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DIGITAL IONOSPHERIC SOUNDING IN THE ARCTIC

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20. Abstract

propagation ionograms between the GBIO Digisonde and the moving AIO sounder facilitates the interpreting of different modes of propagation. Software for the AFGL CDC 6600 computer and for a microcomputer was developed for the processing of the digital ionograms. The identification of ordinary and extraordinary echoes in the Goose Bay ionograms greatly simplify the automatic processing of ionograms. Indeed, it became clear that for automatic ionogram trace identification the Q and X tagging is a prerequisite. In support of the ESD 414L project an ionogram communicator (ICOM) was added to the GBIO Digisonde providing - via telephone lines, - real-time ionogram printouts at the Over-The-Horizon Backscatter Experimental Radar System in Maine. Another Digisonde station was equipped and brought to operation in Keflavik, Iceland, to provide environmental data for the OTH radar operation.

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1.0 INTRODUCTION

This report is a summary of the effort performed by ULCAR from March 1978 to March 1980 in support of arctic ionospheric research at Goose Bay (Labrador), Keflavik (Iceland), the OTH Radar Site in Maine and AFGL's Flying Ionospheric Observatory. The Digisondes 128PS at Goose Bay and on board AFGL's KC135 aircraft have been updated and are operating to satisfaction. A Digisonde 128 was installed at Keflavik in Iceland and is recording good quality ionograms on magnetic tape and paper printout. A telephone link connects the Goose Bay Ionospheric Observatory and the Over-The-Horizon Radar Site in Maine to print in real time Goose Bay ionograms at the Radar Site, providing the ionospheric mid-point information when the radar operates in the northern half of its coverage area.

Computer software was developed for the processing of the tape recorded ionograms from the aircraft and from Goose Bay. For the automatic processing of Goose Bay ionograms we used the Geomonitor (Reinisch and Smith, 1976) data to extract the ionospheric parameters foF2, MUF(3000), ftEs and fmin. This Automatic Evaluation Program was successfully tested on some one thousand ionograms, and the results were published in Scientific Report No. 1 (Smith et al, 1979).

Routine evaluation of the hourly Goose Bay ionograms in terms of the standard URSI parameters was carried out. All parameters were coded onto punch cards for use by the Air Force and the World Data Center. Appendix A shows the graphic presentation of the monthly median values for 1977 and 1978.

2.0 DIGITAL SOUNDING SYSTEMS

To improve the diagnostic capabilities of the ionospheric sounding systems aboard AFCL's KC135 aircraft and at the Goose Bay Ionospheric Observatory (GBIO), the digital processing and control chassis were replaced by the Digisonde 128PS version. This new digital sounder (Bibl and Reinisch, 1978a) measures doppler frequencies as well as wave polarization and incidence angle if an adequate receiving antenna array is available.

2.1 Goose Bay Ionospheric Observatory

The GBIO Digisonde system comprises: a new Digisonde 128PS Processor chassis with ionospheric drift measurement capabilities and on-line spectrum analysis, the analog Receiver, Synthesizer and Translator chassis covering a frequency range from 0.5 to 20 MHz, a new 2 x 4 loop Antenna Switch, an additional antenna switch for 2 x 12 oblique receiving antennas, a vertical rhombic transmitter antenna, one low-incidence-angle vertically polarized logarithmic periodic antenna pointing to magnetic north, and a steerable horizontally polarized log-periodic antenna, the latter three driven by two Granger Pulse Transmitters. In addition to the local Plasma Display and the double-ionogram printer, there are two remote outputs: one connecting via dedicated telephone lines to the Geomonitor in the "Receiver" building (building T831), and the Ionogram Communicator (ICOM) chassis connecting via RS-232C and modem interface to a dedicated telephone line for remote printout of ionograms at the OTH site in Maine.

The System Description and Manual for the Digisonde 128PS (Bibl and Reinisch, 1978b) which was prepared for the system operators explains the different modes of operating the Digisonde. For routine ionogram operation, vertical and ob-

lique backscatter ionograms are alternated, initially at a rate of 12 vertical and 12 backscatter ionograms per hour, presently at 4 and 4 ionograms per hour. All amplitude values in an ionogram are accompanied by 4-bit status words which the Digisonde prints as a separate status ionogram (Figure 1). Table 1 explains the meaning of these status words for the different time periods since 1978. The so-called vertical off-hour ionogram (A-program) actually scans three directions: north-north-west, north-north-east (elevation 68°), and vertical as indicated in Table 1. The hourly ionogram (C-program), starting at one minute before the full hour, scans the magnetic meridian plane with elevation angles of 68° , 70° and 90° . The vertical rhombic antenna with a height of approximately 60 m is used for transmission. In June 1980 the transmitter output was increased from 0.5 to 10 kW peak pulse power. The 2×4 loop antenna receiving array provides the right and left hand circular polarized signals to the Digisonde's Antenna Switch which selects the O and X polarization alternating from pulse to pulse. The 3 dB beamwidth of the array is 11° for a frequency of 10 MHz. The first full side lobe for this frequency occurs at a zenith angle of 37° .

The backscatter ionograms (B-program) use the linear 12-antenna array for reception and the fixed log-periodic antenna for transmission in magnetic north direction. The status words indicate the doppler frequencies from -14 to +14 Hz for status numbers from 0 to 15. Peak transmitter power is now also 10 kW. Figures 1a, b, c show a sequence of vertical and backscatter ionograms demonstrating the three types of ionograms.

On 3 July 1978 the Digisonde 128PS was brought to full operation. During a very severe thunderstorm lightning hit the equipment and destroyed a number of circuits in the Processing Controller. The Controller was transported back

INTERPRETATION OF STATUS FOR GOOSE BAY IONOGRAMS

IONO.		STATUS															Tt	Z
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Vertical Hourly 14 Jun 80	I/P	N ₂	N ₁	V _x	V ₀	N ₂	N ₁	V _x	V ₀	N ₂	N ₁	V _x	V ₀	N ₂	N ₁	V _x	V ₀	42
	S	-2	-2	-2	-2	-1	-1	-1	-1	+1	+1	+1	+1	+2	+2	+2	+2	
Vertical Off-Hour 14 Jun 80	I/P	O ₂	G ₂	V _x	V ₀	O ₂	G ₂	V _x	V ₀	C ₂	G ₂	V _x	V ₀	O ₂	G ₂	V _x	V ₀	42
	S	-2	-2	-2	-2	-1	-1	-1	-1	+1	+1	+1	+1	+2	+2	+2	+2	
Backscatter Nov 79	I/P	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	7
	S	-8	-7	-6	-5	-4	-3	-2	-1	+1	+2	+3	+4	+5	+6	+7	+8	
Vertical Hourly Jul 79	I/P	N ₂	N ₂	V _x	V _x	N ₁	N ₁	V ₀	V ₀	N ₂	N ₂	V _x	V _x	N ₁	N ₁	V ₀	V ₀	42
	S	-1	-2	-1	-2	-1	-2	-1	-2	+1	+2	+1	+2	+1	+2	+1	+2	
Vertical Off-Hour Jul 79	I/P	O ₂	O ₂	V _x	V _x	G ₂	G ₂	V ₀	V ₀	O ₂	O ₂	V _x	V _x	G ₂	G ₂	V ₀	V ₀	42
	S	-1	-2	-1	-2	-1	-2	-1	-2	+1	+2	+1	+2	+1	+2	+1	+2	
Backscatter 1978	I/P	*	D	V	N ₂	*	D	V	N ₂	*	D	V	N ₂	*	D	V	N ₂	45
	S	*	-1	-1	-1	*	-2	-2	-2	*	+1	+1	+1	*	+2	+2	+2	

I/P Incidence Angle and Polarization S Spectrum, Relative Doppler Frequencies
 N₂ Mag. North, 68° Elevation V Vertical
 N₁ Mag. North, 79° Elevation V₀ Vertical, Ordinary Component
 O₂ Mag. 30° West, 68° Elevation V_x Vertical, Extraordinary Component
 G₂ Mag. 30° East, 68° Elevation D DAASM Array

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Table 1

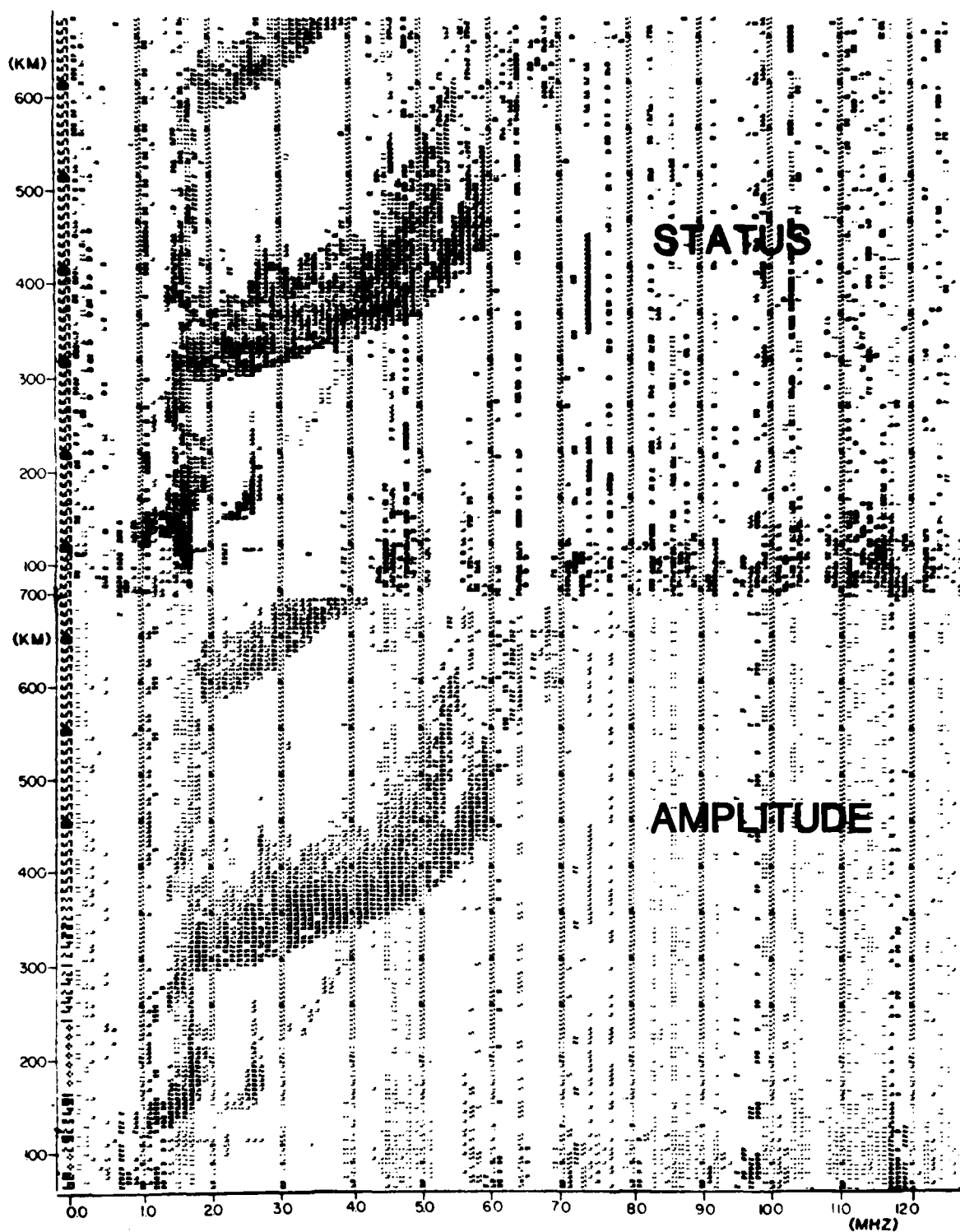


Figure 1a. Goose Bay Vertical Ionogram
29 JAN 1980 2349 AST

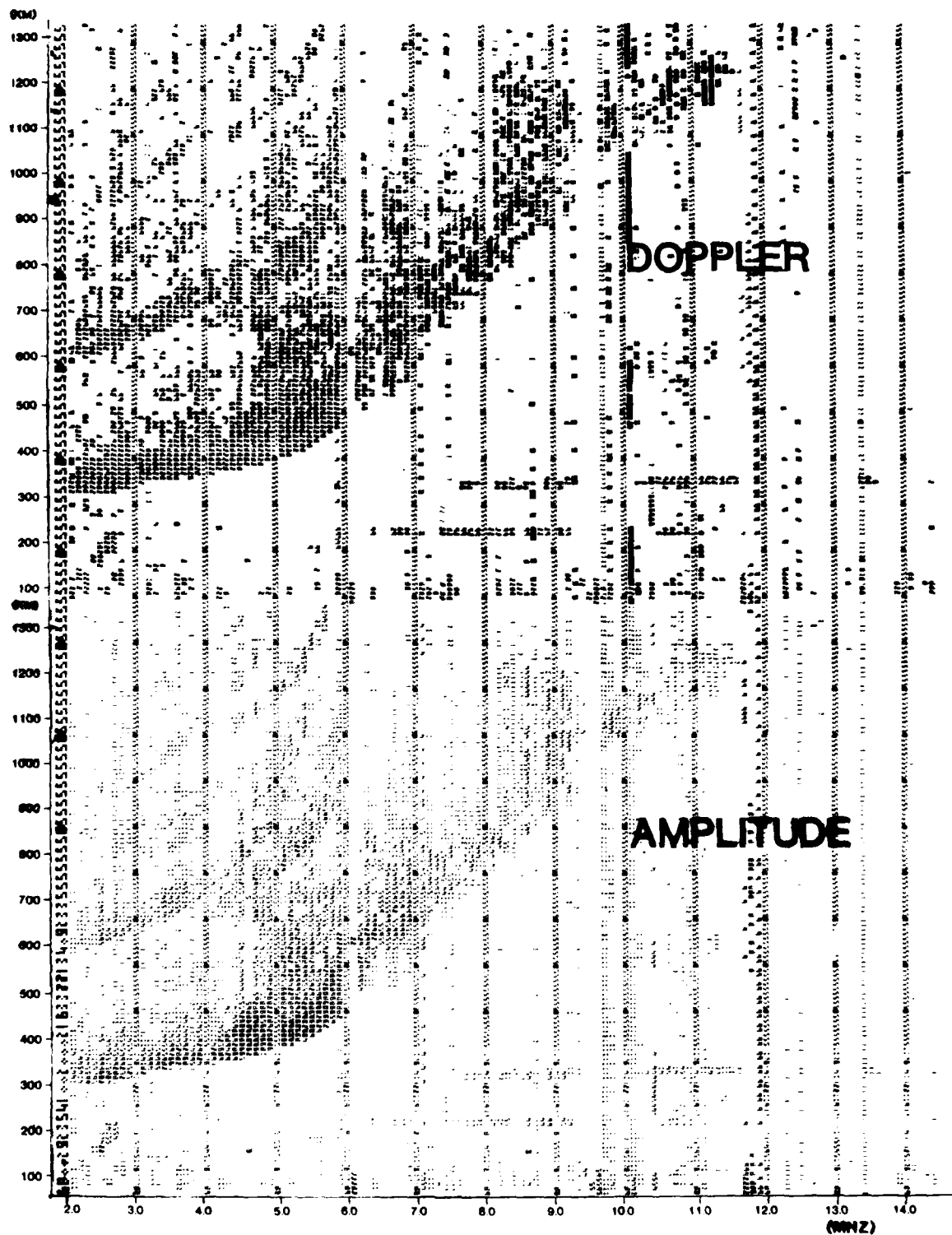


Figure 1b. Goose Bay Backscatter Ionogram
29 JAN 1980 2354 AST

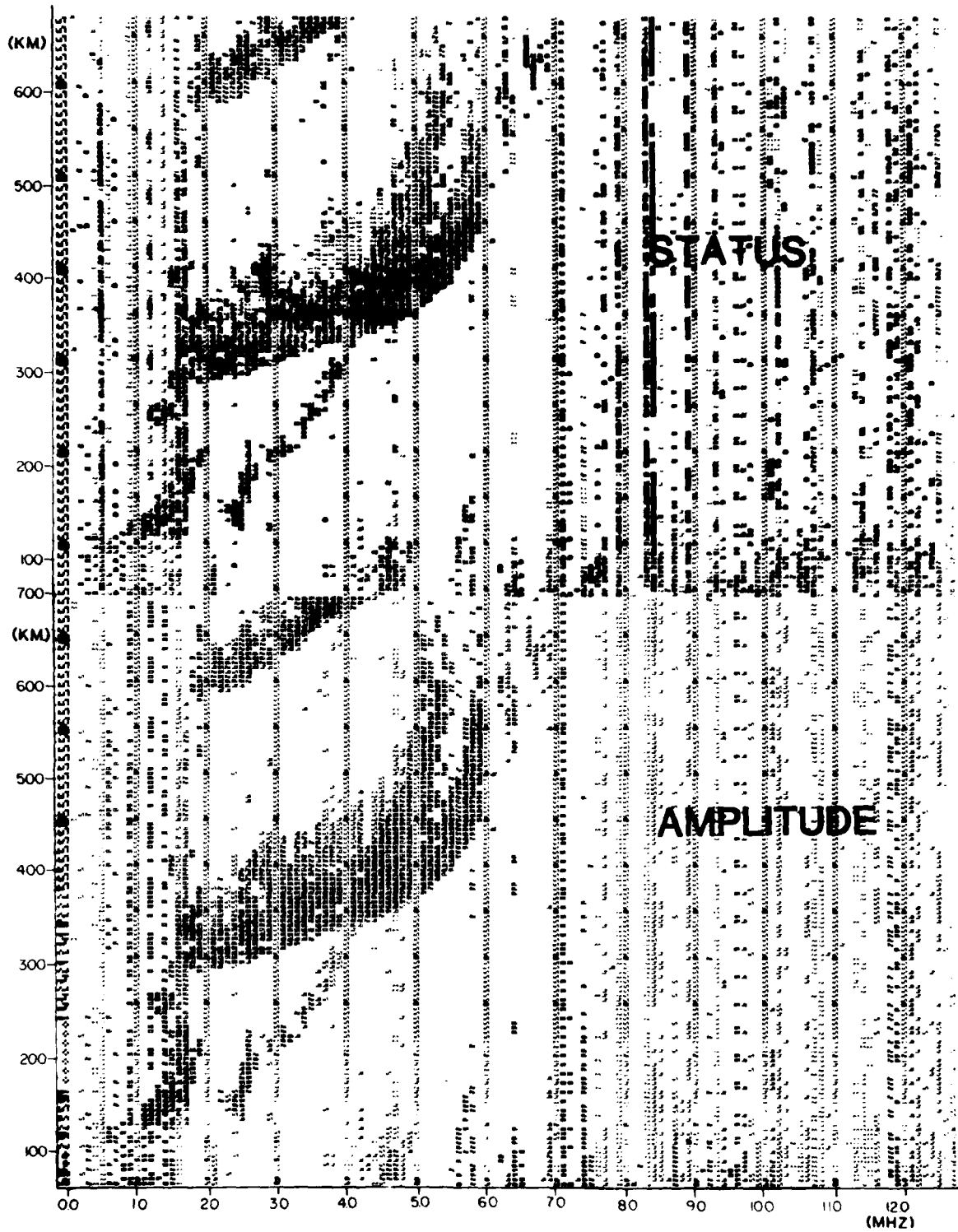


Figure 1c. Goose Bay Vertical Ionogram, Hourly Program
29 JAN 1980 2359 AST

to ULCAR for repair. Since the old Digisonde 128 had been left in place to serve as an alternate it was used during the repair period. Components in the interface between the Digisonde and the Geomonitor were also destroyed. A new interface card, located in the digital chassis, was built and an additional interface buffer with separate power supply installed outside the main frame to avoid a repeat of this occurrence. Also the filtering on both sides of the telephone line has been redesigned and rebuilt to discharge any static electricity on either end of the line and to separate the signals from the large differential AC between the two stations caused by the poor grounding conditions in the sandy soil.

The Digisonde 128PS chassis was updated to include the capability of suppressing the X-echoes in the on-line and Geomonitor outputs and to be able to produce double ionograms with amplitude on one frame and the status on the other, in addition to the split screen capability. Figure 2a shows an amplitude ionogram on top and the respective status ionogram on the bottom. Printing of X-polarized echoes was suppressed in this ionogram except during small frequency intervals marked by an "X". Suppression of the X-echoes is programmable and was deactivated during the "X" intervals to demonstrate the effectiveness. In this 1978 ionogram the status numbers are even for the O-echoes, and odd for the X-echoes. Figure 2b illustrates the optically weighted number font that had previously been developed for the Digisonde ionograms (Bibl et al, 1971).

