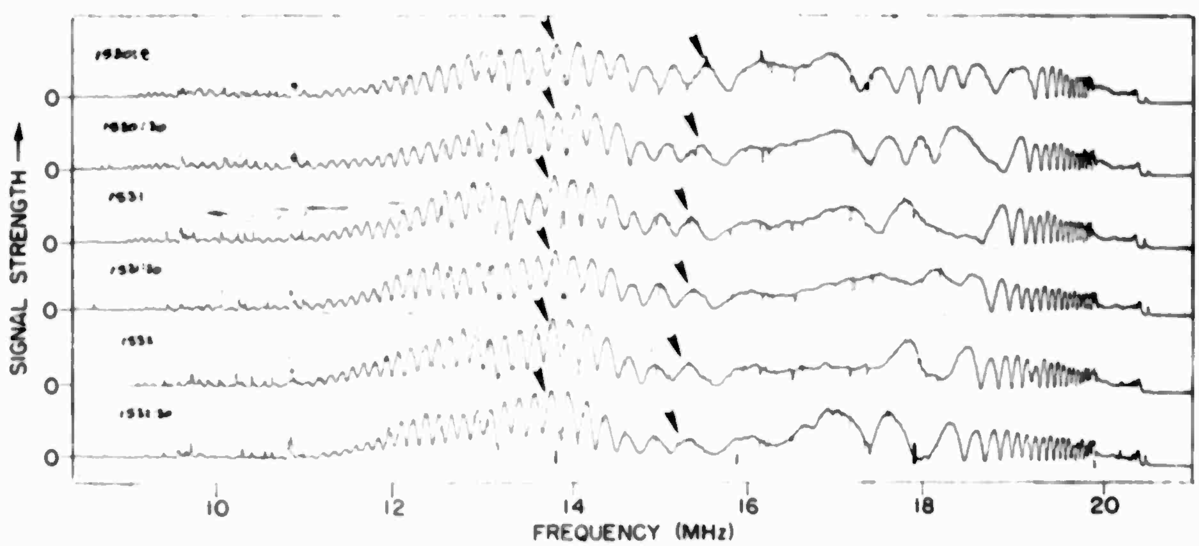
B. Data Reduction

The data reduction techniques employed for this experiment have been described in detail in a previous report [2]. Reference 2 also contains a description of the techniques for identifying amplitude vs frequency variations due to polarization. To review briefly, individual modes (here, one-hop F lower rays) may be selected by simple bandpass filtering from the appropriate FM-CW sounder output because of the relation between sounder output frequency and group time delay. After detection, the amplitude of the selected signal is displayed with a chart recorder in order to provide a record of received signal amplitude vs frequency along a given ray.

In the experiments, a 4 to 30 MHz FM-CW sounding was made once every 30 sec throughout each test period. All data were recorded on magnetic tape. Chart recordings were made from the recorded signals once every half hour for a 5 min period. Typical chart-recorded sequences of received signal amplitude vs radio frequency over the E-W and N-S paths, and the corresponding oblique ionograms, are shown in Fig. 2. A nighttime record illustrating sporadic E propagation is presented in Fig. 3. Figure 4 shows the maximum observable frequency of the ordinary ray (MOF_o) as a function of time of day for both paths.

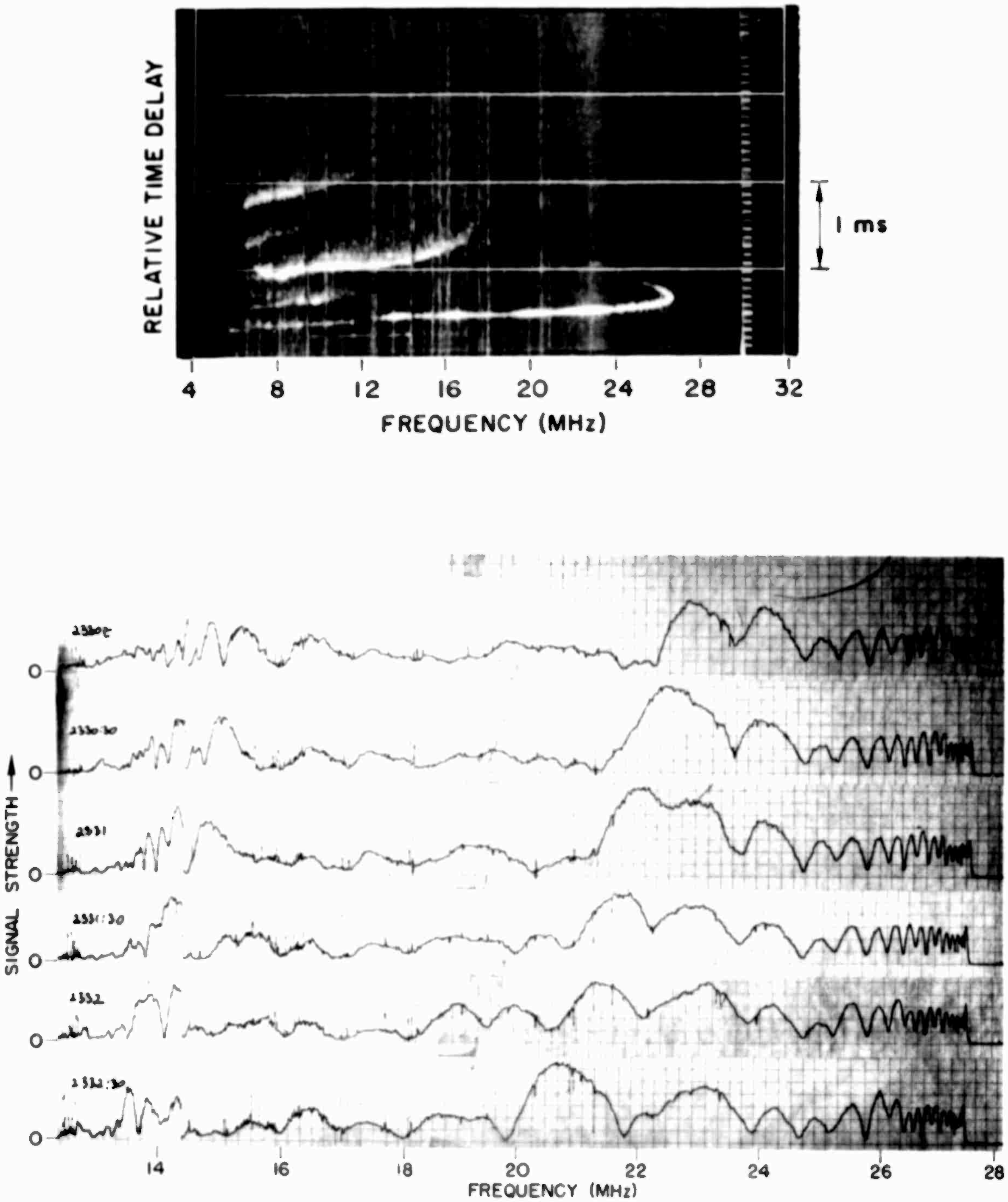
Amplitude null-to-null spacing in frequency (at an instant of time), and the amount of displacement in frequency traversed by the signal strength nulls and maxima from one record to the next (as shown, for example, by the arrows in Fig. 2a) were scaled from the chart records at 0.9, 0.8, and 0.7 of the one-hop MOF_o. The resulting data can be interpreted as the rate of change of polarization with frequency at an instant of time, and as the rate of change of polarization with time at a given frequency. Owing to low signal-to-noise conditions (which occurred mostly at night) and equipment failures, interruptions in the data occur from time to time.





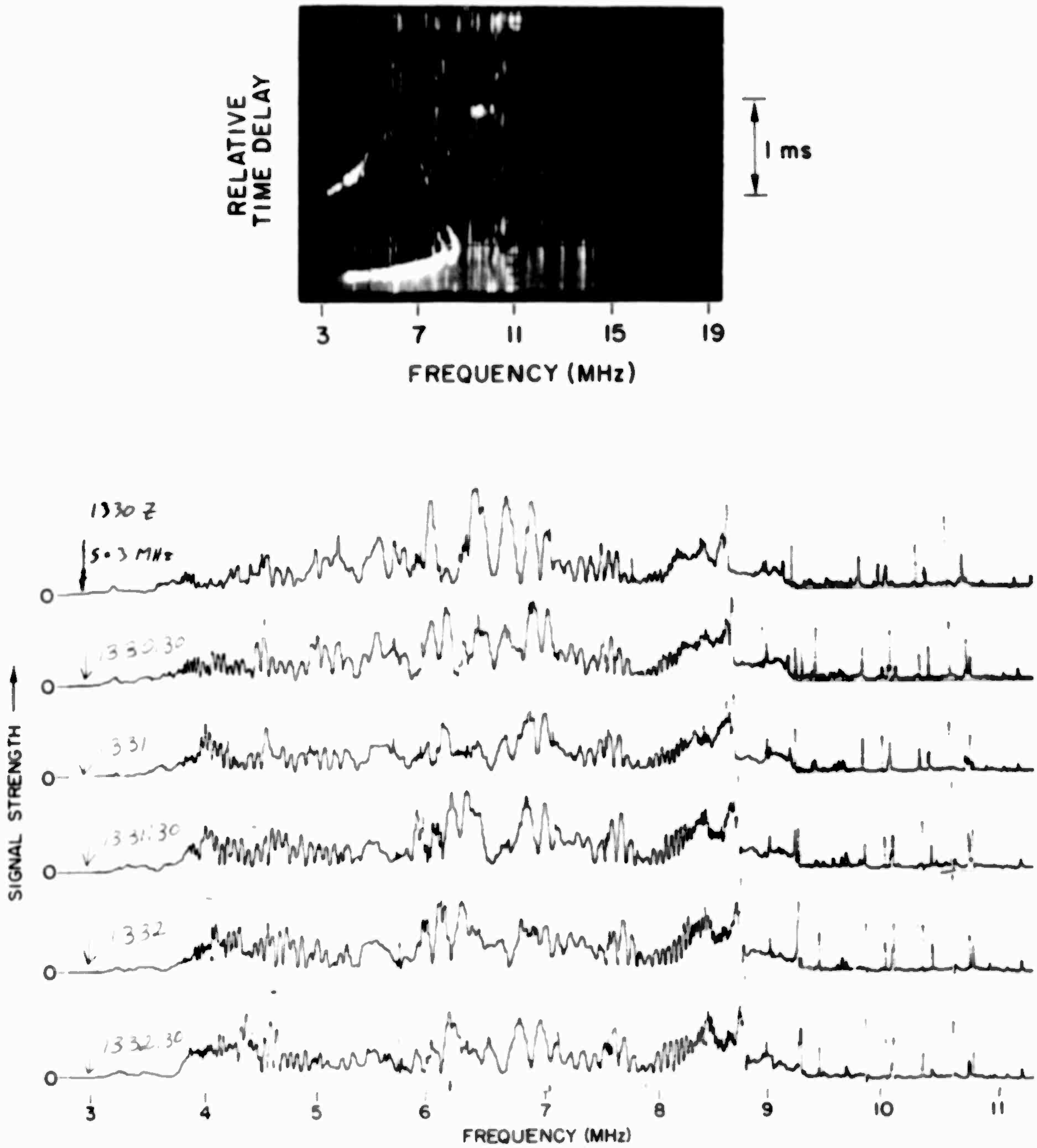
a. Daytime, Bozeman-Stanford path (19 October 1967)

Fig. 2. TYPICAL IONOGRAMS AND AMPLITUDE RECORDS.



b. Daytime, Lubbock-Stanford path (21 February 1967)

Fig. 2. CONTINUED.



c. Nighttime, Bozeman-Stanford path (19 October 1967)

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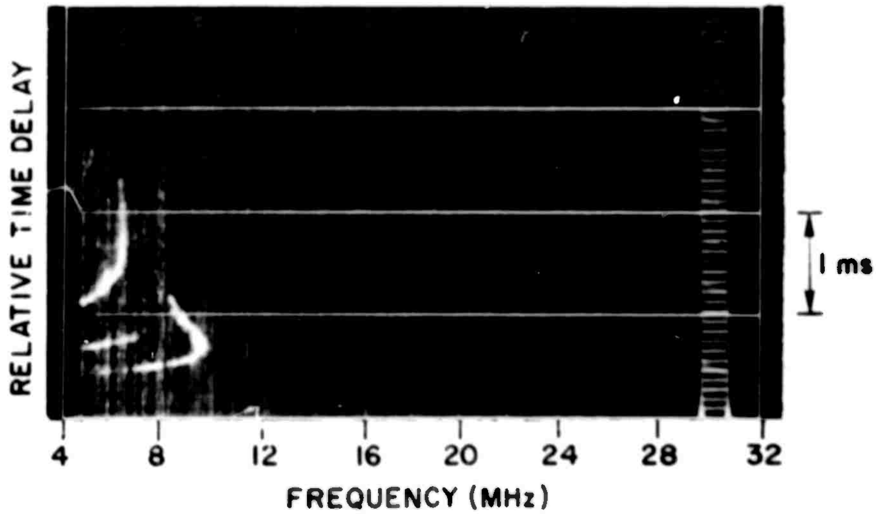