2.2 Geomonitor Interface

A special interface card was designed and built at ULCAR for interfacing the Processing Controller to the Geomonitor. This new card, GEOMON MII 26, simulates the data rate and format of the Memory of the old Digisonde 128. For

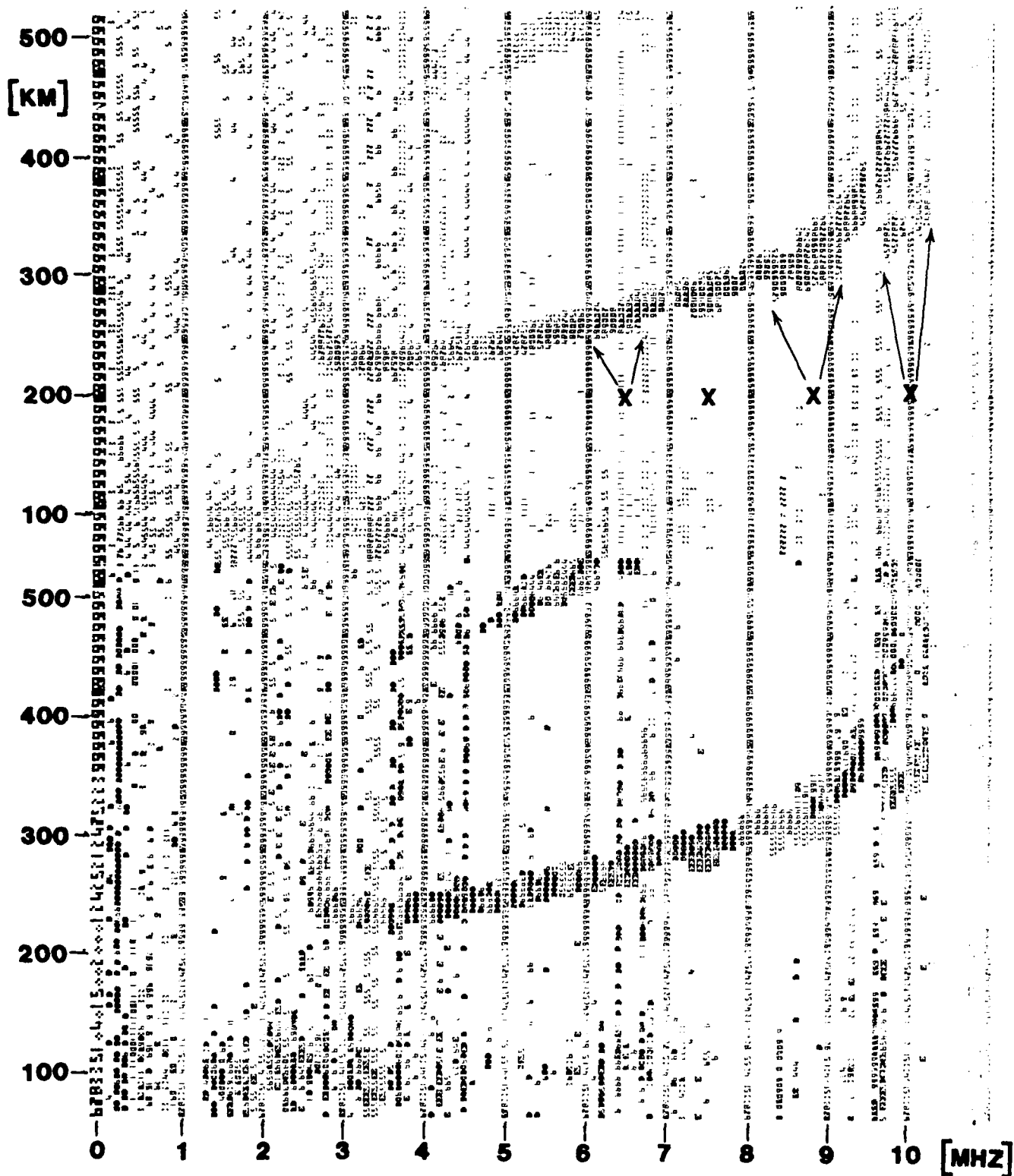


Figure 2a. Amplitude and Status Ionogram with Switched Suppression of X-Polarization

each ionogram frequency a group of 216 six-bit characters is outputted at a rate of 500 Hz. The first 24 characters are the preface, which is followed by 128×1.5 data characters. The two highest bits of the first preface character (Station Identifier) are set equal to 1, signalling to the Geomonitor that the arriving data are coming from the new Processing Controller. The 32-character preface of the Processing Controller is compressed on GEOMON to 24 characters as indicated in Table 2. Most characters in the Processing Controller preface are BCD (0-9 representation). To keep a consistent preface length of 24 for the Geomonitor several characters have been combined. The 2LSB of the first character are placed in the 2MSB of the new 6-bit word. For example in combining Bb the new compressed character has the configuration

bit	
32	B(2)
16	B(1)
8	b(8)
4	b(4)
2	b(2)
1	b(1)

A new subroutine was added to the Geomonitor firmware, so that the Geomonitor can now be connected to the new Processing Controller or to the old Memory. Both operations were successfully demonstrated.

2.3 Geomonitor

After having been damaged by lightning the Geomonitor had been shipped to ULCAR. The necessary repairs were performed and the following software changes were made: (1) a coding error in the NOISE algorithm was eliminated, and (2) the number of processed frequencies was increased from 128 to 170 frequencies to accommodate the high critical frequencies

CHARACTER NO. 128PS GEOMON		SYMBOL	FUNCTION		CHARACTER NO. 128PS GEOMON		SYMBOL	FUNCTION	
1	1	V	Station Id.		19	16	E	End Frequency	
2	2	Y	YEAR		20		e		
3	3	y			21	17	R	Rep. Rate	
4	4	Δ	DAY		22		W	Pulse Width	
5	5	D			23	18	T	Task	
6	6	d			24	19	t		
7	7	H	HOUR		25		Q	Freq. Incr.	
8	8	h			26	20	N	Integr. Number	
9	9	M	MINUTE		27		X	Phase Code	
10	10	m			28	21	Z	Azimuth	
11	11	S	SECOND		29	22	K	Range Incr.	
12	12	s			30	23	J	Range Start	
13	13	r	FREQUENCY		31		G	Gain	
14	14	F			32	24	G'	Mod. Gain	
15	15	f							
16	16	a							
17	17	B	Beginning Frequency						
18	18	b							

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Table 2. Modified Preface for Geomonitor

of the F layer experienced during the years of high sunspot numbers. The latter change increased the amount of output data from 2340 to 3072 six-bit characters. A hardware modification in the Geomonitor was necessary for the new magnetic tape record length of 3072 bytes. This record length applies to both ionogram and geophysical data. In the latter case only the first 2340 bytes contain meaningful data. Table 3 shows the magnetic tape recording format for the ionogram data.

A five position rotary switch, mounted on the Geomonitor front panel, selects the number of ionograms that are printed on the Versatec printer, and the type of ionogram, i.e. reconstituted or raw (dynamically cleaned) ionograms. The Plasma Display is always activated and the rotary switch merely selects cleaned or reconstituted ionograms. Table 4 lists the available options.

2.4 Ionogram Communicator

ULCAR has submitted to AFGL a System Description and Manual of the Remote Ionogram Communicator (Smith et al, 1979). This report gives a detailed description of the ICOM system. Since its installation in July 1979 the remote printout system is working very reliably, communicating the ionogram information from Goose Bay to the Maine OTH Receiver Site.

Figure 3 is the ICOM flow chart which describes the priorities of the system. In the event of a failure in the system, several modes of operation are available to isolate the device producing the problem. In the block diagram, Figure 4, the progression of data is shown.

Character No.	Explanation
1 - 12	Header
13 - 36	Modified 128PS Preface
37 - 1396	{N, G, AE1, AE2, AF1, AF2, AF3, AF4} x 170 Frequencies
1397 - 2926	{HE1, HE2, DE, HF1, HF1/E1, HF2, HF3, HF4, DF} x 170 Frequencies
2927 - 3054	{IH} x 128 Range Bins
3055 - 3072	Not Used

Table 3. Geomonitor Ionogram Data Tape Format

Rot. Switch	Cleaned Ionograms Iono. Times [min]	Reconstituted Ionograms Iono. Times [min]
1	59, 04	
2	59, 14, 29, 44 (all vert.)	
3	All Ionograms	
4		
5		All Ionograms 59, 04

Table 4. Geomonitor Ionogram Printout

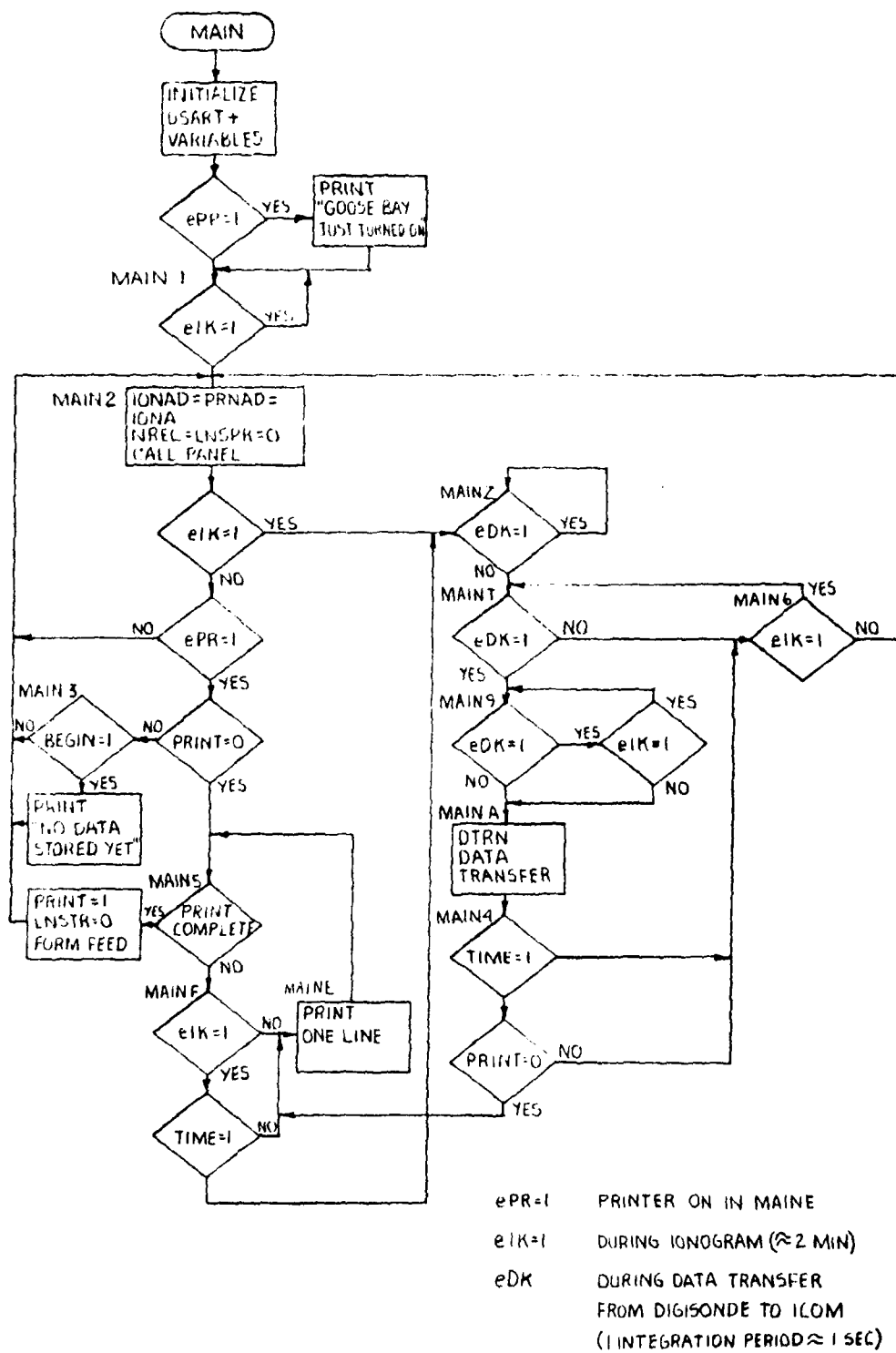


Figure 3. Main Flowchart ICOM 7810 005

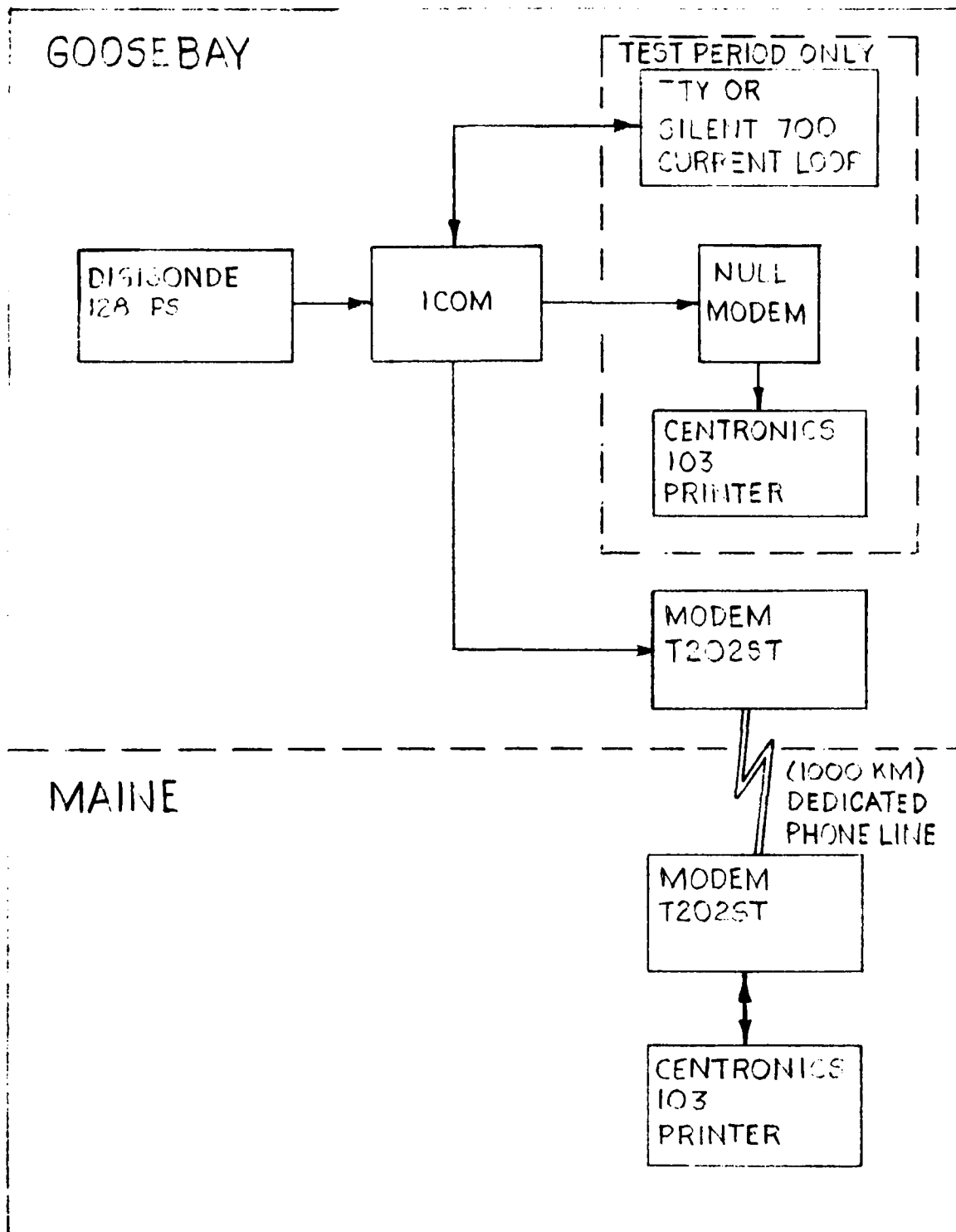


Figure 4. ICOM Block Diagram 7810 005

2.4.1 ICOM→TTY

In the ICOM a sample set of data is stored in PROM (Programmable Read Only Memory). This enables a check of the static shift register (SR) hardware and the programming within the ICOM independent of the Digisonde. The output is the PROM ionogram which is printed on the Silent 700 after processing for noise and X-trace identification. The flow of data is:

PROM → SR → ICOM ^{RAM} PROGRAM → ^{RS232} CURRENT → SILENT 700
LOOP

2.4.2 DIGISONDE→ICOM→TTY

The next step in testing the system is DIGISONDE→ICOM. Here we interface to the Digisonde using a 7-bit parallel data stream. The Digisonde 128PS provides a system calibration ionogram which is processed and displayed on the Silent 700. Only after completion of the ionogram (end of ionogram sensed) is the entire ionogram sent to the print device. Ionogram time is always tested: only ionograms recorded at times specified by the front panel SELECT switch are chosen for transfer to the printer. Figure 5 shows part of a calibration ionogram scanning from 2 to 12 MHz.

2.4.3 CENTRONICS (self test)

An important feature of ICOM is the ability to isolate each device for troubleshooting. The Centronics printer has been modified to display the Opti-Font character set across 132 columns in a self test mode. This is accomplished by pushing

- a) ON button
- b) self test switch under front cover to test (alert light indicates self test is on)

- c) SELECT button
- d) FORMS OVERRIDE button.

If the FORMS OVERRIDE button is pushed using a momentary action the printer displays the font-equivalent of 0 - 15. If the FORMS OVERRIDE button is held down, the font equivalent of 16 - 31 is displayed. The numbers 16 - 31 are the same as the 0 - 15 numbers except for an underlining of the numbers. This underlining technique can be used to emphasize the ordinary or the vertical echoes. Figure 6 is an example of the display.

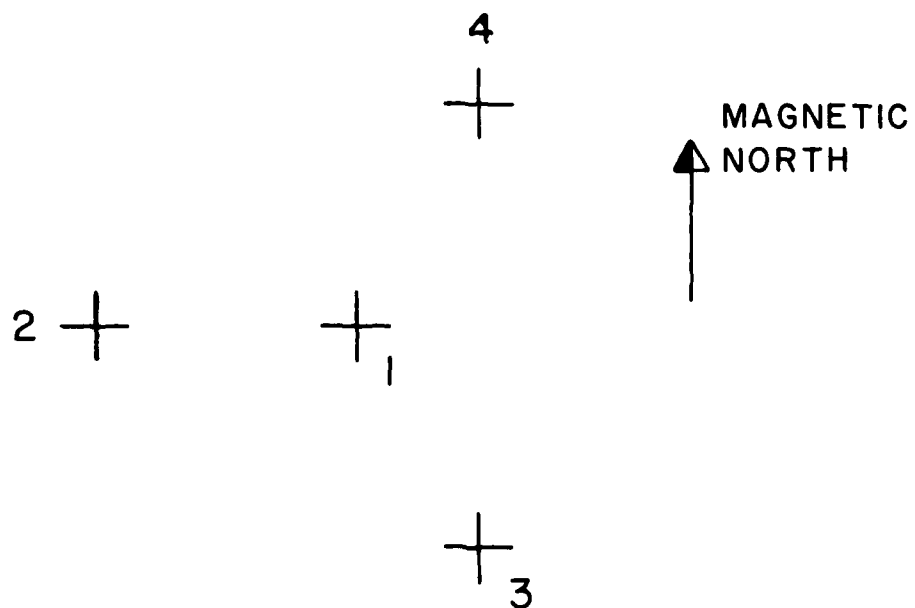
After final testing at ULCAR the ICOM was installed at the Goose Bay Ionospheric Observatory in the first half of July 1979. At the same time the modified Centronics printer with Opti-Font^R was installed at the USAF's Experimental OTH Radar System in Maine. The ICOM system was adapted to the Government supplied modems and routine transmission of Goose Bay ionograms to Maine began about 20 July 1979. An ICOM transmitted ionogram as printed in Maine is shown in Figure 7; here the X-echoes are suppressed and the vertical echoes underlined.

2.5 Antenna Switch

A new Antenna Switch was built, tested and installed at Goose Bay, interfacing the 2 x 4 receiving loops and the linear 12-antenna array to the Digisonde. The orientation of the four crossed-loop antennas is shown in Figure 8. All eight receiving antennas were tested and the antenna cables were equalized. An existing antenna switch was used to combine the signals of the 12-antenna array into one input to the new Antenna Switch.