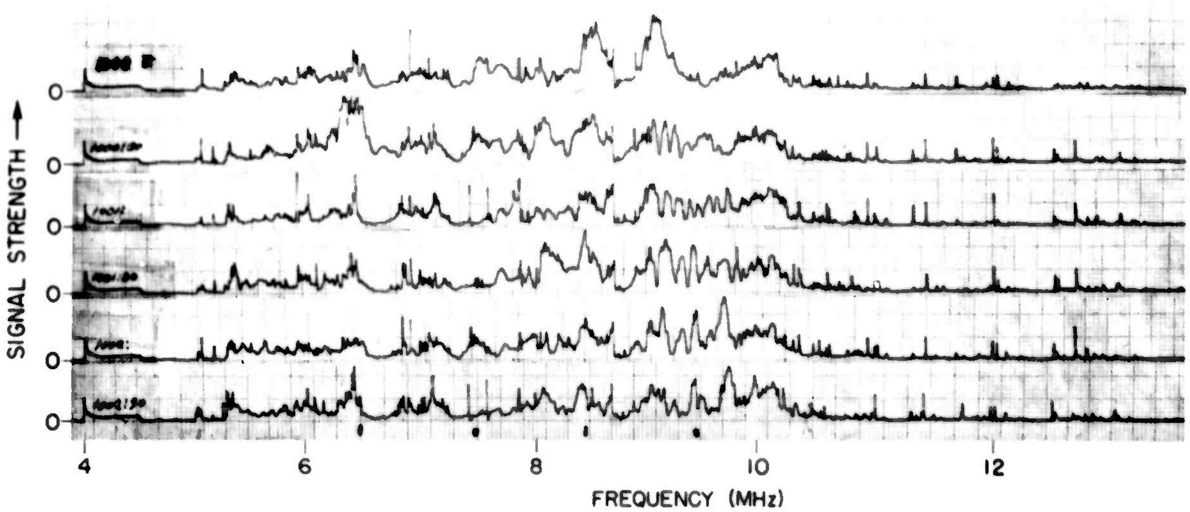

d. Nighttime, Lubbock-Stanford path (21 February 1967)