[illegible]

22



CROSSED LOOP ANTENNA SYSTEM
GOOSE BAY, LABRADOR

Figure 8

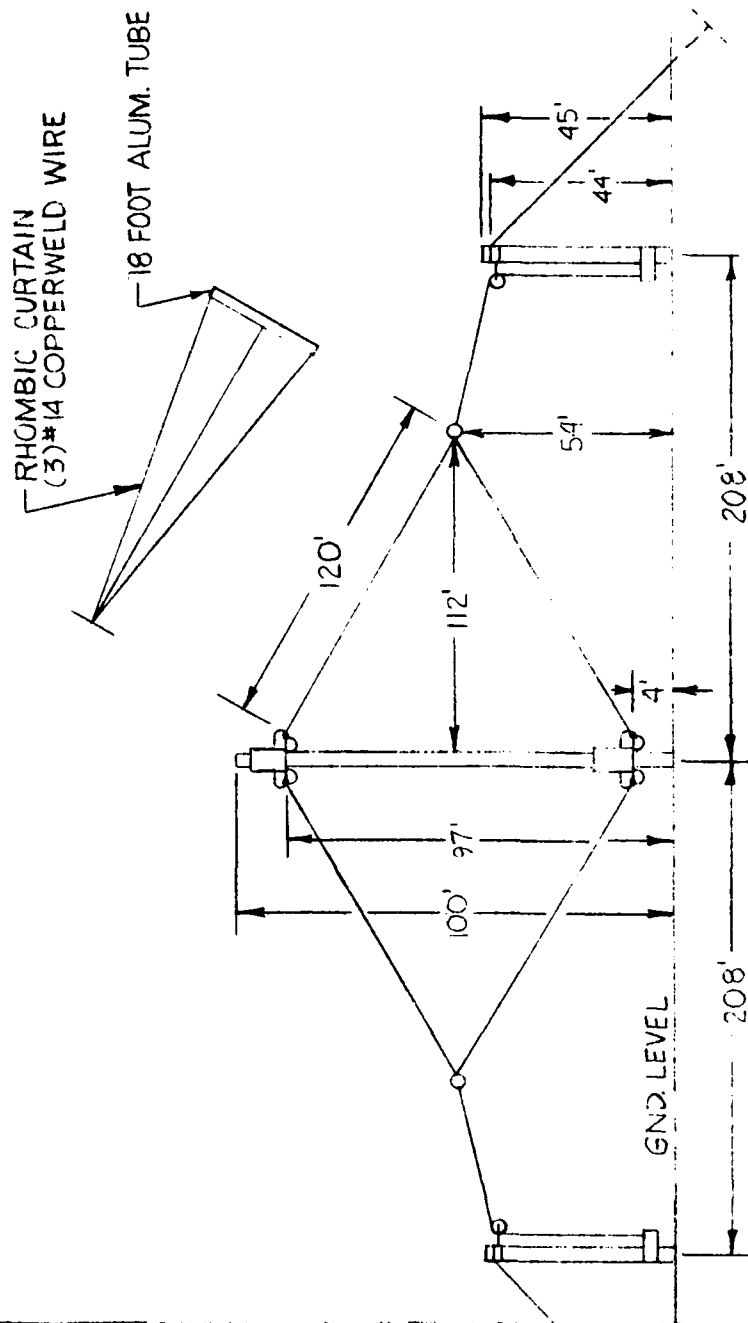
2.6 Iceland Sounder

The Digisonde 128 No. 3 was prepared for field operation at Keflavik NAS, Iceland, in support of the OTH radar tests. This Digisonde, originally operated in Maynard, Mass. and in storage at AFGL for six years, was in surprisingly good condition. The Memory, Synthesizer, and Translator sections of the "Iceland Sounder" were checked and repaired and the peripheral equipment, tape recorder and Magnafax printers, were tested. One printer was new and worked well, but the other needed a complete overhaul. The 30 kW Granger transmitter, which has not been operated during the last period of the sounder operation in Maynard, required a thorough check-out.

New designs for a pair of crossed rhombic antennas taking into account the site layout and pole locations at Keflavik were prepared. The Digisonde system and the antennas were installed at Keflavik in September 1979. Each rhombic antenna has a height of 97' (Figure 9) and the corners are 208' apart. The antenna conductor consists of three no. 14 gauge copperweld wires that are spread by 18' at the corners of the rhombic thus assuring a rather constant impedance over the frequency range from 1 to 16 MHz. An impedance measurement of the antennas was not performed. The managerial and technical on-site support by an AFGL engineer (Mr. Jack Waaramaa) greatly facilitated the timely execution of this task. Lectures and demonstrations were administered to the site operators explaining the system and the ionospheric data collected. A convenient calibration scheme for the Digisonde system was provided and the site personnel were instructed to run a calibration ionogram at the start of each new data tape.

2.7 Aircraft Digisonde 128PS

After each trip the Aircraft Digisonde 128PS chassis was returned to our laboratory for improvements and modifications. The analog part has been upgraded for a better signal



ICELAND RHOMBIC ANTENNA

Figure 9

to noise ratio by narrowing the bandwidth after installation of the new 225 kHz Intermediate Frequency (IF) cards. Also the demodulated output for Oscilloscope display has been improved.

The digital chassis underwent several modifications to incorporate the improvements implemented in the two other systems (Goose Bay and Kwajalein, M.I.). Specifically, the equalization of the Doppler frequency sign in all operating frequency bands has been implemented to compensate for the complicated frequency synthesis in the original DGS 128 system. Intermittent faults, only visible in the very variable temperature environment of the aircraft, have been repaired.

To enable correct parameter selection during aircraft experiments, we prepared Table 5 which shows the Doppler frequencies as function of N (number of integrations) and R (repetition rate and spectral line spacing).

2.8 Field Trips

Several trips were made to Goose Bay. The October 1978 trip's main purpose was to reinstall the Digisonde 128PS after its repair following the lightning storms of July-August 1978. The November-December 1978 trip was in support of aircraft experiments. At that time the Geomonitor was repaired and drift measurements were made. The tape recorded drift data were technically not correct and could not be evaluated. Several modifications to the Versatec print output were made to increase the value of the status information. The extraordinary signals were suppressed in the on-line printout and in the data stream to the Geomonitor. Sequential ionogram examples with and without X-trace may be seen in Figure 10. It should be noted that all X-trace information is still retained on the ionogram tapes. In the hourly ionograms the X-traces were retained during the period from December 1978 to January 1979.

(N,R)	±[Hz]									
	16 SELECTED SPECTRAL LINES*									
4,0	<u>.07</u>	<u>.2</u>	<u>.4</u>	<u>.6</u>	<u>.8</u>	<u>1.0</u>	<u>1.2</u>	<u>1.4</u>		
4,1	<u>.07</u>	<u>.2</u>	<u>.4</u>	<u>.8</u>	<u>1.4</u>	<u>2.0</u>	<u>2.7</u>	<u>3.5</u>	<u>(1.6)</u>	
3,0 4,2	<u>.13</u>	<u>.4</u>	<u>.8</u>	<u>1.2</u>	<u>1.6</u>	<u>2.0</u>	<u>2.3</u>	<u>2.7</u>		
3,1 4,3	<u>.13</u>	<u>.4</u>	<u>.8</u>	<u>1.6</u>	<u>2.7</u>	<u>3.9</u>	<u>5.5</u>	<u>7.0</u>	<u>(3.1)</u>	
2,0 3,2 4,4	<u>.26</u>	<u>.8</u>	<u>1.6</u>	<u>2.3</u>	<u>3.1</u>	<u>3.9</u>	<u>4.7</u>	<u>5.5</u>		
2,1 3,3 4,5	<u>.26</u>	<u>.8</u>	<u>1.6</u>	<u>3.1</u>	<u>5.5</u>	<u>7.8</u>	<u>10.9</u>	<u>14.1</u>	<u>(6.3)</u>	
1,0 2,2 3,4	<u>.52</u>	<u>1.6</u>	<u>3.1</u>	<u>4.7</u>	<u>6.3</u>	<u>7.8</u>	<u>9.4</u>	<u>10.9</u>		
1,1 2,3 3,5	<u>.52</u>	<u>1.6</u>	<u>3.1</u>	<u>6.3</u>	<u>10.9</u>	<u>15.6</u>	<u>21.9</u>	<u>28.2</u>	<u>(12.5)</u>	
1,2 2,4	<u>1.04</u>	<u>3.1</u>	<u>6.3</u>	<u>9.4</u>	<u>12.5</u>	<u>15.6</u>	<u>18.8</u>	<u>21.9</u>		
1,3 2,5	<u>1.04</u>	<u>3.1</u>	<u>6.3</u>	<u>12.5</u>	<u>21.9</u>	<u>31.2</u>	<u>43.8</u>	<u>56.3</u>	<u>(25.0)</u>	
1,4	<u>2.08</u>	<u>6.3</u>	<u>12.5</u>	<u>18.8</u>	<u>25.0</u>	<u>31.2</u>	<u>37.5</u>	<u>43.8</u>		
1,5	<u>2.08</u>	<u>6.3</u>	<u>12.5</u>	<u>25.0</u>	<u>37.5</u>	<u>50.0</u>	<u>62.5</u>	<u>75.0</u>	<u>(50.0)</u>	
0,0	<u>1.04</u>	<u>3.1</u>	<u>6.3</u>	<u>9.4</u>	<u>12.5</u>	<u>15.6</u>	<u>18.8</u>	<u>21.9</u>		
0,1†	<u>1.04</u>	<u>3.1</u>	<u>6.3</u>	<u>12.5</u>	<u>21.9</u>	<u>31.2</u>	<u>43.8</u>	<u>56.3</u>		
0,2	<u>2.08</u>	<u>6.3</u>	<u>12.5</u>	<u>18.8</u>	<u>25.0</u>	<u>31.2</u>	<u>37.5</u>	<u>43.8</u>		
0,3†	<u>2.08</u>	<u>6.3</u>	<u>12.5</u>	<u>25.0</u>	<u>37.5</u>	<u>50.0</u>	<u>62.5</u>	<u>75.0</u>		
0,4	<u>4.17</u>	<u>12.5</u>	<u>25.0</u>	<u>37.5</u>	<u>50.0</u>	<u>62.5</u>	<u>75.0</u>	<u>87.5</u>		
0,5†	<u>4.17</u>	<u>12.5</u>	<u>25.0</u>	<u>50.0</u>	<u>75.0</u>	<u>100.0</u>	<u>125.0</u>	<u>150.0</u>		

*Subsets of 8 and 4 are single or double under-lined; subset of two uses only first spectral lines.

†Highest Doppler frequencies of 16 spectral line set are redundant for single antenna modes.

Table 5. Spectral Width and Resolution for Single Antenna Spectral Integration in Ionogram Mode



GOOSE BAY, LABRADOR AFGL 3 DEC 78

Figure 10. Digisonde 128PS X-Trace Suppression

In November 1979 the digital automatic gain control was implemented. All antennas were tested to prepare for drift measurements. The frequency scans for the A, B and C programs (Section 2.) were extended to 18 MHz. During the night the end frequency is automatically reduced to 14 MHz.

The Aircraft Digisonde was modified to allow for external start commands of the A and B programs. Also, an external transmitter on/off switch is sensed and the off position is indicated in the preface of the recorded data by setting the 4-bit in the 100 digit of the day counter. A day count of 712, for example, means day 312 and transmitter off. This feature is helpful in the computer processing of the ionogram data.

In November 1979, the Geomonitor system was reinstalled in Goose Bay. In February 1980, a trip was made to Keflavik, Iceland, to reduce the interference which the Digisonde 128, installed there in September 1979, produced in other communication systems. The following modifications were made: (1) screen voltage of Granger transmitter was set to 2200V, (2) power of radiated signal was reduced by 11 dB over the entire frequency band, and additional 10 dB for the band 6 to 8 MHz, and 6 dB for 8 to 10 dB, (3) data integration was reduced from 320 to 160 samples without changing the frequency stepping time (2 sec). These modifications have diminished but not resolved the RFI problem.

In the same month the synchronization of the aircraft and Goose Bay Digisondes was completed by equalizing the timing of program start, signal integration and transfer time and the phase sequence code. Figure 11 shows an oblique ionogram received at the aircraft with Es, 1F and 2F propagation modes.

3.0 DATA PROCESSING

3.1 Fixed Frequency Program

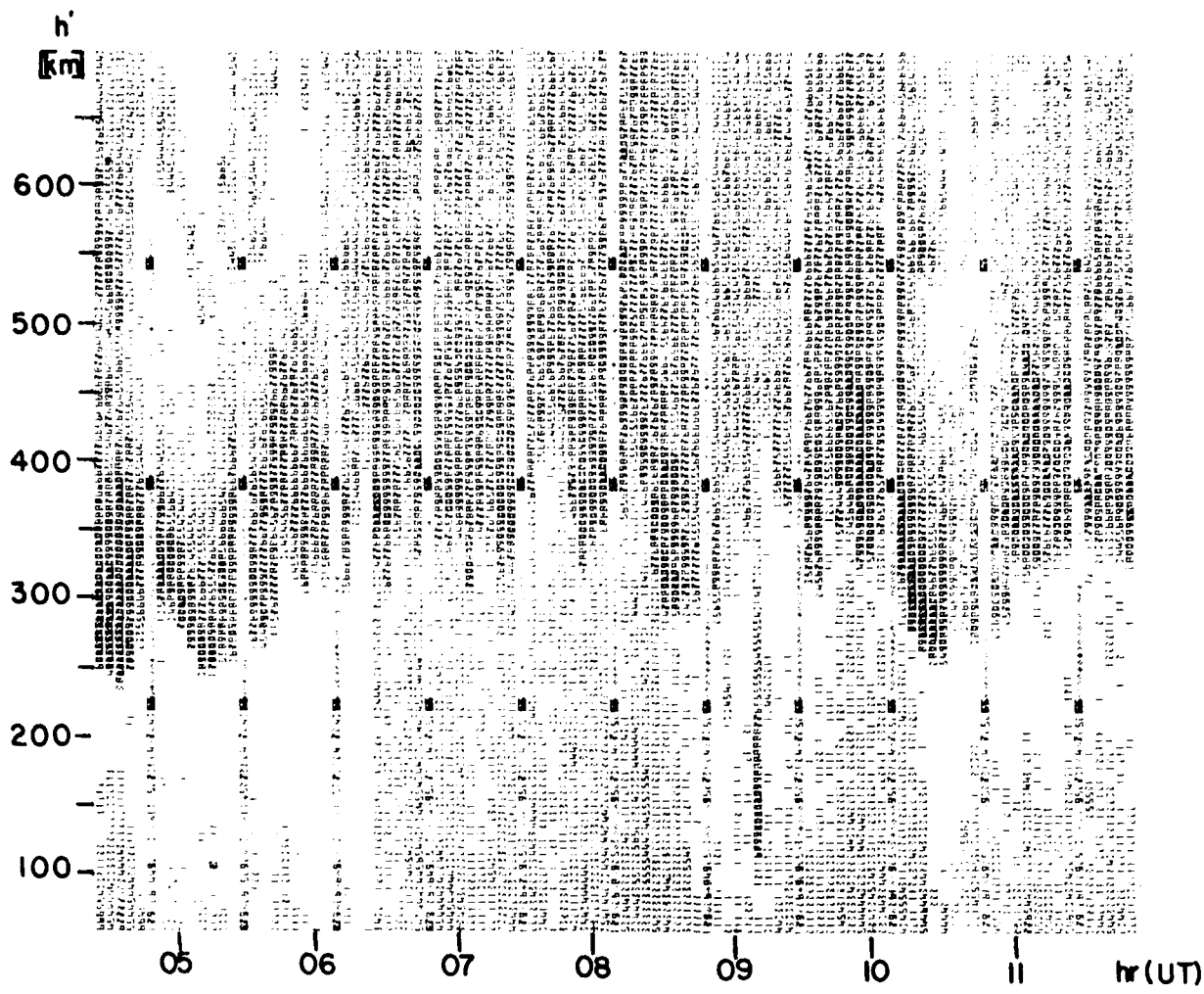
A program was developed which extracts from each ionogram one specific frequency; provided the ionogram satisfies certain criteria, i.e. $K = 7$ (5 km/range bin). Since the total preface information (the K parameter specifically), is not available until the second record of the ionogram, it is advisable not to select any of the first ten frequencies in the ionogram. Data of the January 1979 aircraft expedition has been processed using this program. The example in Figure 12 shows the virtual height variation of the electron density surface $N_e = 10^{11} \text{ m}^{-3}$. This technique is more sensitive than the integrated-heights method, that we normally use, which sums the amplitudes at each height bin over all frequencies and applies a linear normalization. The equation for normalization is:

$$A_i \text{ normalized} = \frac{63}{(A_{\max} - A_{\min})} * (A_i - A_{\min}).$$

The fixed-frequency program processes all ionograms with $K = 7$ at frequency $f = 3.0 \text{ MHz}$ in its default mode; a data card can be inserted in the program deck to vary frequency or type of ionogram to be processed. If several data cards are submitted the program will produce several N_e profiles.

A sample set of control cards to run this program is

1. SMITH,CM55000,T200,TP2. 3675 SMITHS
2. VSN,TAPE1=D79026.
3. REQUEST,TAPE1,HI,NR,S.(D79026/NORING).
4. VSN,TAPE7=F79026.



FIXED FREQUENCY
 26 JANUARY 1979
 LORING - THULE
 0436 - 1149 [UT]

Figure 12

5. REQUEST,TAPE7,HI,RING,S.(F79026/RINGIN).
6. ATTACH,AAA,FXFRQ,ID=SMITHS,MR=1.
7. FTN,SL,I=AAA,R=3.
8. MAP,ON.
9. LGO.
10. EXIT.
11. 789
12. 3.0,17,0,21,7.
13. 789
14. 6789

3.2 Automatic Parameter Identification

A comprehensive program for automatic parameter identification in digital ionograms was developed, which is described in Scientific Report No. 1 (Smith et al, 1979). The abstract of this report is reproduced here.

AUTOMATIC IONOSPHERIC PARAMETER EXTRACTION FROM DIGITAL IONOGRAM DATA

"Development of techniques to automatically extract the ionospheric ionization parameters of foF2, M(3000), fmin, and ftEs from digital ionograms have become feasible with the advent of advanced digital sounders. From digital ionogram data of the Digisonde 128PS the six most significant echoes for each frequency are extracted in the Geomonitor. They are further processed in the Automatic Parameter Evaluation program (A.P.E.) to determine the main echo height for each frequency. The program takes into consideration the frequency continuity of the reflection height, multiple hop reflection heights, rate of change of slope and the physical properties of the ionogram such as foE's dependence on the solar zenith angle. The output data are mathematically smoothed to produce

a refined ionogram. From this refined ionogram the A.P.E. program determines the four ionospheric parameters. In a study of 1500 ionograms the automatically evaluated ionogram parameters are compared with the manually scaled values and the differences are analyzed statistically. Also some case studies are discussed concentrating on the reasons for larger deviations. The program has been written considering the future possibility of implementation in a microcomputer which can integrate the functions of the Geomonitor, as well as a True Height Analysis program."

3.3 Playback of Aircraft Ionograms with Microcomputer

Aircraft ionograms from day 079-080, 1979 have been played back from magnetic tape to display amplitude and status (Figure 13) using ULCAR's Microcomputer chassis which forms part of a standard Digisonde 128PS. The software of the Microcomputer was revised to display the echoes with positive and negative Doppler in separate ionograms (Figure 14). Originally the status words have different meanings for different ionogram modes varying with Tt, R and N. This makes it difficult to compare different mode ionograms in terms of signal Dopplers. By encoding the status word as a function of Tt, R and N, the Doppler values in the ionogram are now printed independent of the ionogram mode using the Doppler-Group-Numbers (Table 6).

3.3.1 Amplitude-Status Ionograms

The actual set-up for the Microcomputer to run amplitude-status ionograms is:

- 1) Load tape without write ring on synchronous tape recorder.
- 2) Make sure KJ tape recorder cable and KP printer (Versatec) cables connect Microcomputer to peripherals.