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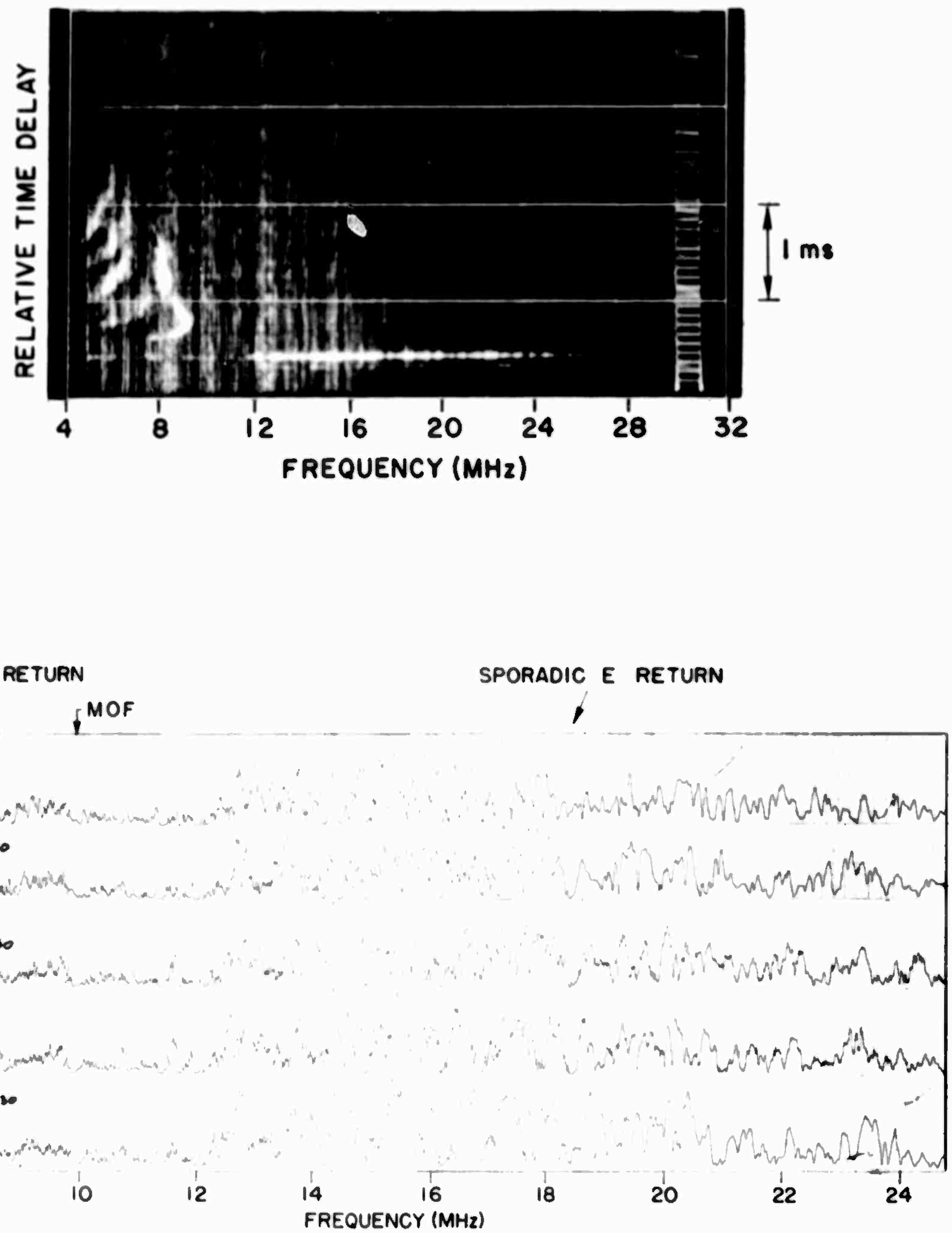
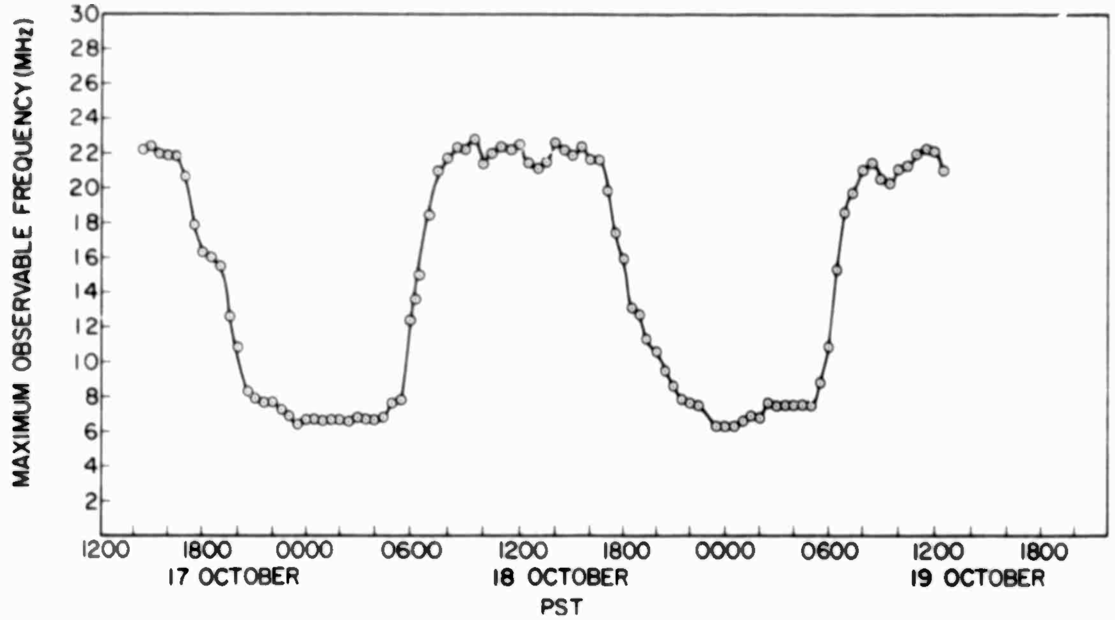
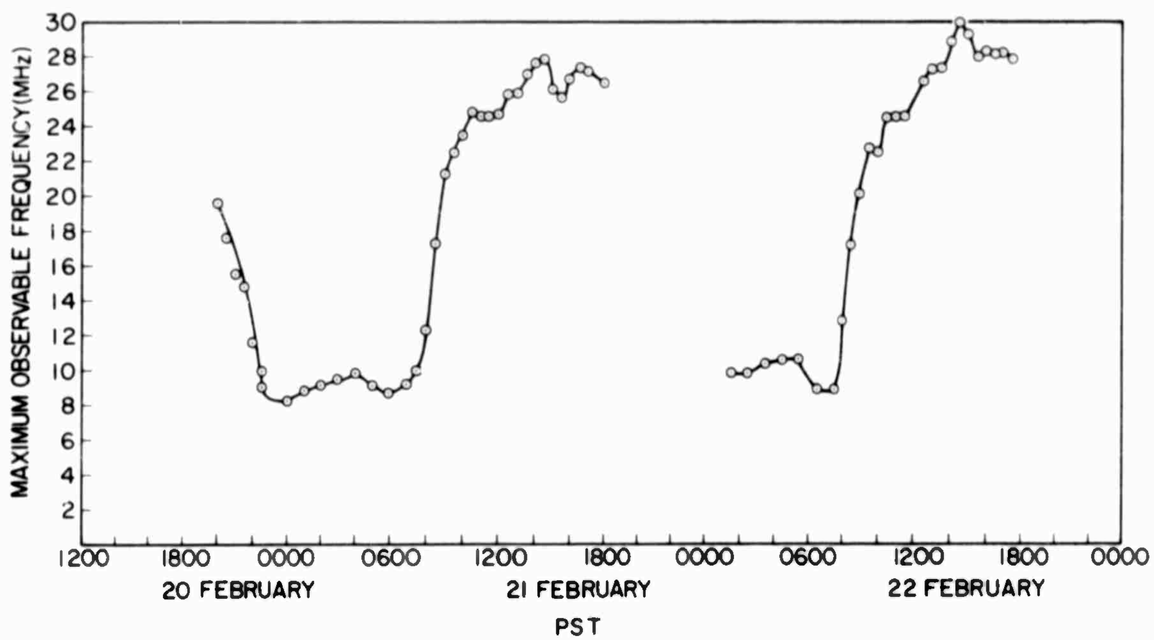


Fig. 3. NIGHTTIME SPORADIC E IONOGRAM AND AMPLITUDE RECORD (23 FEBRUARY 1967, STANFORD-LUBBOCK PATH).



a. Bozeman-Stanford path



b. Lubbock-Stanford path

Fig. 4. MAXIMUM OBSERVABLE FREQUENCY OF THE ORDINARY RAY AS A FUNCTION OF TIME OF DAY.

III. RESULTS

Results of the data reduction are shown for both paths in Figs. 5 and 6. Figure 5 displays the rate of occurrence of amplitude nulls due to variations of polarization with time vs time of day. Figure 6 displays the null-to-null spacing in the frequency spectrum of amplitude variations due to polarization rotation with frequency vs time of day. The following general observations may be made from these two figures:

1. Large fluctuations in the polarization variations with both time and frequency occur throughout the day.
2. Polarization variations with time do not appear to be the primary factor producing signal strength amplitude variations during the nighttime period.
3. Differences in the polarization data with changes in operating frequency are more apparent in the variations of polarization with frequency than in the variations with time.
4. Of the three frequencies scaled, the rate of variation of incoming polarization with frequency (which is inversely proportional to the signal amplitude null-to-null spacing) appears to be highest at 0.9 MOF_o over both transmission paths. Inspection of the raw data indicates that the rate of polarization rotation continues to increase above 0.9 MOF_o until the MOF_o is reached. No polarization effects occur between MOF_o and MOF_x because only one magnetoionic component propagates (see Fig. 2a). Over the Bozeman path, the 0.8 MOF_o data clearly possess the slowest polarization variation with frequency; over the Lubbock path it is not clear whether the 0.7 MOF_o or the 0.8 MOF_o record possesses the slowest polarization variation.
5. The rate of change of received polarization with time was very low during nighttime periods. In comparing successive nighttime records, it was difficult at times to find any differences in the location of the nulls and maxima for several minutes. This circumstance is probably related to the great stability of f_oF_2 at night.
6. The approximate average daytime and nighttime values of null-to-null spacing with frequency over both paths are tabulated below:

	Bozeman Path		Lubbock Path	
MOF_o	Day	Night	Day	Night
0.7	500 kHz	500 kHz	3.0 MHz	800 kHz
0.8	1.5 MHz	200 kHz	4.5 MHz	1.2 MHz
0.9	500 kHz	200 kHz	3.0 MHz	1.2 MHz

7. Rates of polarization variation with frequency were larger at night than during the day by about a factor of 2.

8. The approximate average daytime rate of null occurrence with time over both the Bozeman and Lubbock paths was 0.5 null/min for the three frequencies considered, with occasional peaks to 1.3 nulls/min. At night this average was 0.1 null/min.