STATUS

AMPLITUDE AND
STATUS IONOGRAMS
AIRCRAFT
26 JAN 1979

AMPLITUDE

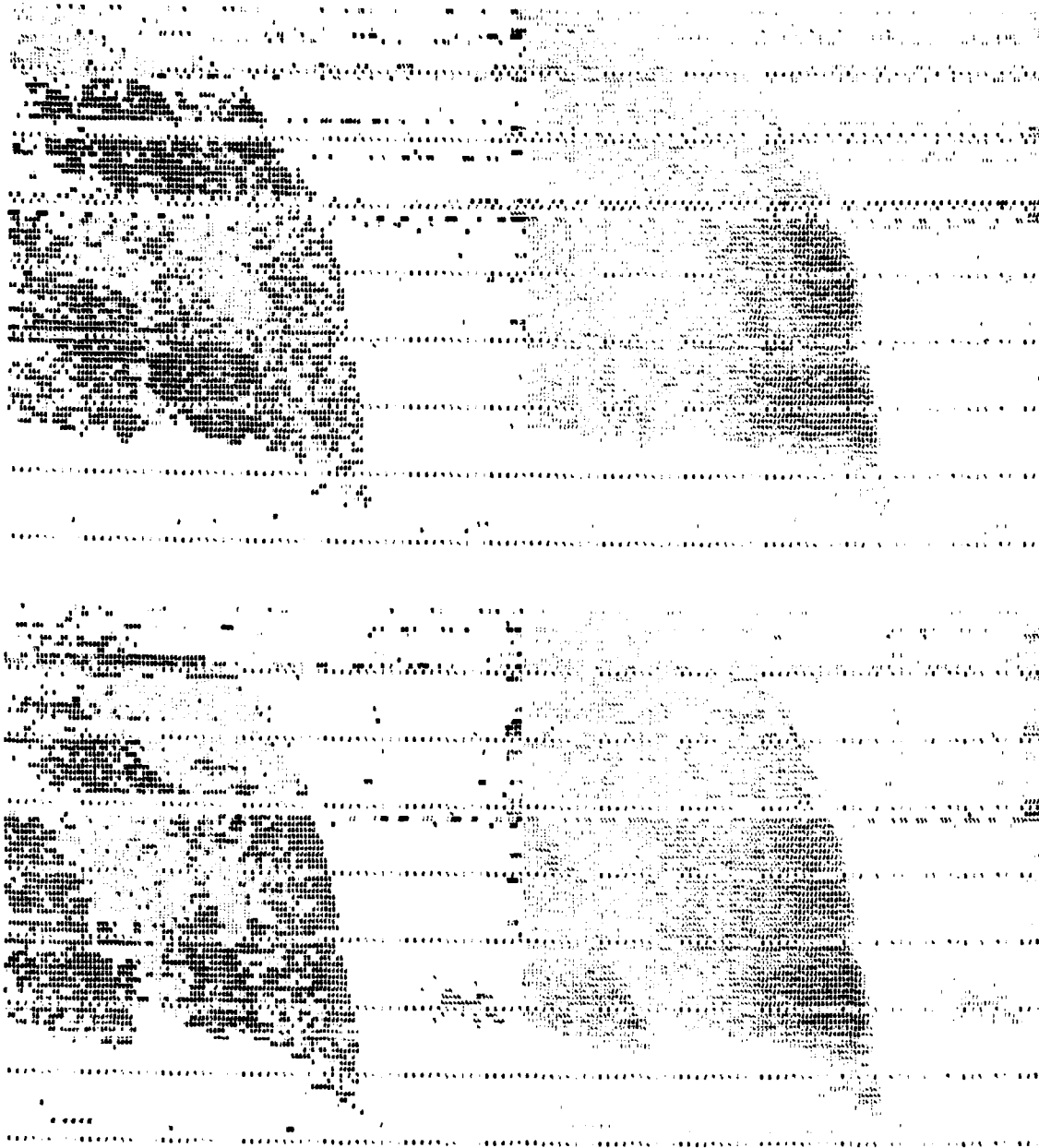
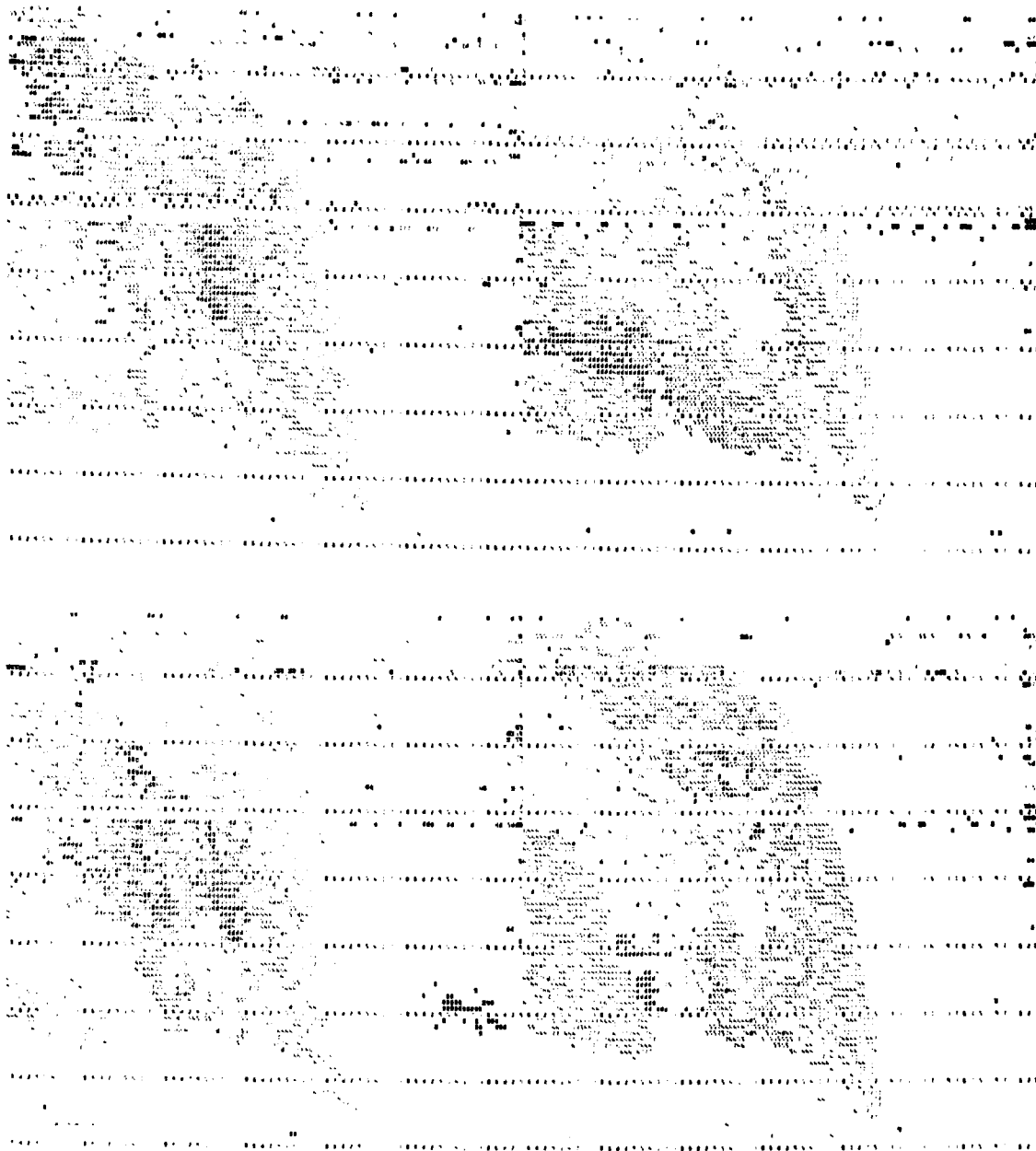


Figure 13

NEGATIVE
DOPPLER

DOPPLER-SPLIT
IONOGRAMS
AIRCRAFT
26 JAN 1979

POSITIVE
DOPPLER



0534 (UT)

0529 (UT)

Figure 14

In the program for Doppler-Split Ionograms the displayed numbers represent the magnitudes of the Doppler frequencies in a non-linear scale.

No. Represented	Doppler [Hz]
1	0 < S < .52
2	.6 < S < 1.4
3	1.6 < S < 2.3
4	2.7 < S < 4.7
5	5.5 < S < 6.3
6	7.0 < S < 7.8
7	9.4 < S < 10.9
8	12.5 < S < 14.1
9	15.6 < S < 18.8
10	S = 21.9
11	S = 25.0
12	28.2 < S < 31.2
13	37.4 < S < 43.8
14	50.0 < S < 56.3
15	62.5 < S < ∞

Table 6. Scale of Doppler Group Number for Doppler-Split Ionograms

- 3) Command Microcomputer

ME000 F7FF 4000 (RET)

This loads working program from PROM into RAM.

- 4) Depress front panel buttons [1] and [MODE]. This defines a AKADN (read from tape) operation.

- 5) Turn printer ON.

- 6) Command Microcomputer

G4198 (RET)

Versatec will execute a form feed.

- 7) Depress ON-LINE on tape recorder. Tape will advance and the Versatec will begin printing. After ten lines are printed, the tape will advance reading the next record.

- 8) Remove button [1]. This will process data with noise cleaning. The lowest four height bins will show the raw data and the height bins 5-128 will have all data with echoes less than or equal to NOISE set equal to zero. The noise threshold is simply defined as the amplitude average over the first four range bins:

$$\text{NOISE} = \frac{\sum_{i=1}^4 M(i)}{4} + 5$$

where $M(i)$ = 6 bit magnitude. If the LSB of the magnitude contains status information the error is ± 1 dB.

With button [1] depressed no cleaning is performed on the data. For the aircraft this is usually unacceptable.

3.3.2 "Split-Doppler" Ionogram

To run "Split-Doppler" ionograms:

- 1) Repeat steps 1 - 3 from Section 3.3.1.

2) Command Microcomputer

S4617 FE 1B
S4660 C5 01 00 6A C3 7A 46
S463A C5 01 10 6A C3 7A 46
S4594 CD A8 45
S45DF C3 F4 45
S45F5 C6 08 E6 0F 00 00 00 00
S4659 00 00 00
S4624 C3 40 6A
S6A40 21 00 3E 11 80 3D 06 80
CD 9F 45 C1 D1 E1 C9
S42CD 00 00 00
S4680 7B FE 10
S464E E6 0F

3) Command Microcomputer

S45BA C3 01 46

4) An equivalence table for each ionogram mode must be placed in RAM. The RAM space allocations for the Doppler Group Number (DGN) are as follows:

Tt = 73 4689 - 4698
Tt = 63 6A00 - 6A0F
Tt = 60 6A10 - 6A1F

For example, for program Tt = 63 N = 1, R = 3, the equivalent table is:

STATUS	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
DGN	02	05	08	0B	02	05	08	0B	12	15	18	1B	12	15	18	1B

In the equivalence table the sixteen bit, 10H, indicates the sign of the Doppler. For any new ionogram mode the equivalence table must be determined by using 8, 5 and 7 and placed in RAM for the "Split-Doppler" presentation. As it stands now, for each Tt only one N, R combination is allowed, but this limitation can be overcome by expanding the program.

3.3.3 Doppler Sign Inversion

Prior to December 1978 the sign of the Doppler produced by the Digisonde changed from frequency band to band due to the method of frequency synthesis. The Microcomputer has the relevant firmware to correct for the sign switching. Following steps must be done to run the program:

Amplitude-Status Display with Doppler Sign Inversion:

- 1) Repeat steps 1 - 3 of Section 3.3.1.
- 2) Command Microcomputer

S4601 C3 24 46

S4594 CD A8 45

- 3) Repeat steps 4 - 8 of Section 3.3.1.

Split-Doppler Presentation with Sign Correction:

- 1) Repeat steps 1 - 2 of Section 3.3.2.
- 2) Exclude instruction 3.
- 3) Repeat step 4 of Section 3.3.2.

3.4 Special Programming

Several new programs were developed for the processing of digital ionogram data based on the existing Automatic Ionogram Reduction (AIR) program (Bibl et al, 1976).

3.4.1 Adapting AIR to the Digisonde 128PS

The AIR program had been tailored toward DGS 128 ionograms. Since both at Goose Bay and in the Aircraft the new 128PS systems are in operation, the program was modified to take account of the new preface structure. This program version, dubbed AIRPS, was tested and is in operational condition.

3.4.2 Expansion of the AIRPS Program

A new output tape of the AIRPS program is generated as an input for an AFGL data mapping program. This new "MAIRPS tape" contains the amplitudes of one echo each for E and F region, respectively, for each of 170 frequencies per ionogram, always starting at 1.0 MHz. Appended to these data is the integrated height array.

A fixed frequency routine was added to the AIRPS program. For three selectable frequencies the heights of the main E and F echo are extracted and outputted on the MAIRPS tape. If no selection is made 3.5, 4.5 and 5.5 MHz are taken by default.

The data are preceded by a Doppler indicator, as explained in the next paragraph, and a 33 word preface, where the first two preface words contain the station identifier, i.e. 2 - 12 for the Aircraft Digisonde. The tape is written in CDC computer words each record containing 556 words as shown in Table 7.

The MAIRPS program also classifies all data according to their sign of the Doppler shift. As a result each MAIRPS output tape has three files. The first file contains the MAIRPS data obtained from processing the ionograms without regard to the Doppler frequency. This is indicated by a zero in the leading word in each record. The second file is the result of processing only the ionogram data with positive Doppler, indicated by a +1 as leading word. The third file, marked by a -1 as leading character in each record, contains the negative Doppler signals.

Word No.	Explanation
1	Doppler Identifier (0, 1 or -1)
2 - 34	Preface
35 - 204	170 F Amplitudes
205 - 374	170 E Amplitudes
375 - 544	128 Integrated Heights + 42 Zeroes
545 - 550	FQ1, HF(FQ1), FQ2, HF(FQ2), FQ3, HF(FQ3) (Fixed Frequency)
551 - 556	FQ1, HE(FQ1), FQ2, HE(FQ2), FQ3, HE(FQ3) (Fixed Frequency)

Table 7. Record Format on MAIRPS Tape

4.0 DATA ANALYSIS

4.1 Routine Ionogram Scaling

Two years of Goose Bay ionograms, 1977 and 1978, were scaled in terms of the following parameters: foF2, foF1, h'F, MUF3000, foE, h'E, foEs, fbEs, h'Es, fmin. For oblique echoes on the "vertical" ionograms the following parameters were scaled: ftEs, h'Es, ftF and h'F. Punch cards were prepared in accordance with URSI specifications, but extended to include the oblique parameters. Table 8 explains the format. The monthly median curves for the period January 1977 to December 1978 for foF2, foF1, foE, h'F2, h'F1, h'E, h'Es and the foEs distribution functions are shown in Appendix A of this report.

Some analysis of aircraft ionograms was performed and results were supplied to AFGL.

4.2 Ionogram Scaling Seminar

In September 1979 ULCAR conducted a special course on the scaling of digital ionograms with emphasis on the Goose Bay ionograms. This course, conducted by Miss Sheryl Smith, was given to personnel of the Air Weather Service, responsible for the ionogram interpretation at the OTH Radar Site in Maine, to the operators and data technicians of Marconi Canada, in charge of the Goose Bay Ionospheric Observatory, and to new personnel of ULCAR.

Table 8. Punch Card Format for Ionogram Parameters

Height Card #1		Frequency Card #2		Supplement Card #3	
Heights in km		Freq. in 20 kHz MUF in 100 kHz			
1-2	Card Code	1-2	Card Code	1-2	Card Code
3-5	Station	3-5	Station	3-5	Station
6-7	Year	6-7	Year	6-7	Year
8-9	Month 01-12	8-9	Month 01-12	8-9	Month 01-12
10-11	Day 01-31	10-11	Day 01-31	10-11	Day 01-31
12-13	Hour 00-23	12-13	Hour 00-23	12-13	Hour 00-23
14	Ø	14	Ø	14	Ø
15-17	h'E	15-17	fmin	15-17	h'Es
18-19	Q+D	18-19	Q+D	18-19	Q+D
20	Ø	20	Ø	20	Ø
21-23	h'Es	21-23	foE	21-23	h'Fob
24-25	Q+D	24-25	Q+D	24-25	Q+D
26	Ø	26	Ø	26	Ø
27-29	h'F	27-29	frEs	27-30	Ø
30-31	Q+D	30-31	Q+D	31	Type Es2
32	Ø	32	Ø	32	Ø
33-35	h'F2	33-35	fbEs	33-35	fminFob
36-37	Q+D	36-37	Q+D	36-37	Q+D
38	Ø	38	Ø	38	Ø
39-41	hpF2	39-41	foEs	39-41	foEs2
42-43	Q+D	42-43	Q+D	42-43	Q+D
44	Ø	44	Ø	44	Ø
45	Type Es	45-47	foI	45-47	foFob
46-80	Ø	48-49	Q+D	48-49	Q+D
		50	Ø	50-80	Ø
		51-53	foF1		
		54-55	Q+D		
		56	Ø		
		57-59	foF2		
		60-61	Q+D		
		62	Ø		
		63-65	foT		
		66-67	Q+D		
		68	Ø		
		69-71	MUFF1		
		72-73	Q+D		
		74	Ø		
		75-77	MUFF2		
		78-79	Q+D		
		80	Ø		

NOTE: All fields beyond column 14 may be replaced by Descriptive letter (D) only. All fields may be blank (Ø) except: Cards 1-2-3 columns 1-13; Card 1 columns 27-31, 39-43, and 15-19 during daytime; Card 2 columns 15-19, 57-61, 75-79, and 21-25 during daytime.

5.0 PUBLICATIONS

A number of publications and reports used results of the research and development performed under this project. All papers give proper credit to the Air Force support received.

1. K. Bibl and B. W. Reinisch, "The Universal Digital Ionosonde," 1978, Radio Science, 13, 519-530.
2. K. Bibl and B. W. Reinisch, Digisonde 128PS - System Description and Manual," 1978.
3. S. Smith, B. W. Reinisch, D. F. Kitrosser and K. Bibl, "Remote Ionogram Communicator - ICOM," 1979, University of Lowell Center for Atmospheric Research.
4. S. Smith, B. W. Reinisch, J. S. Tang and K. Bibl, "Automatic Ionospheric Parameter Extraction from Digital Ionogram Data," 1979, AFGL-TR-80-0102, Scientific Report No. 1.
5. K. Bibl, "Complex Amplitudes of Spectrum Analyzed Ionograms," 1978-1979, Rivista Italiana di Geofisica e Scienze Affini, Vol. V, pp. 111-114.
6. K. Bibl and B. W. Reinisch, "Digital On-Line Processing and Display of Multiparameter HF Transmission Data," AGARD, Lisbon Conference Proceedings No. 263, pp. 46-1 to 46-9.

Presentations were made at the XIX International URSI Meeting in Helsinki, Finland (1978), at the IUGG General Assembly in Australia (1979) and at the North American URSI Meeting in Quebec, Canada (1980).

6.0 PERSONNEL

The work reported here could not have been successful without the dedicated support by the following members of ULCAR:

Mr. Richard B. Bemis
Mr. James F. Gorman
Miss Selma E. Johnson
Mr. William T. Kersey
Mr. David F. Kitrosser
Mrs. Claire T. LeClair
Miss Sheryl Smith
Miss Jane S. Tang

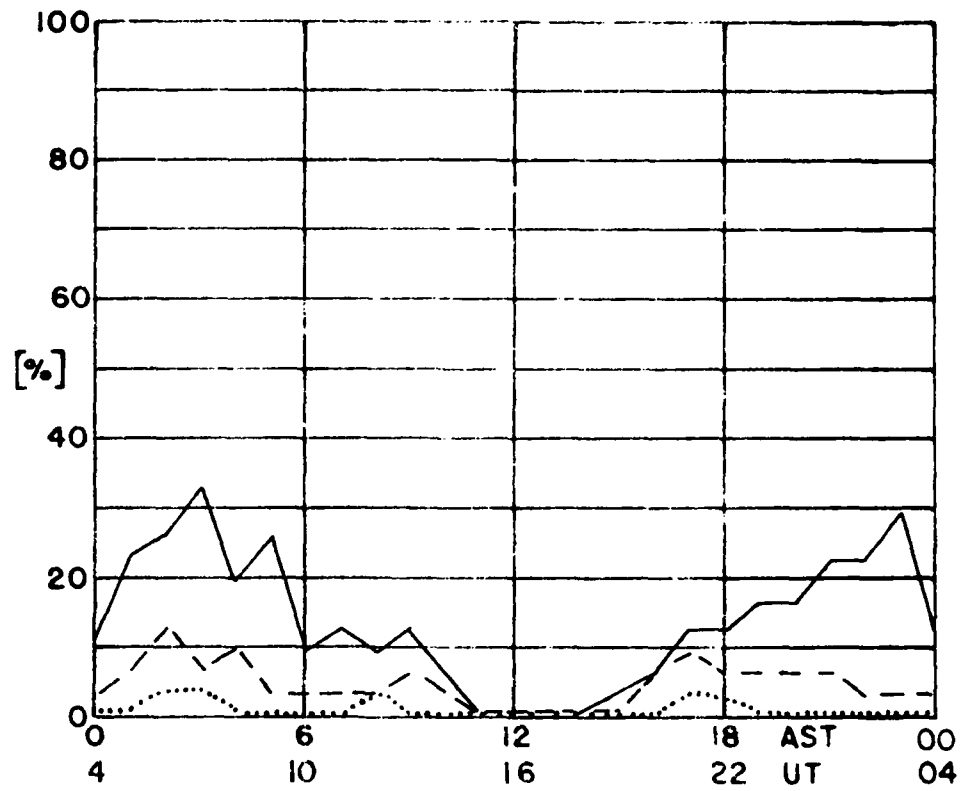
7.0 REFERENCES

- Bibl, K., J. A. Patenaude and B. W. Reinisch (1972), "Digital Ionosonde for Monitoring the Ionosphere," Final Report, AFCRL-71-0507.
- Bibl, K., B. W. Reinisch and S. Smith (1976), "Digital Ionospheric Sounding in Support of Arctic Research," Final Report, AFGL-TR-76-0037.
- Reinisch, B. W. and S. Smith (1976), "Geomonitor - Digital Real Time Processor for Geophysical Data," Scientific Report, AFGL-TR-76-0292.
- Smith, S., B. W. Reinisch, J. S. Tang and K. Bibl (1979), "Automatic Ionospheric Parameter Extraction from Digital Interim Report, ULRF-404/CAR, AFGL-TR-80-0102.
- Bibl, K. and B. W. Reinisch (1978a), "The Universal Digital Ionosonde," Radio Science, Vol. 13, No. 3, 519-530.
- Bibl, K. and B. W. Reinisch (1978b), "Digisonde 128PS for Ionospheric Dynamics and Three-Dimensional Structure Studies," System Description and Manual, University of Lowell Center for Atmospheric Research.
- Smith, S., B. W. Reinisch, D. F. Kitrosser and K. Bibl (1979), "Remote Ionogram Communicator - ICOM," University of Lowell Center for Atmospheric Research.

A P P E N D I X A

MONTHLY MEDIAN VALUES FOR 1977 AND 1978

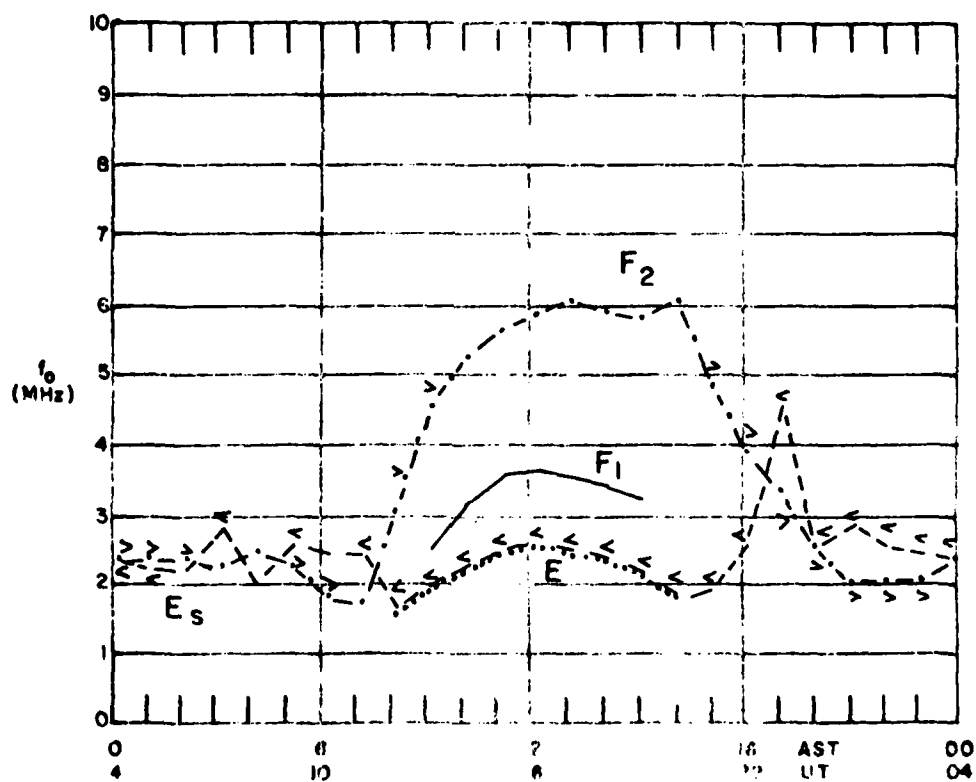
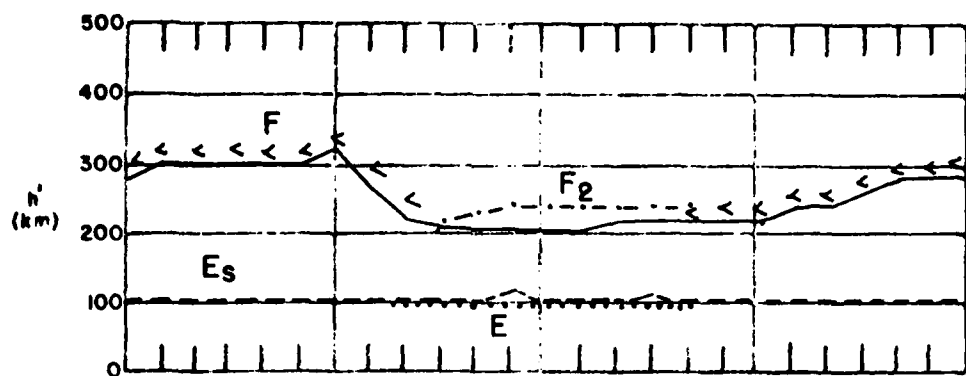
JANUARY, 1977
GOOSE BAY, LABRADOR



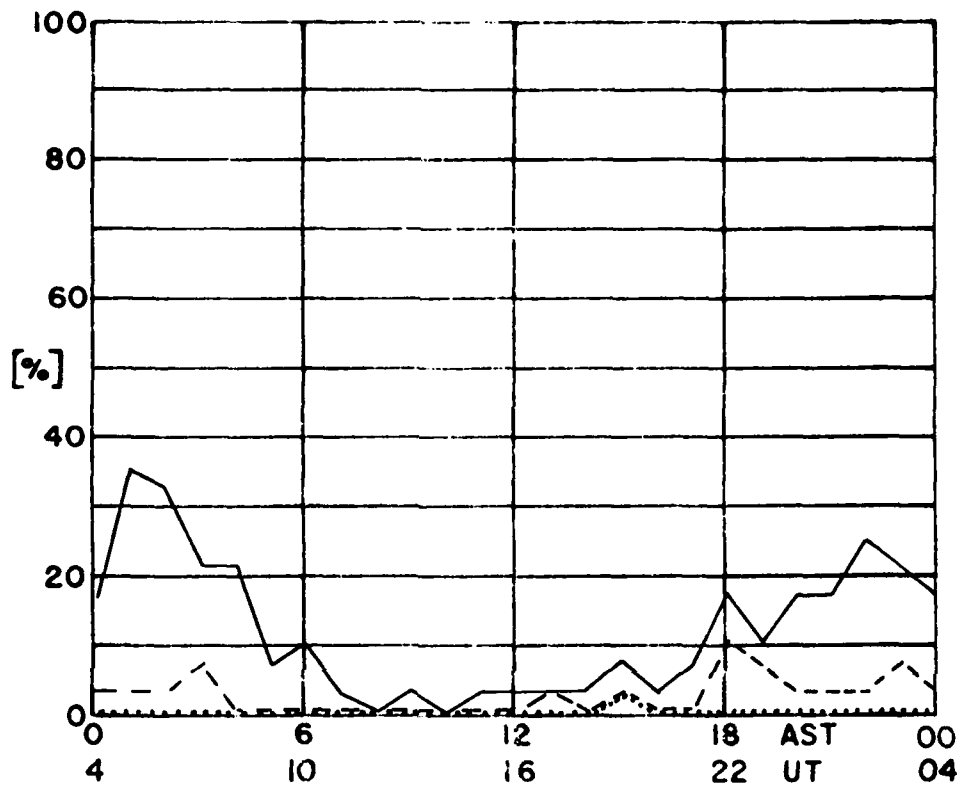
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF N' AND f_o AT GOUSEMY, LABRADOR FOR JANUARY, 1977



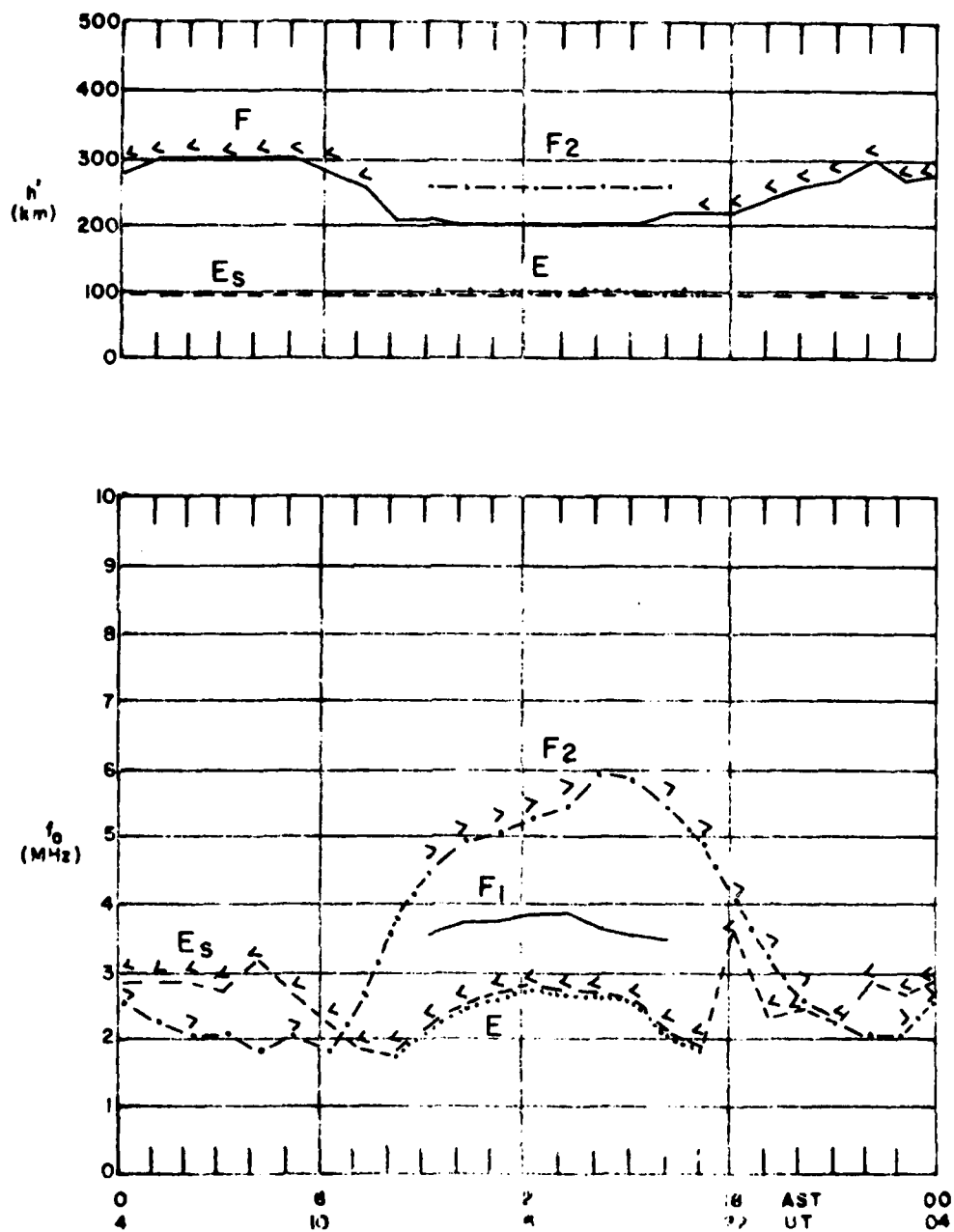
FEBRUARY, 1977
GOOSE BAY, LABRADOR



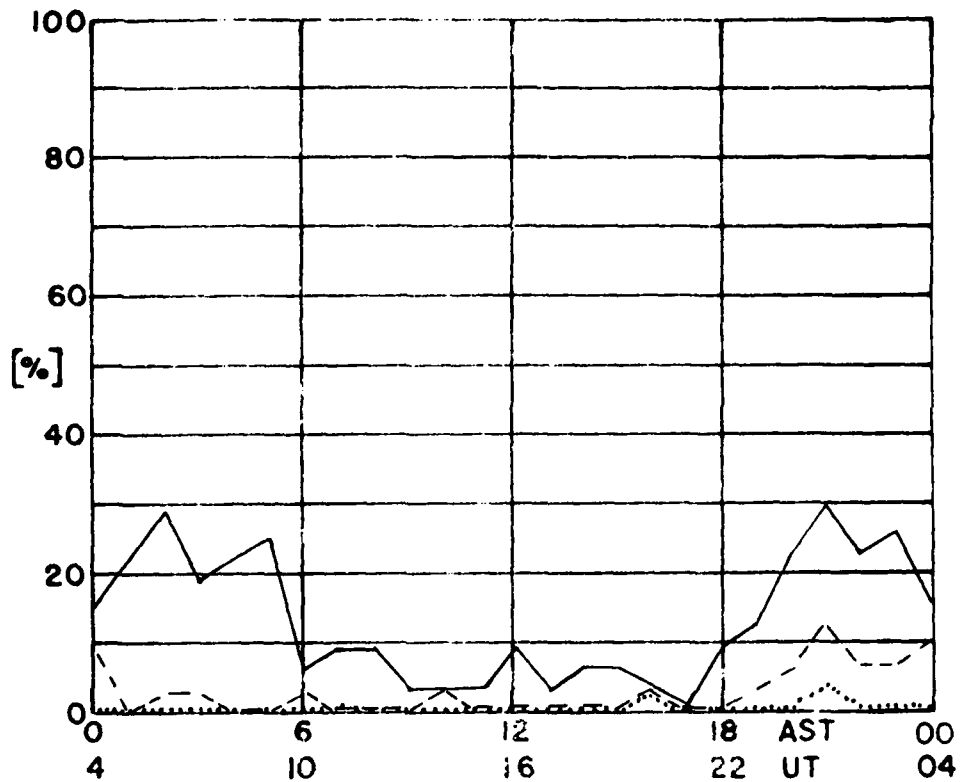
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR FEBRUARY, 1977



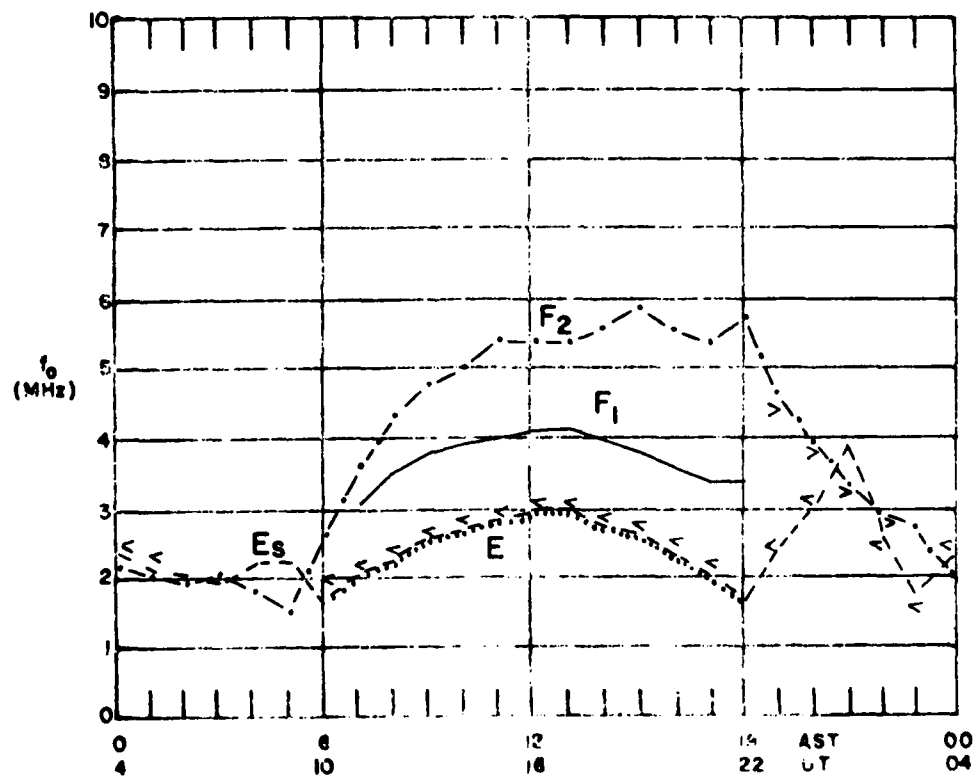
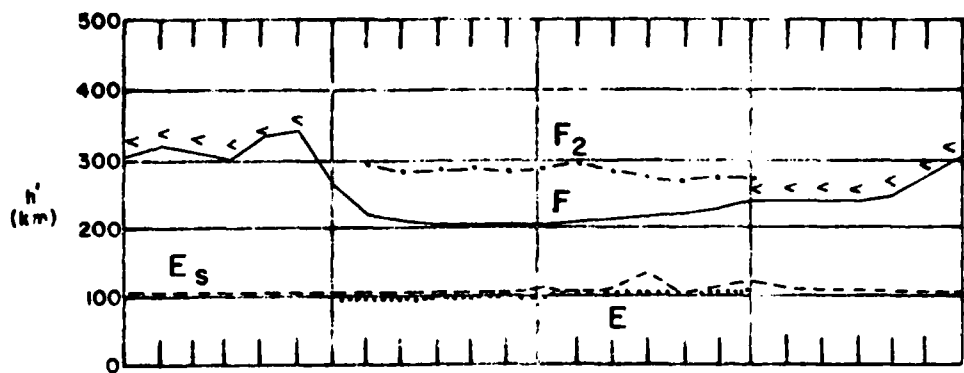
MARCH, 1977
GOOSE BAY, LABRADOR



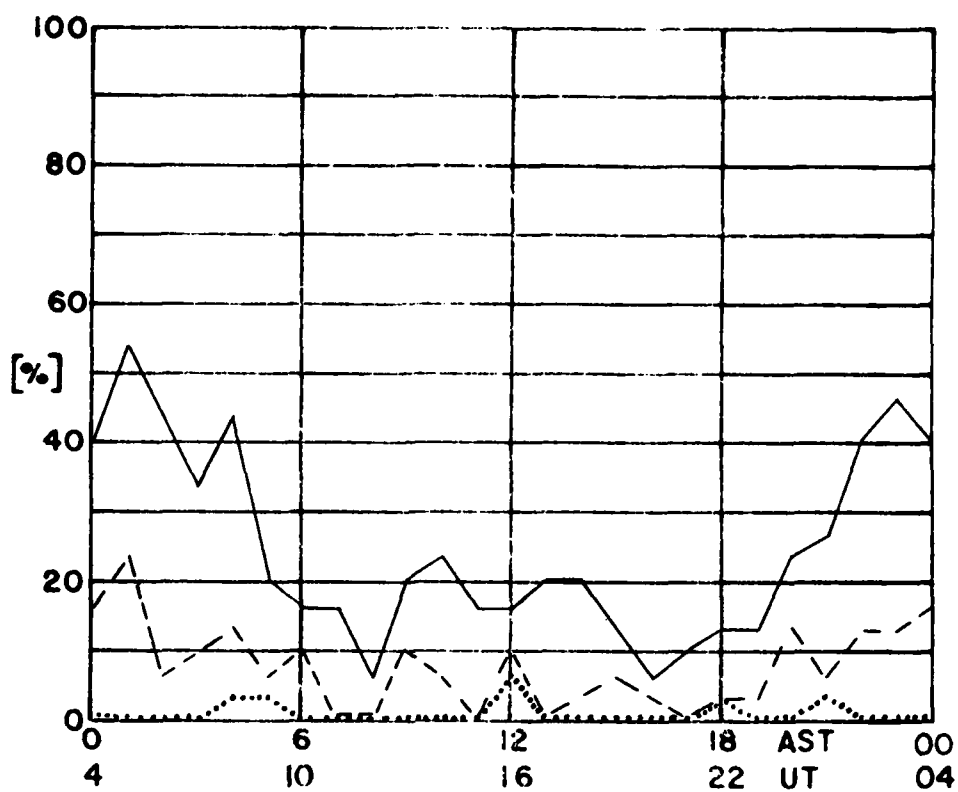
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR 10th MARCH, 1977



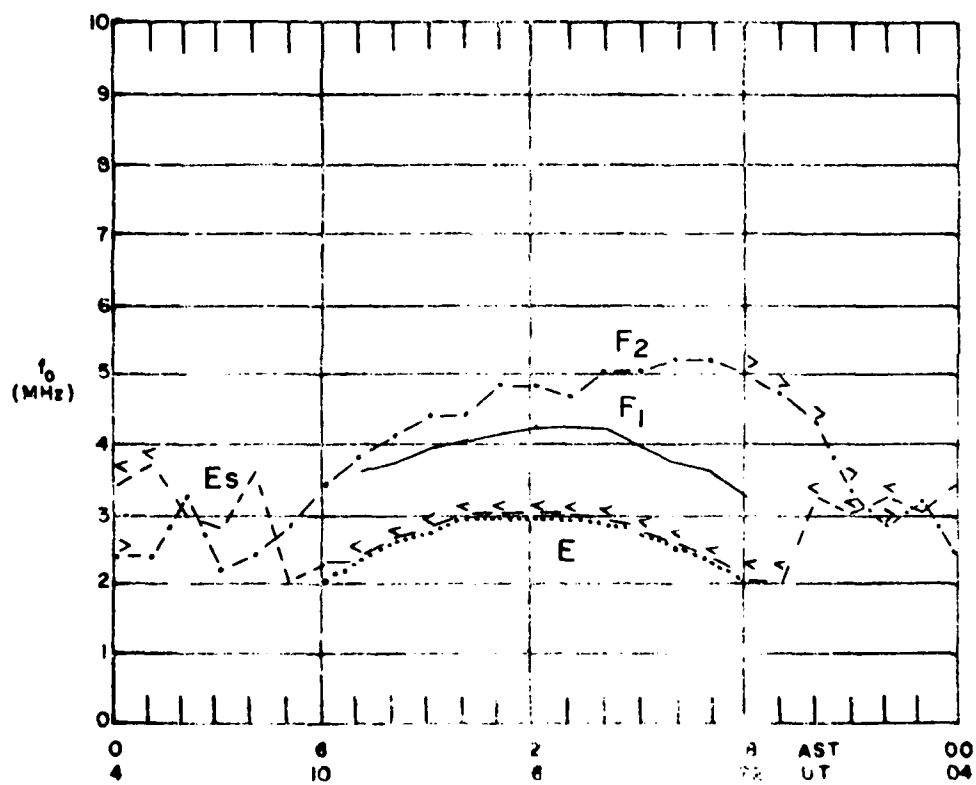
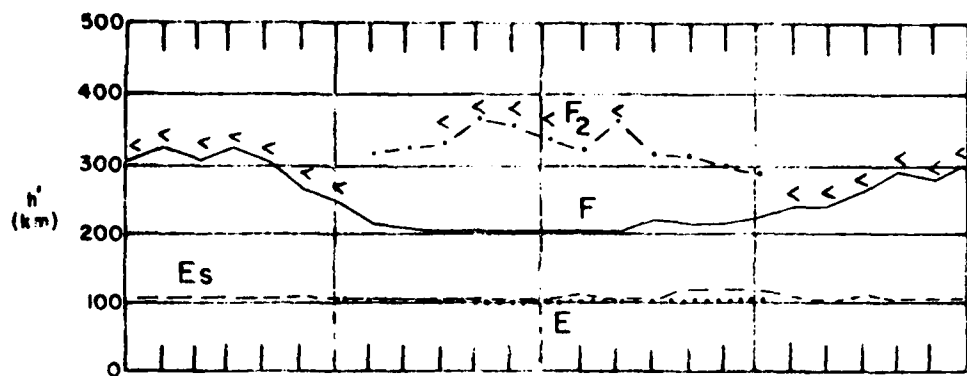
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GOOSE BAY, LABRADOR