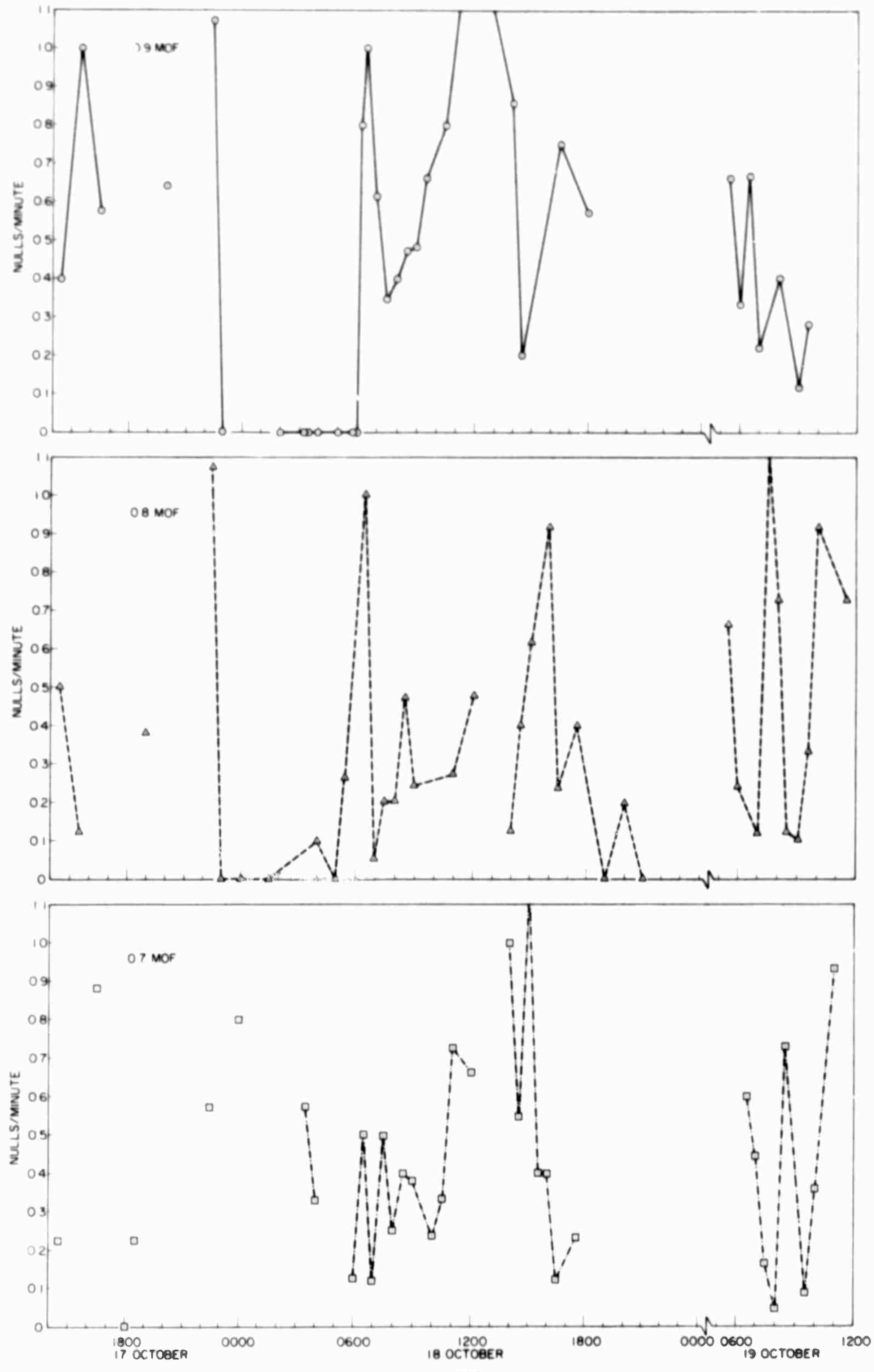
9. On the occasions when nighttime sporadic E occurred, it appeared that polarization effects were not the dominant cause of amplitude variations. Adjacent amplitude vs frequency records were uncorrelated.

10. The variation of polarization with frequency is a function of path, but the variation of polarization with time is not.

11. The average rate of polarization variation with frequency was four to five times higher on the N-S path than it was on the E-W path.