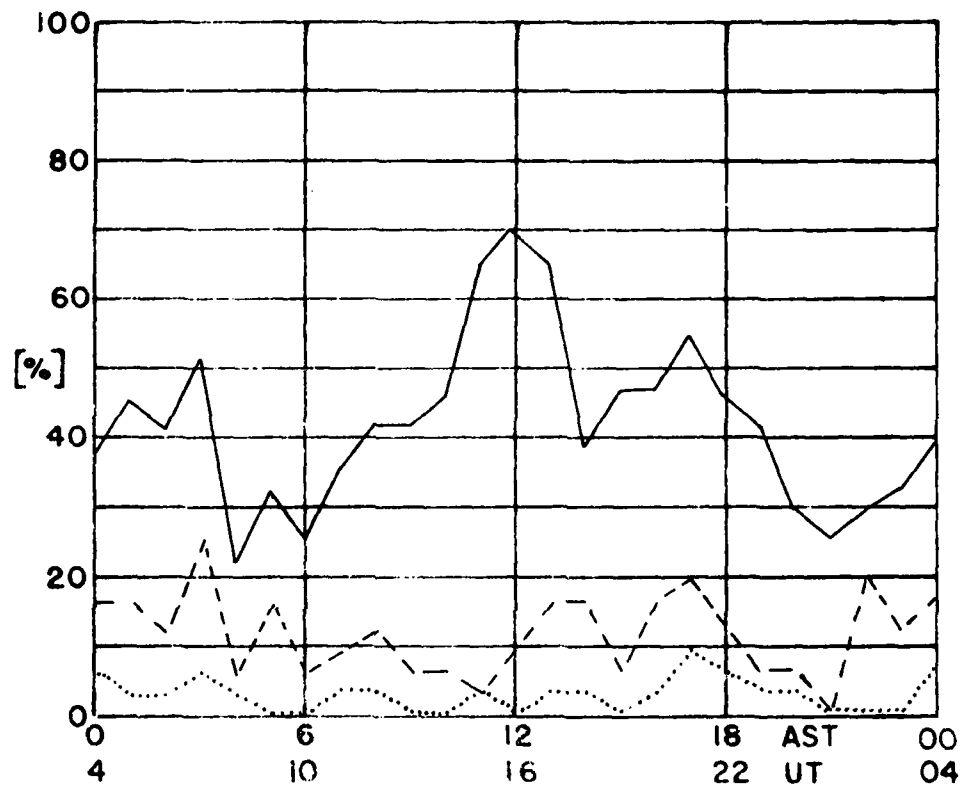
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF h' AND f_o AT GOOSEBAY LABRADOR FOR APRIL, 1977



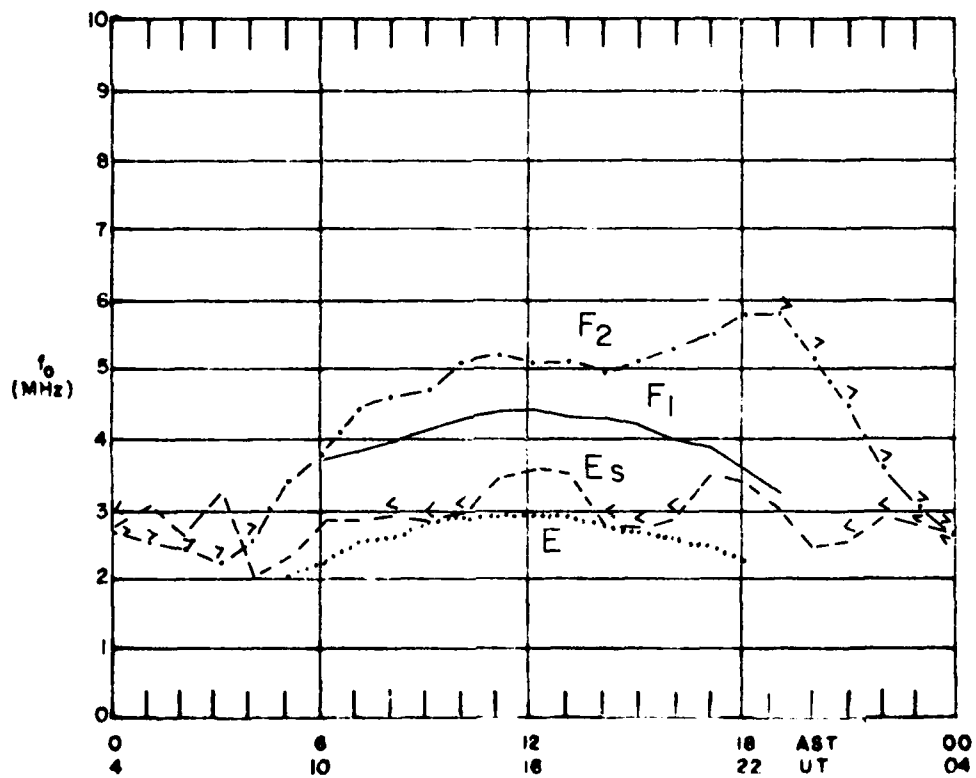
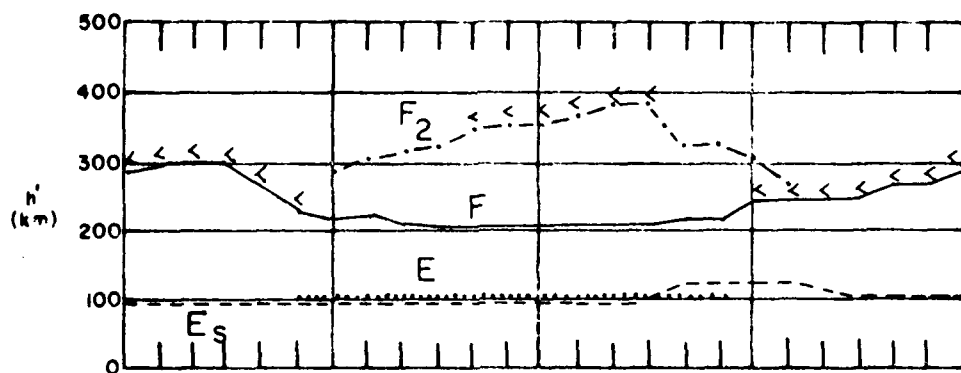
MAY, 1977
GOOSE BAY, LABRADOR



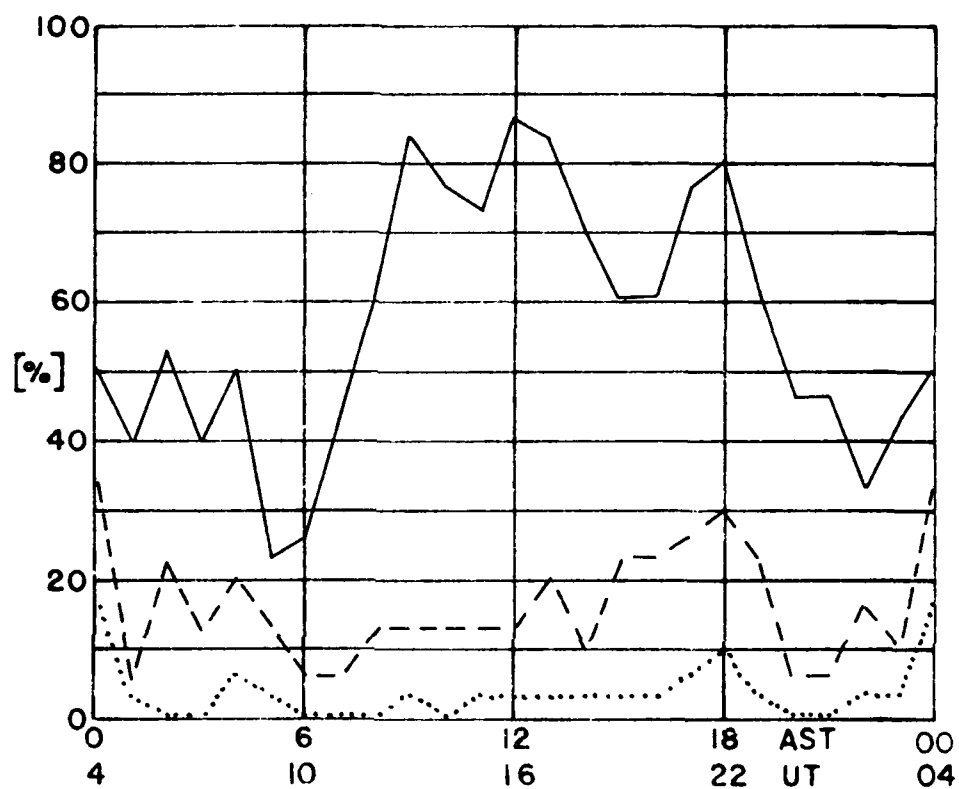
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR MAY, 1977



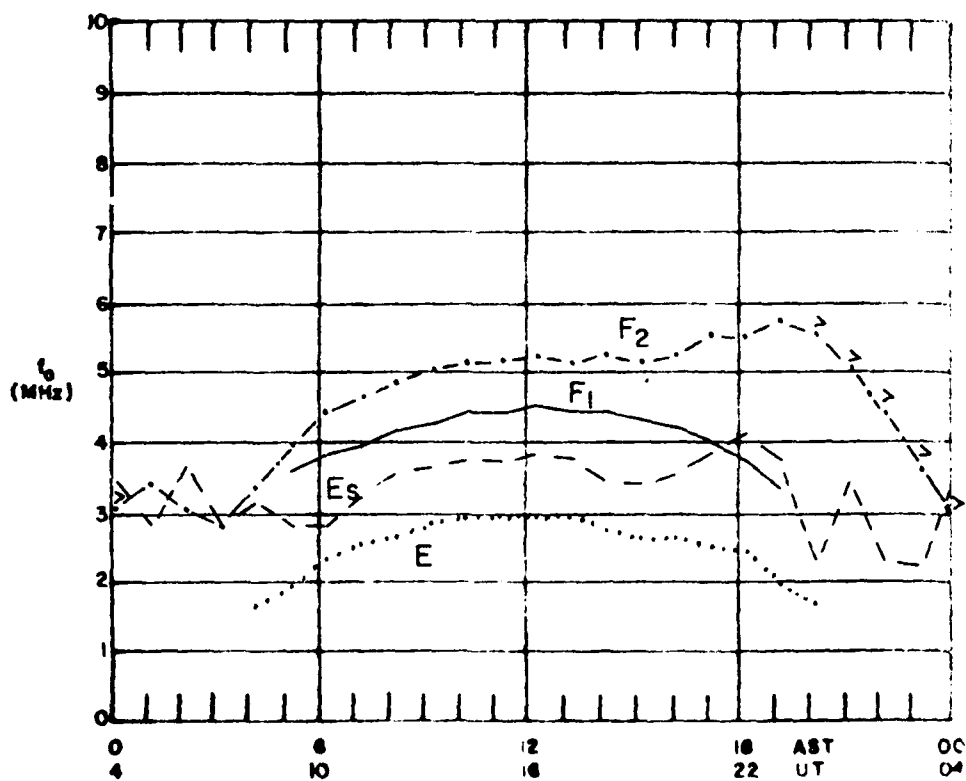
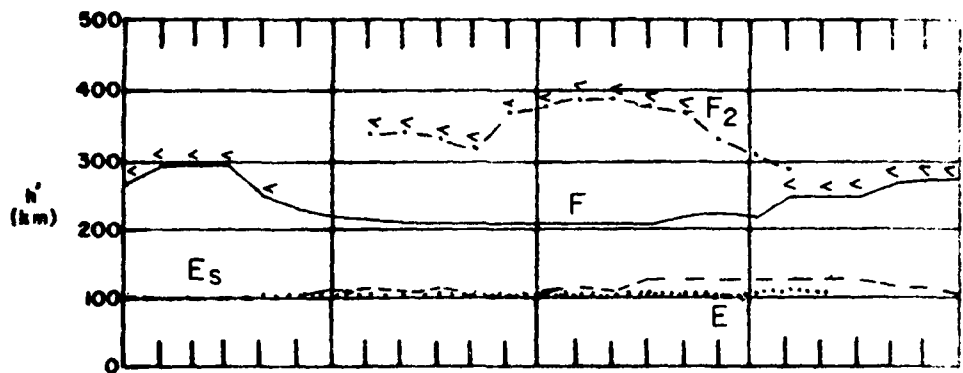
JUNE, 1977
GOOSE BAY, LABRADOR



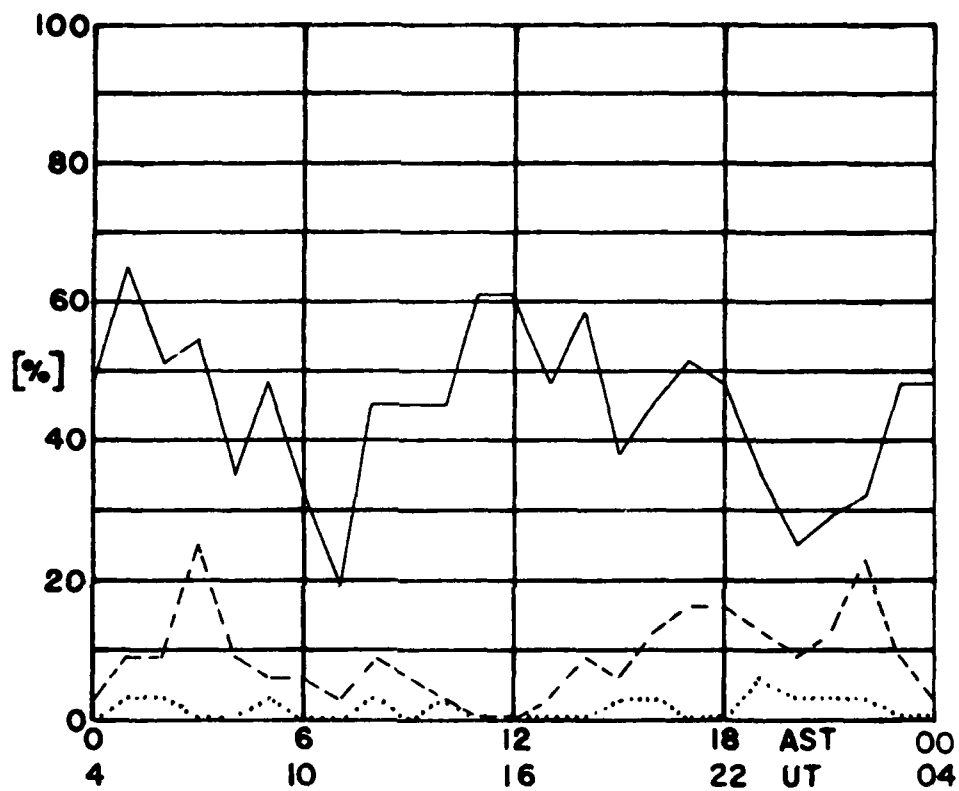
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 LIMITING FREQUENCY = 7MHz

PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF N' AND f_o AT GOOSEBAY, LABRADOR FOR JUNE, 1977



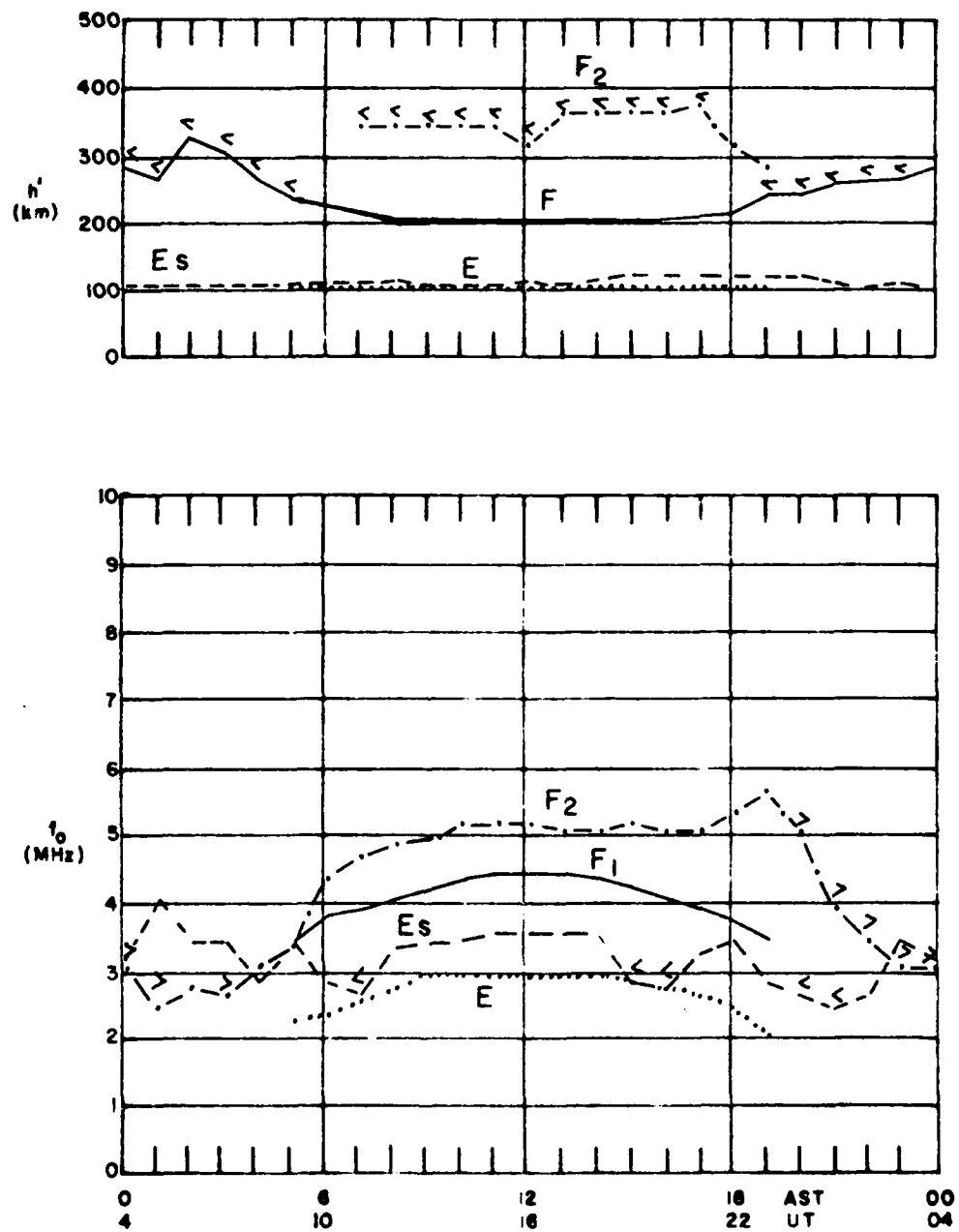
JULY, 1977
GOOSE BAY, LABRADOR



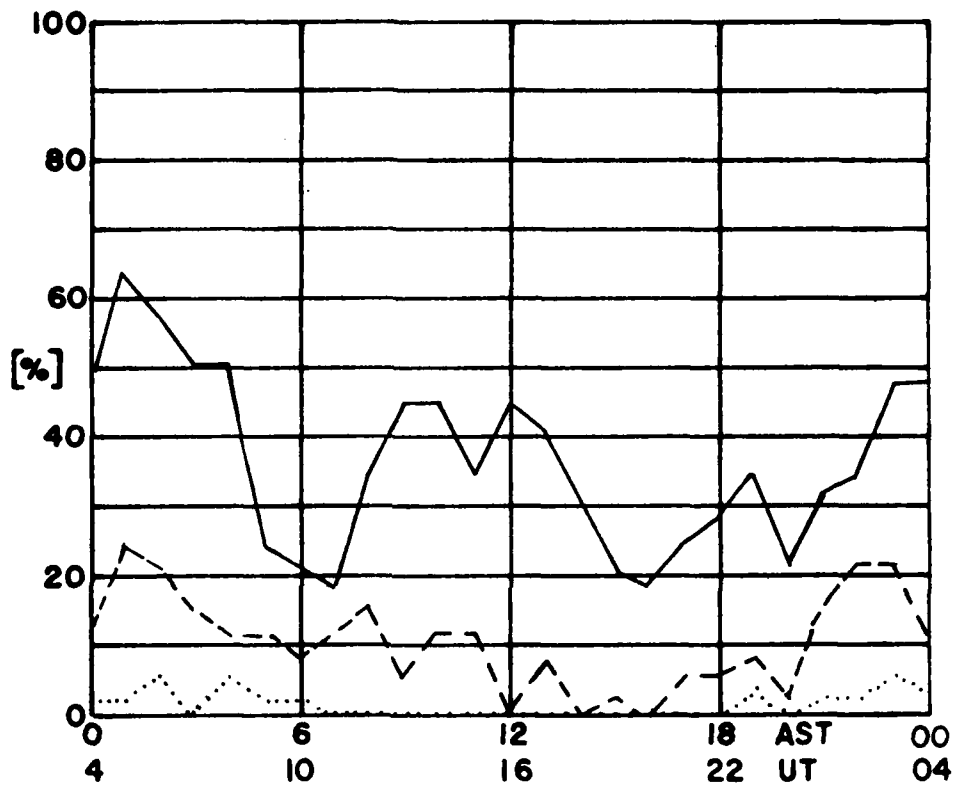
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR JULY, 1977