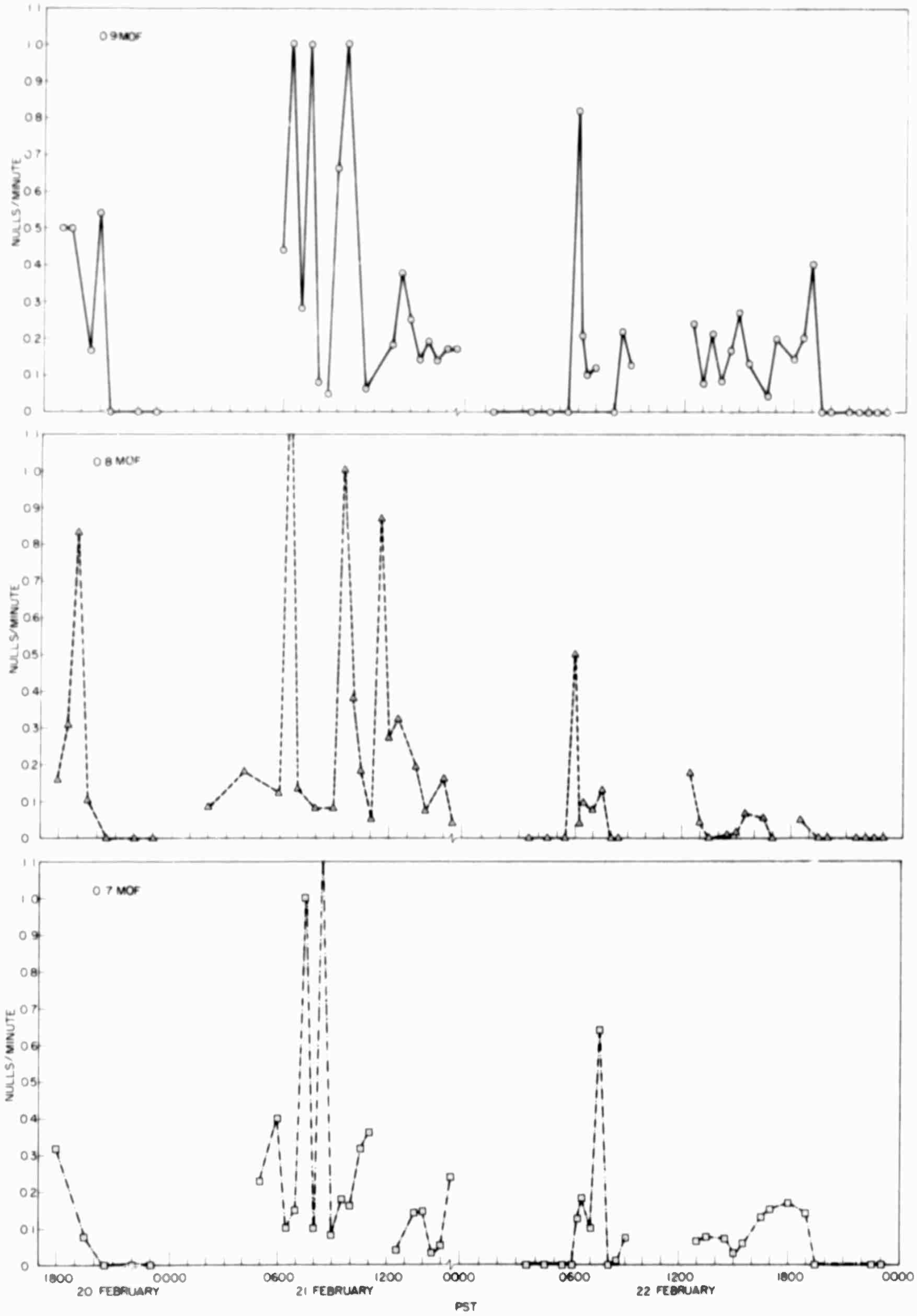
The observed variations of polarization with time are consistent with the CW daytime observations made by Hedlund and Edwards [3] at 12.7 MHz over a 1600 km E-W path. These authors observed rates of rotation of polarization that varied from 0.33 to 1.25 turns/min.

The experimental results are also in agreement with theoretical predictions of the expected rate of polarization rotation as a function of frequency vs azimuth that were made in an earlier report [4]. In Ref. 4 an increase of five to six times was predicted in the rate of polarization variation with frequency along a path aligned 22° E of N compared with an E-W path. However, any conclusions on the differences in the experimental results for the two paths must be carefully drawn since three important parameters differed for the two tests: path azimuth, time of year, and length of path. A larger amount of magnetoionic splitting is theoretically expected on the Bozeman path because the raypath is more closely aligned along the earth's magnetic field. This splitting is further enhanced by the 600 km difference in path length.



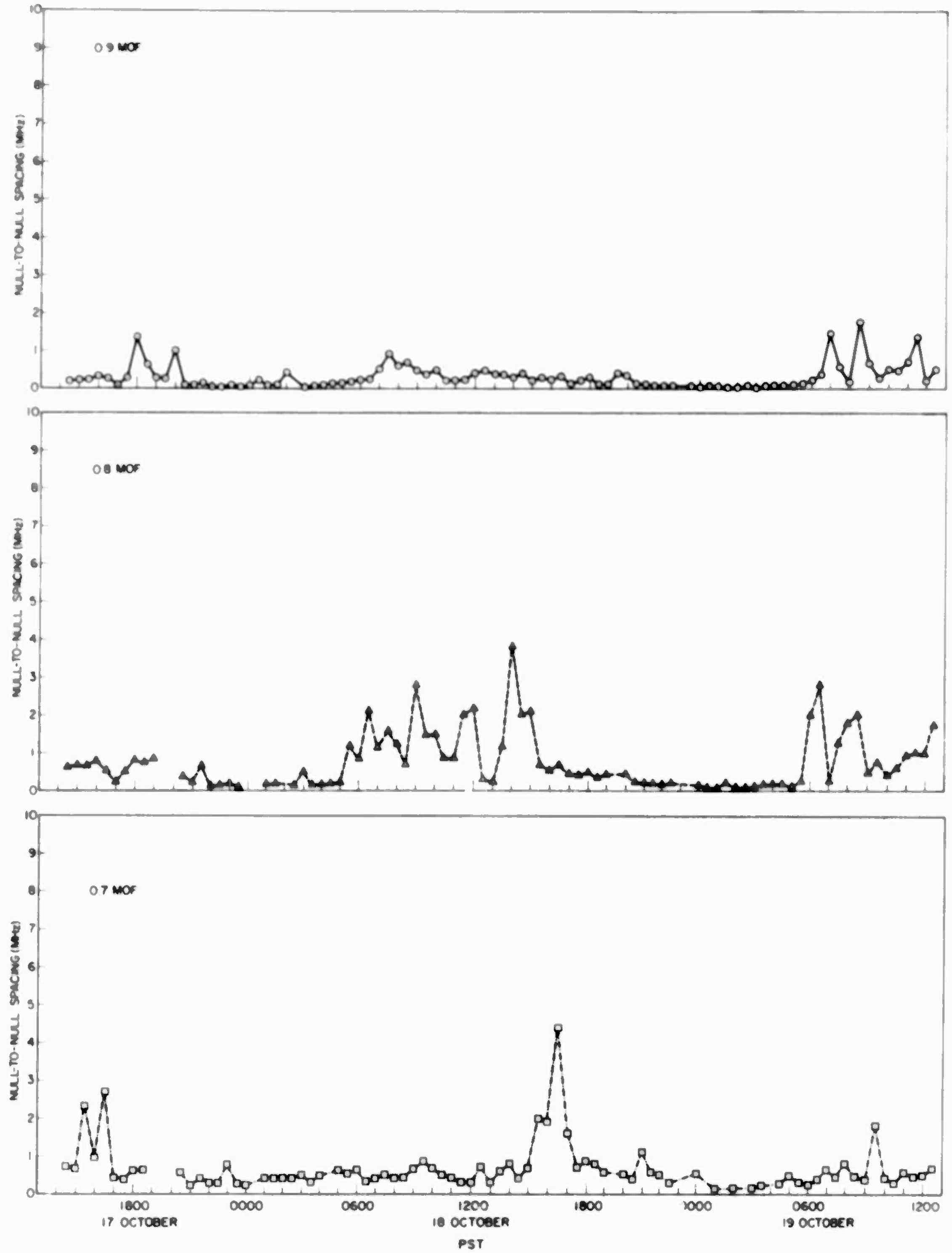
a. Bozeman-Stanford path

Fig. 5. POLARIZATION VARIATIONS WITH TIME.



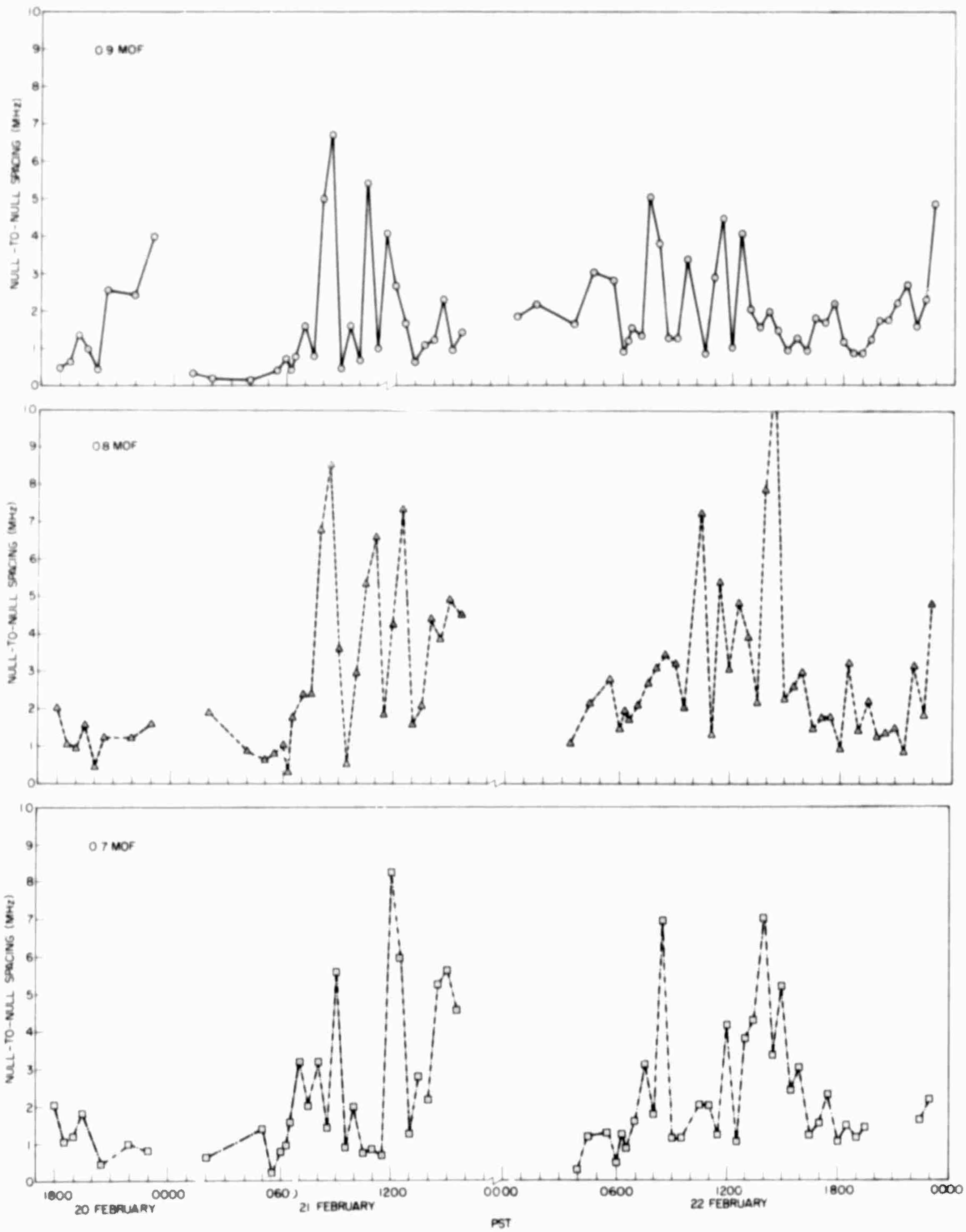
b. Lubbock-Stanford path

Fig. 5. CONTINUED.



a. Bozeman-Stanford path

Fig. 6. POLARIZATION VARIATIONS WITH FREQUENCY.



b. Lubbock-Stanford path

Fig. 6. CONTINUED.

IV. DISCUSSION

The effects of polarization variation due to ionospheric passage on signals received on linearly polarized antennas are considered here as a function of the extent of the signal bandwidth compared with the null-to-null spacing of the polarization-induced amplitude variations.

A. Effects on Narrowband Signals

The comparatively slow rate of change of incoming polarization with time at a fixed radio frequency shows why linearly polarized antennas give acceptable performance for narrowband HF communication. The reason is that signal amplitude variations that occur as a result of the incoming signal polarization becoming orthogonal to the receiving antenna polarization--even when only one mode is present--do so at a rate slow compared with amplitude variations due to normal multipath propagation. In addition, it is comparatively unlikely that the net polarization of the multimode combination of fields will be both linearly polarized and orthogonal to a linearly polarized receiving antenna at a given instant of time. When the net incoming polarization is momentarily linear and orthogonal to that of the receiving antenna, the received signal will disappear, but only for an interval of time whose duration is comparable to that of the occurrence of signal minima due to multipath fading where no polarization effects are involved. This circumstance also provides the reason why polarization diversity reception (i.e., use of antennas of differing polarization with one or the other antenna being employed on the basis of whichever has the higher signal strength) will only occasionally fill in a momentary signal null observed on a single antenna for multipath propagation. The amplitude variations due to polarization will be most pronounced, of course, when only one mode is present, but the signal strength will be below threshold for only short intervals of time if the HF circuit has a high signal-to-noise ratio.

Even for the multimode situation, a signal strength advantage can be obtained for the narrowband case by making the receiving antenna polarization adapt to the polarization of the incoming signal. Such automatic circuits that might be employed must have a speed of response comparable to the speed necessary to follow multipath fading changes. When a single mode is being received, the adaptive speed requirement greatly relaxes, as indicated by the data presented in Section III. The CW multimode situation could also be improved by the use of antennas that receive only one magnetoionic component. Under this circumstance the strongest received mode relative to the other incoming modes will not fade because of polarization effects.

B. Effects on Broadband Signals

Discussions in Reference 2 have shown that when linearly polarized antennas are employed, polarization is the dominant factor in determining the instantaneous value of single-mode ionospheric channel amplitude as a function of both frequency and time. The variation of amplitude with frequency can produce signal waveform distortion. The effects of these variations with frequency can be minimized by choosing the operating frequency to be that at which the slowest rate of polarization variations is observed. The data presented in Section III indicate that the slowest rates occur near 0.8 MOF_o. The occurrence of such a minimum rate of polarization variation with frequency in the one-hop F mode indicates the crossing of the ordinary and extraordinary components. A possible explanation for the (nearly) fixed location in the spectrum of this crossing is that the ratio of MOF(F) and MOF(E) may remain approximately constant a high percentage of the time.

Signal bandwidths beyond which signal waveshape might be distorted due to the effects of polarization variation with frequency (at an instant of time) may be determined from the results presented in item 6 of Section III. These values may be expressed in terms of a polarization bandwidth (which is equal to one-half the polarization-induced null-to-null spacing in frequency--see Refs. 2 and 4). It is important to note that polarization bandwidths that are appreciably less than the average value--as low as 25 kHz--occur many times during the day and night. Since the presence of both magnetoionic components is necessary for the occurrence of polarization effects, one method for removing the effects of polarization variations with frequency is to match the antennas to the ionosphere by using characteristically polarized antennas. It should be noted that polarization diversity, such as is employed for CW signals, does not remove the effects of polarization variations with frequency--even for single-mode communication.

The broadband multipath situation approximately corresponds to the narrowband multipath situation with additional signal distortion due to polarization variations with frequency on each of the propagating modes. However, in addition to polarization and multipath effects, ionospheric dispersion produces a nonlinear variation in incoming signal phase as a function of transmitted frequency which can also be large enough to produce waveshape distortion for broadband signals. The use of characteristically polarized antennas, which allow only one magnetoionic mode to propagate over each raypath, restores the broadband multipath situation to that of the narrowband situation, but it doesn't remove the effect of the ionospheric dispersion.

V. CONCLUSIONS

Round-the-clock measurements of HF wave polarization were made after ionospheric passage over a N-S and an E-W temperate-latitude path for two and one-half days per path. The results indicate that daytime rates of polarization rotation with frequency (at an instant of time) average 1 turn/MHz over the N-S path, and 0.25 turn/MHz over the E-W path. These rates are higher at night by about a factor of 2. Lowest rates of polarization rotation at a given instant of time occur at a transmitted frequency of approximately 0.8 MOF_o. At times, rates as fast as 7 turns/MHz were observed to occur at frequencies lower than 0.9 MOF_o. (Occurrence of very high rates is nearly always observed at frequencies greater than 0.9 MOF_o because of the larger magnetoionic splitting that occurs near the junction frequency.) Daytime rates of polarization rotation with time (at a given frequency) average 0.25 turn/min (equivalent to 0.5 signal strength null/min). These rates do not appear to vary with either path azimuth or radio frequency. Large fluctuations in the polarization variations--with both time and frequency--occur throughout the day.

Polarization measurements made with signals that were reflected from nighttime sporadic E layers indicate that factors other than polarization effects determine much of the observed signal strength variations with frequency and time.

The results indicate that the approximate round-the-clock bandwidth threshold--above which the communications engineer might have to consider the effects of polarization variation with frequency (at an instant of time)--is 100 kHz for N-S paths and 400 kHz for E-W paths. Presumably, those limits decrease in proportion to the number of hops taken by the radio energy along the path. For the paths studied, the effects of polarization distortion may be reduced by operating at 0.8 MOF_o (in preference to other frequencies) because of the slower rates of polarization rotation encountered there, or by the use of antennas whose polarizations correspond to that of one of the two ionospheric characteristic waves along the raypath where the transmitted energy enters and leaves the ionosphere. For many temperate-latitude paths, these characteristic-wave polarizations are nearly circularly polarized.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Stanford Electronics Laboratories
Stanford University, Stanford, California

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
RECEIVED POLARIZATION OF IONOSPHERICALLY PROPAGATED WAVES AS A FUNCTION OF TIME AND FREQUENCY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report

5. AUTHOR(S) (First name, middle initial, last name)
M. R. Epstein and O. G. Villard, Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1968	21	4

8a. CONTRACT OR GRANT NO.
Office of Naval Research Contract
b. PROJECT NO. Nonr-225(64), NR 088-019
ARPA Order No. 196
c.
d.

9a. ORIGINATOR'S REPORT NUMBER(S)
SEL-68-014

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
TR No. 145

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Office of Naval Research
Advanced Research Projects Agency

13. ABSTRACT
The incoming wave polarization of sweep-frequency CW radio transmissions was measured as a function of HF frequency and time of day for one-hop F-layer propagation over 1300 km N-S and 1900 km E-W temperate-latitude paths. Daytime rates of polarization rotation with frequency (at an instant of time) average 2 turns/MHz (equivalent to a null-to-null spacing of 250 MHz) over the N-S path, and 0.25 turn/MHz over the E-W path. These values are in good agreement with predictions that were made using computer raytracing techniques. Higher rates of polarization rotation with frequency are observed at 0.7 and 0.9 MOF_o than at 0.8 MOF_o. The rates are higher at night by about a factor of 2. Typical daytime rates of polarization rotation with time (at a given frequency) average 0.25 turn/min (equivalent to 0.5 signal strength null/min). These rates do not appear to vary either with path azimuth or transmitted radio frequency. Near-zero rates of polarization rotation with time occur for much of the nighttime period. Large fluctuations in the polarization variations occur with both time and frequency throughout the day. Polarization measurements made with signals that were reflected from nighttime sporadic E layers indicate that, for these layers, circumstances other than polarization effects determine much of the observed signal strength variations with frequency and time. The results suggest that for round-the-clock propagation when linearly polarized antennas are employed, envelope distortion of broadband signals--due to variation in the incoming polarization with frequency--begins when signal bandwidths exceed approximately 100 kHz for N-S paths and 400 kHz for E-W paths. The effects of such distortion may be reduced either by operating near 0.8 MOF_o or by the use of circularly polarized antennas.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
POLARIZATION						
HF COMMUNICATIONS						
IONOSPHERIC SOUNDING						
IONOSPHERIC PROPAGATION						