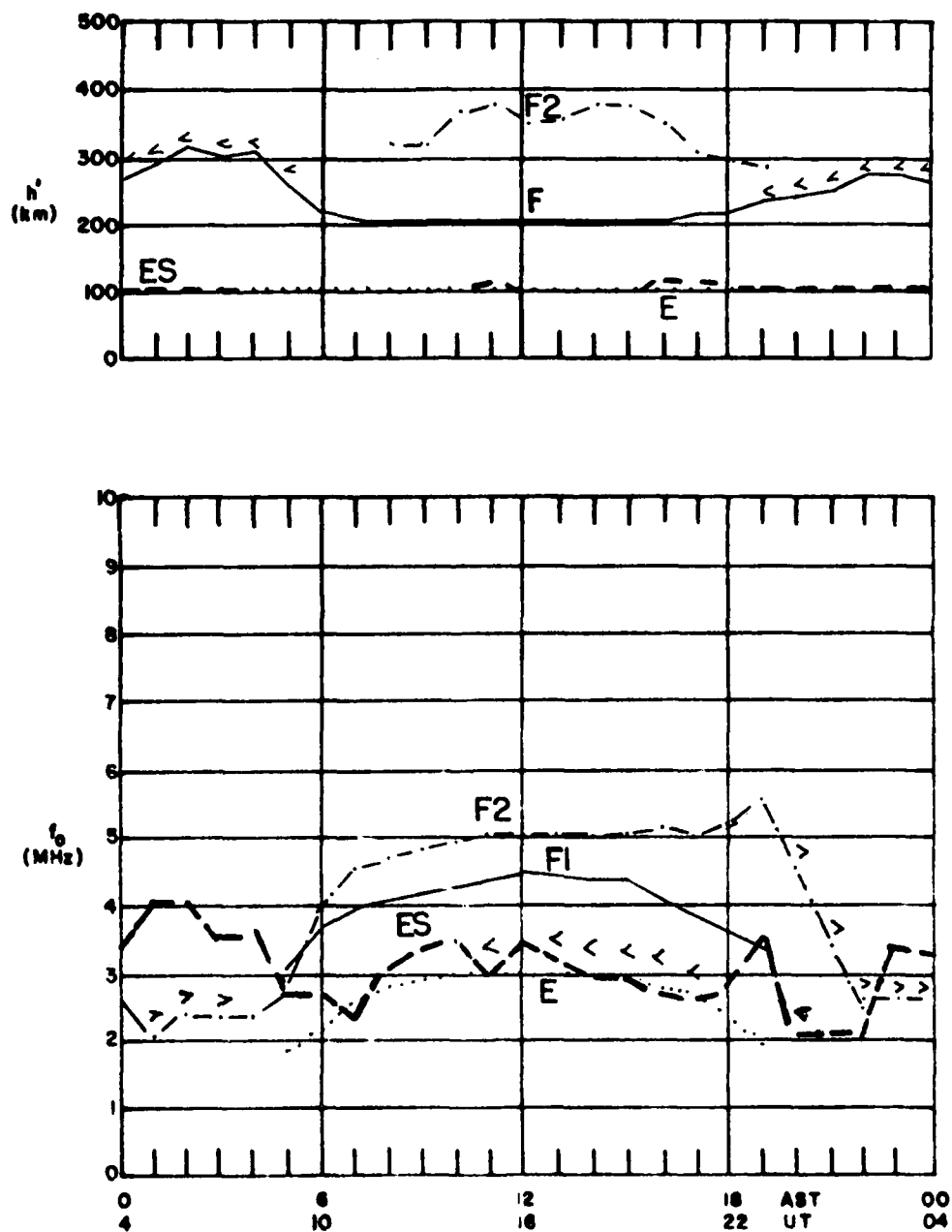
AUG 1977
GOOSE BAY, LABRADOR



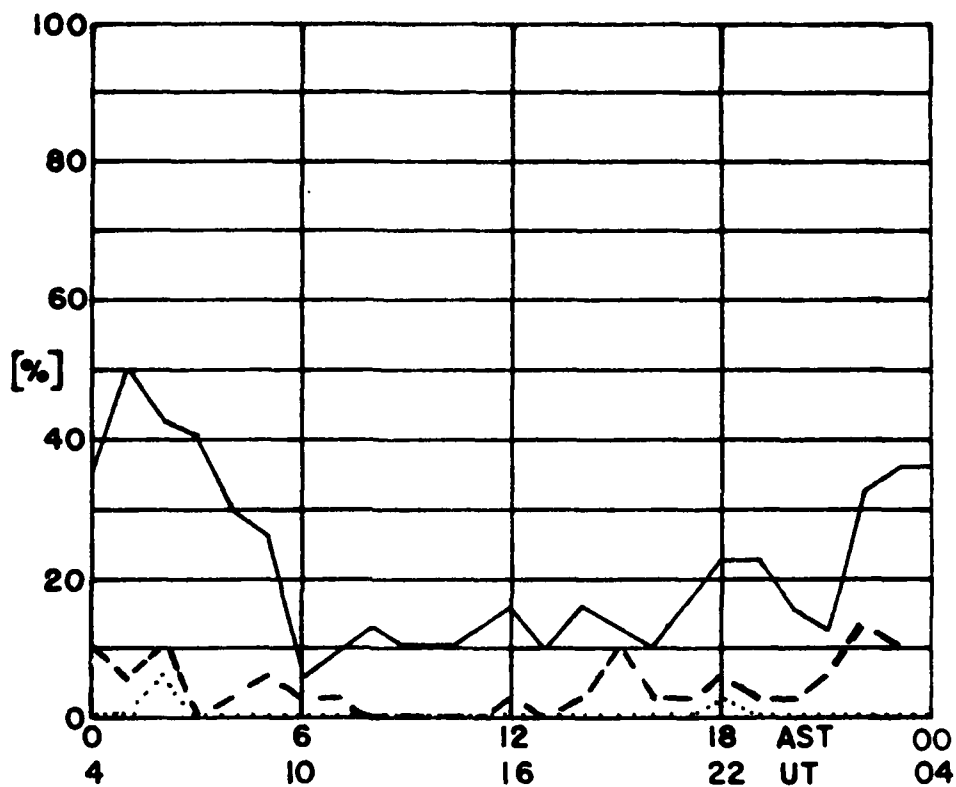
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 LIMITING FREQUENCY = 7MHz

PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR
AUGUST 1977



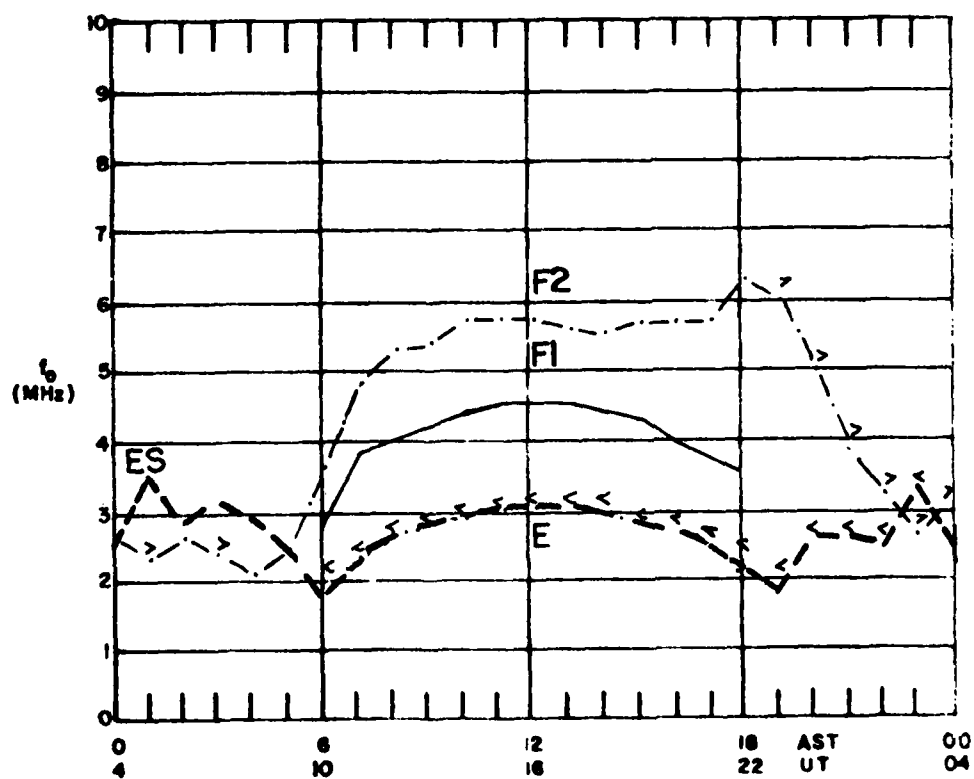
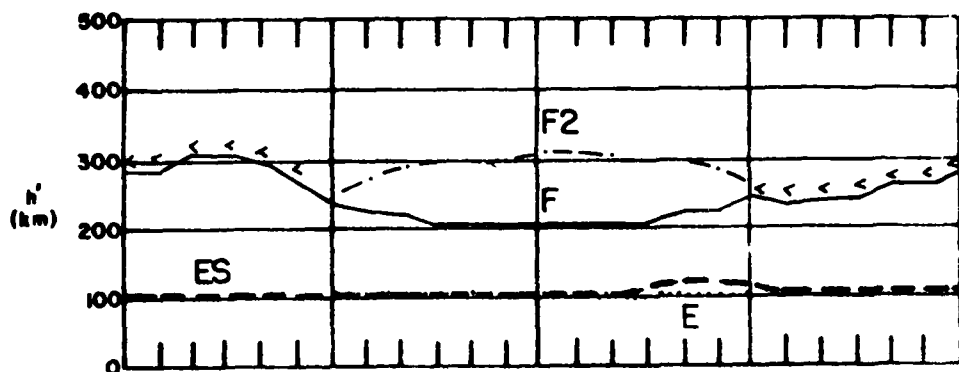
SEPT 1977
GOOSE BAY, LABRADOR



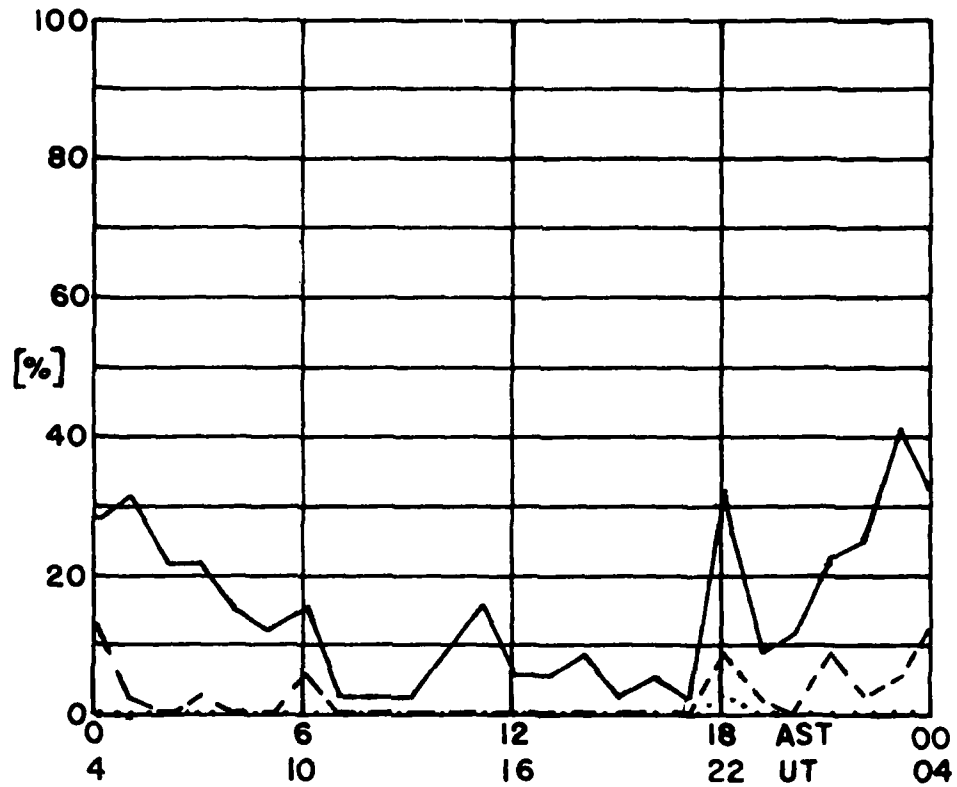
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR
SEPTEMBER 1977



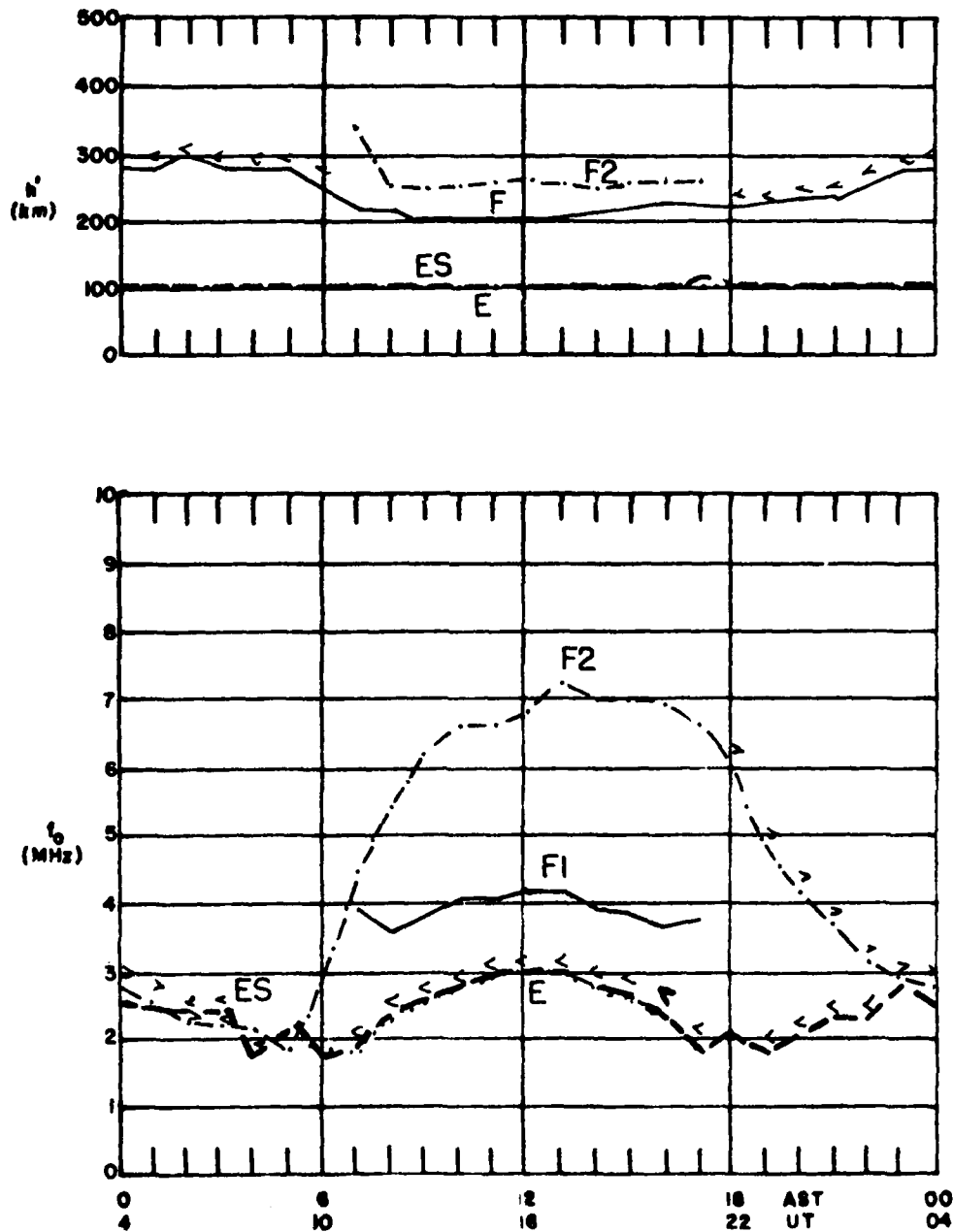
OCT 1977
GOOSE BAY, LABRADOR



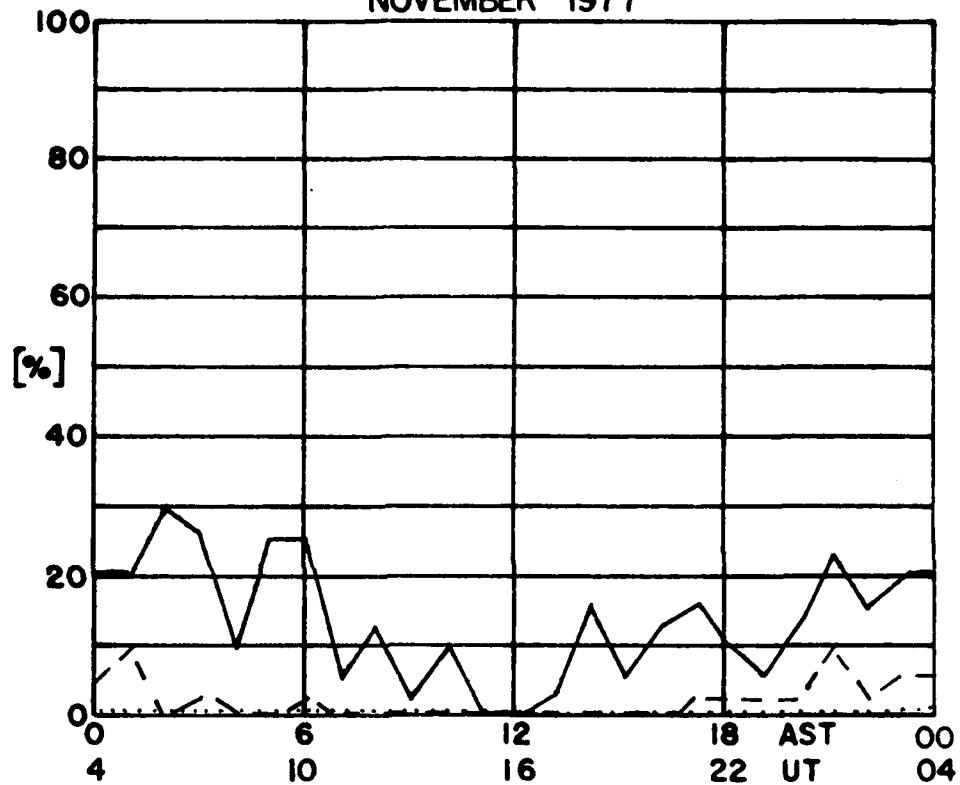
LIMITING FREQUENCY = 3MHz —————
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 LIMITING FREQUENCY = 7MHz

PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR
OCTOBER 1977



GOOSE BAY, LABRADOR
NOVEMBER 1977



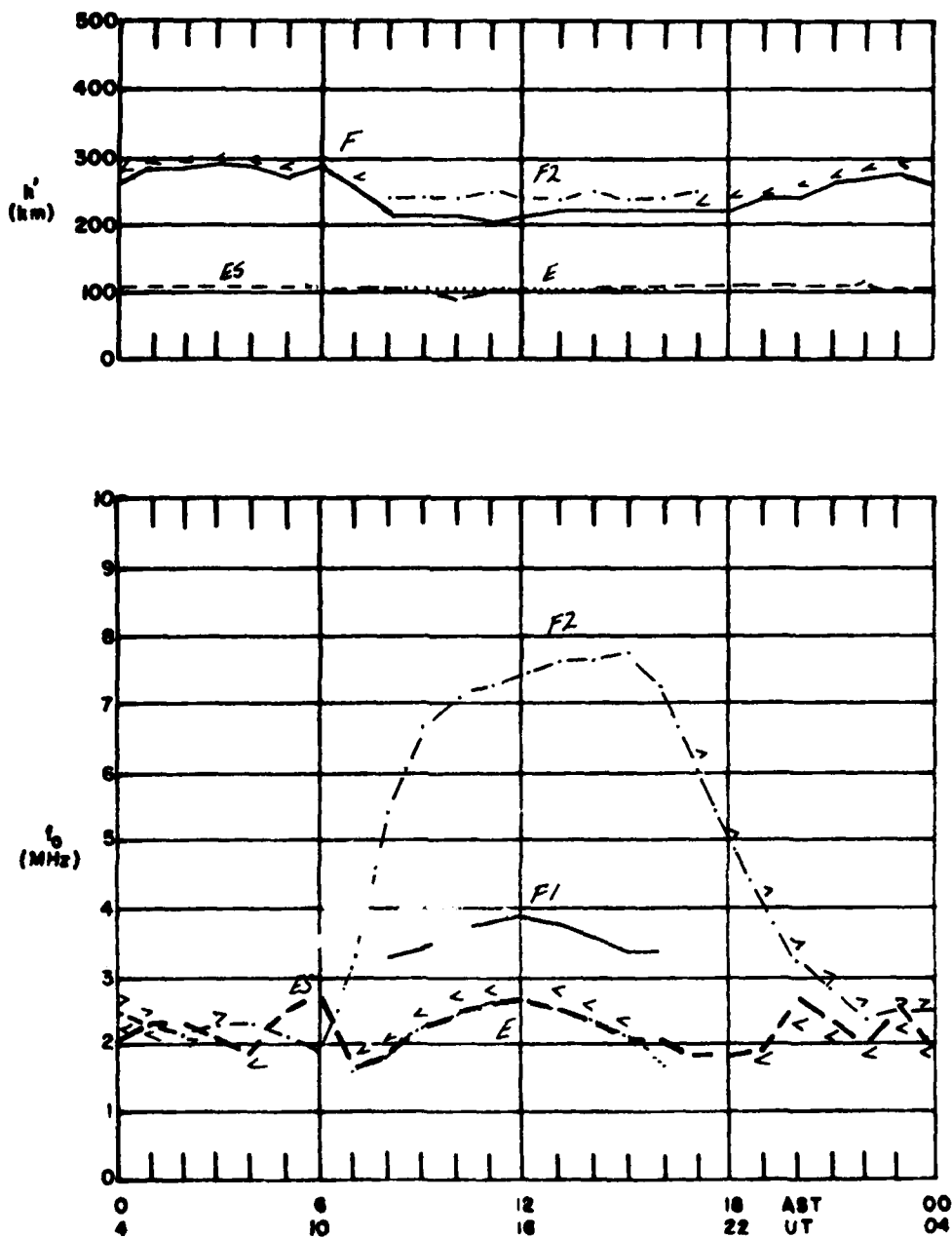
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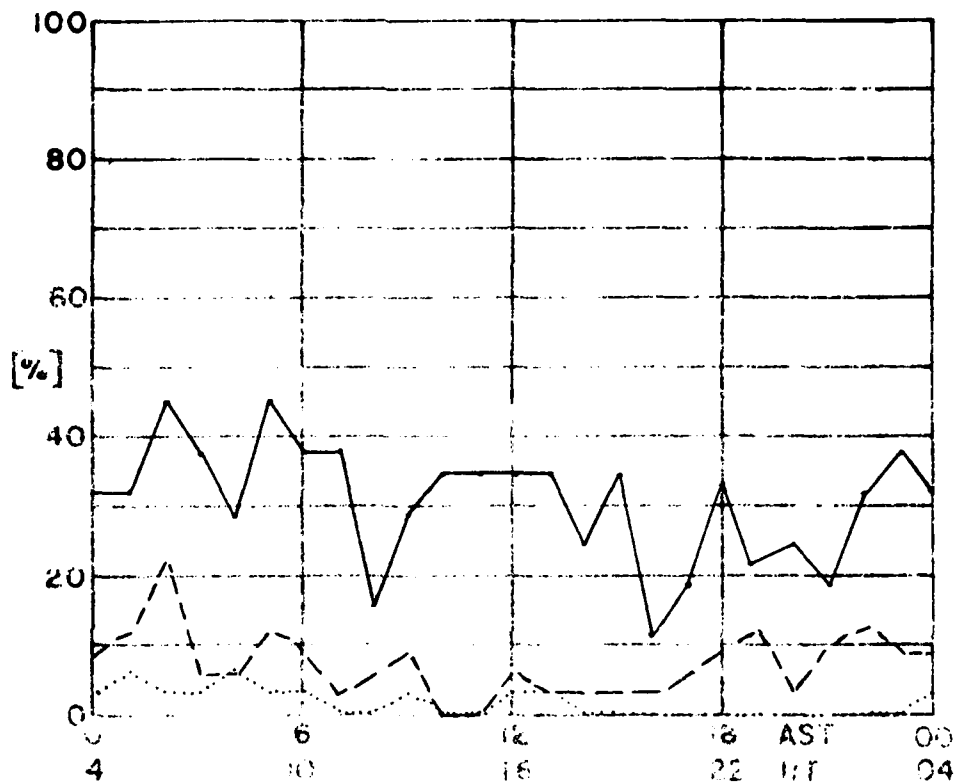
LIMITING FREQUENCY = 7MHz

PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR
NOVEMBER 1977



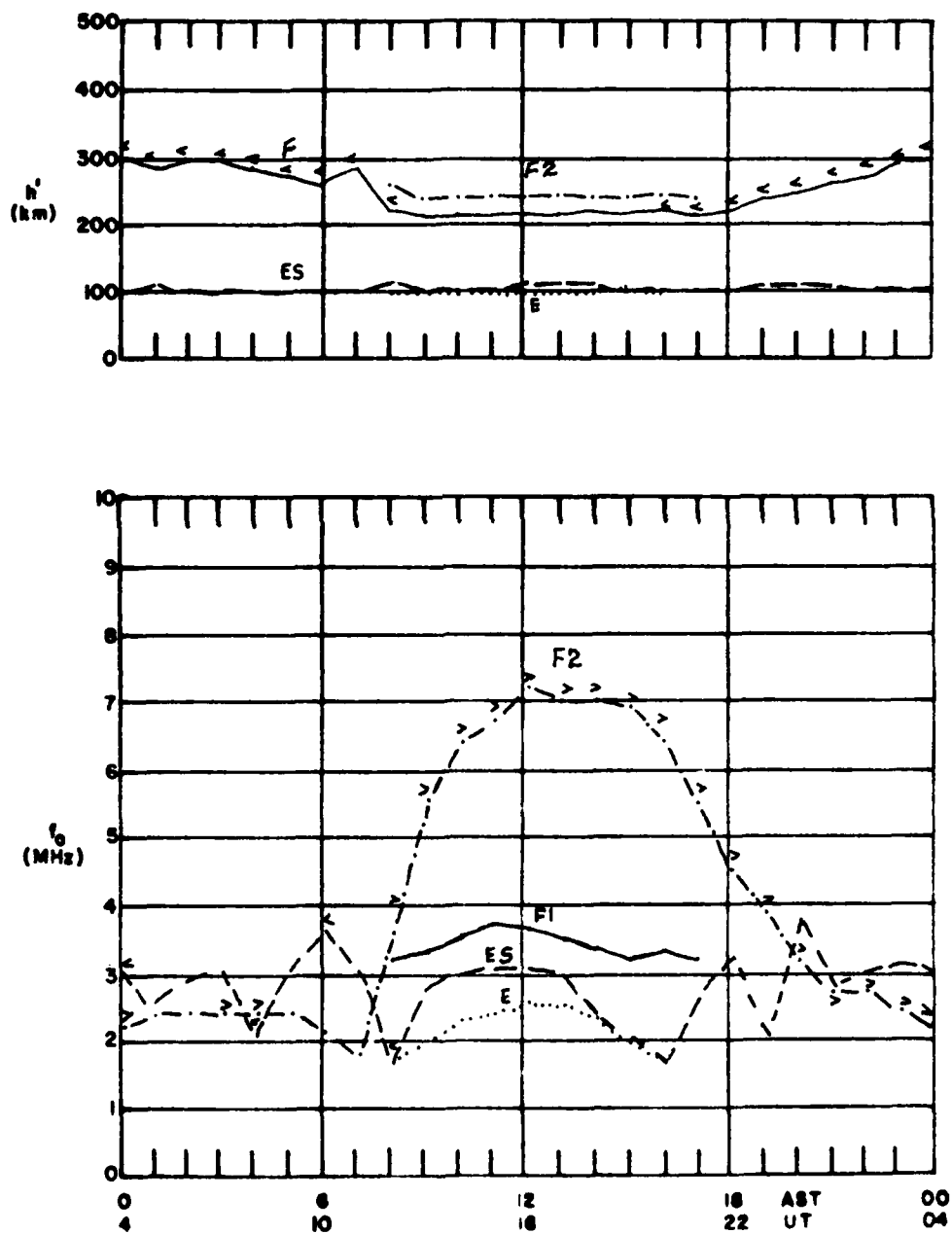
DECEMBER 1977
GOOSE BAY, LABRADOR



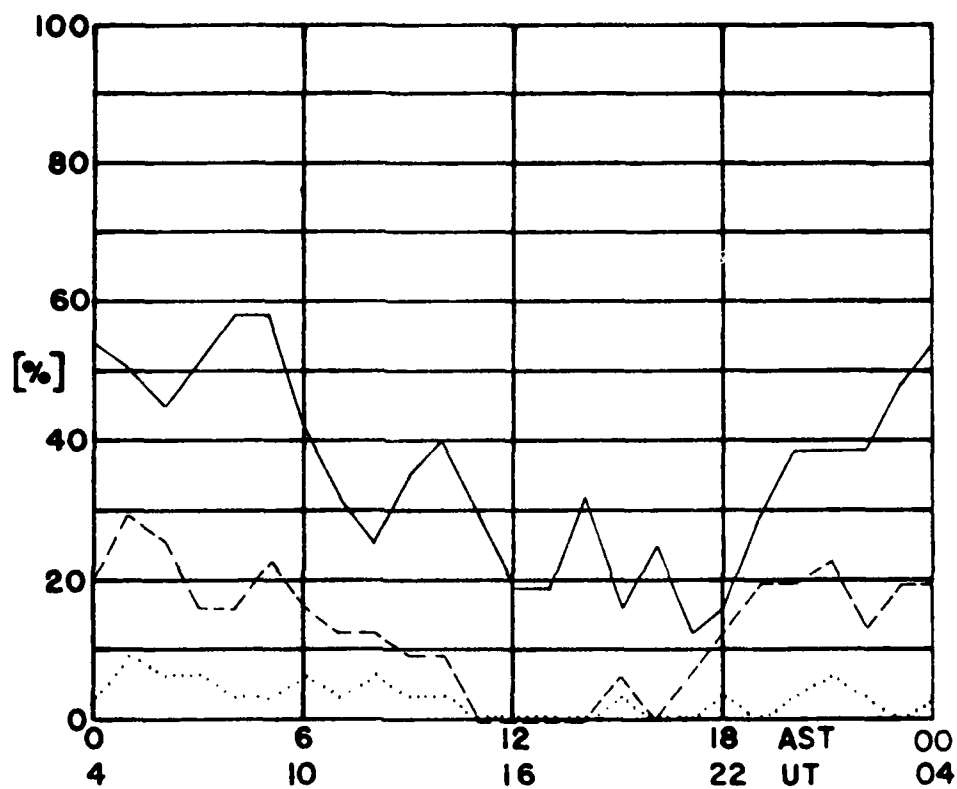
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LIMITING FREQUENCY 6MHz - - - - -
LIMITING FREQUENCY 7MHz
LIMITING FREQUENCY 8MHz - - - - -

PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF n' AND f_o AT GOOSEBAY, LABRADOR FOR DECEMBER 1977



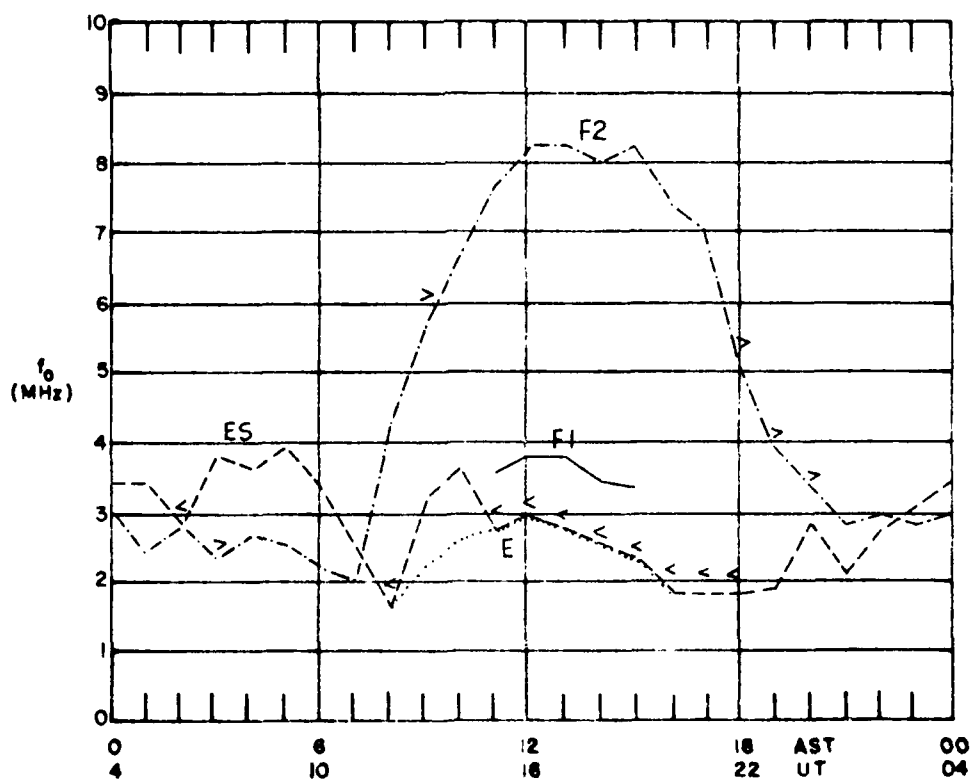
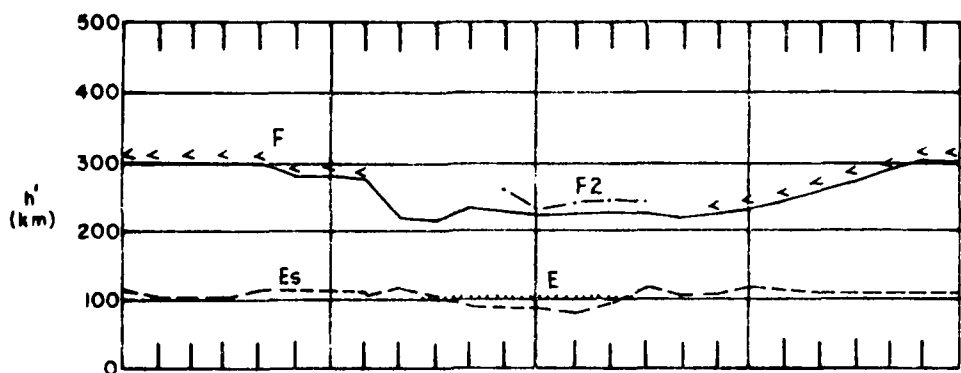
JANUARY 1978
GOOSE BAY, LABRADOR



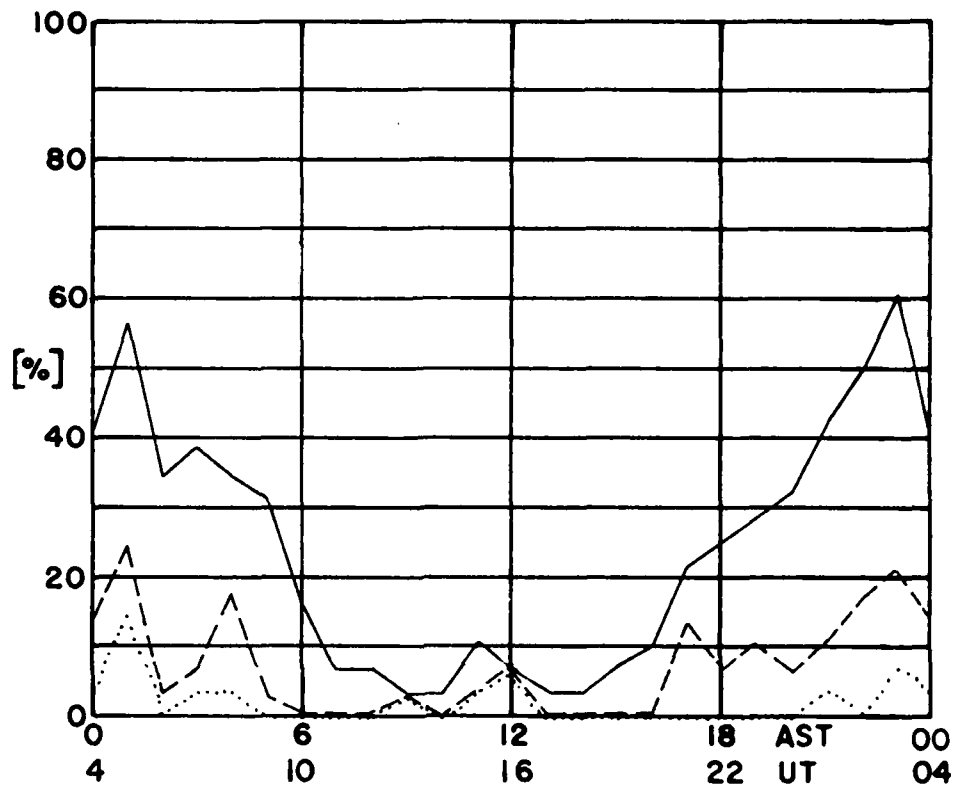
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR JANUARY 1978



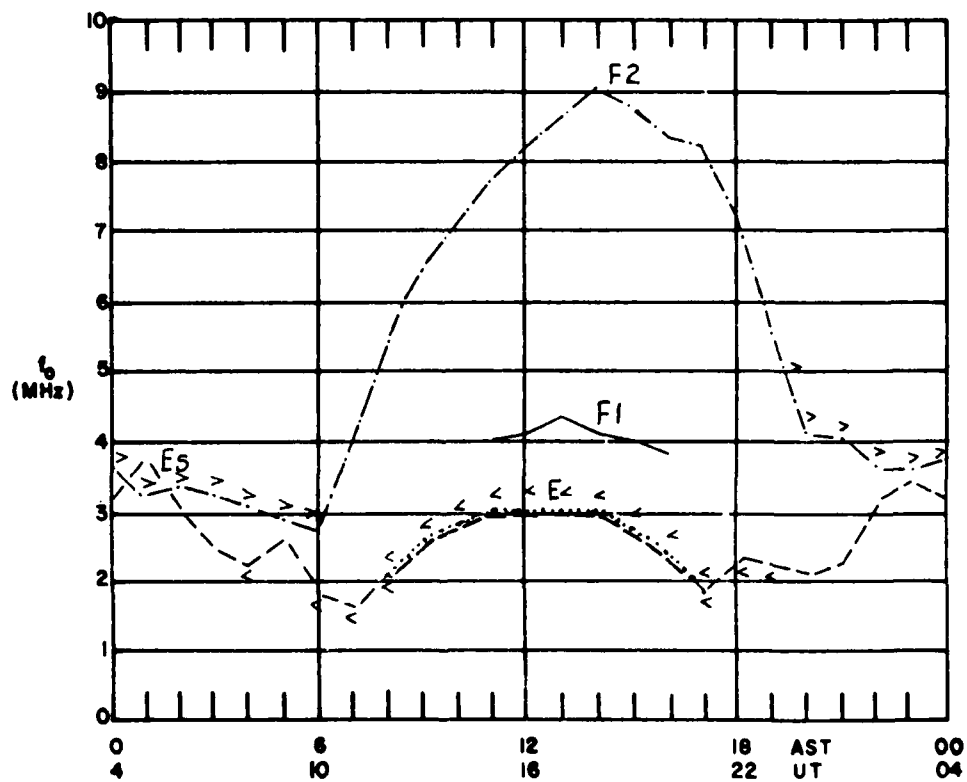
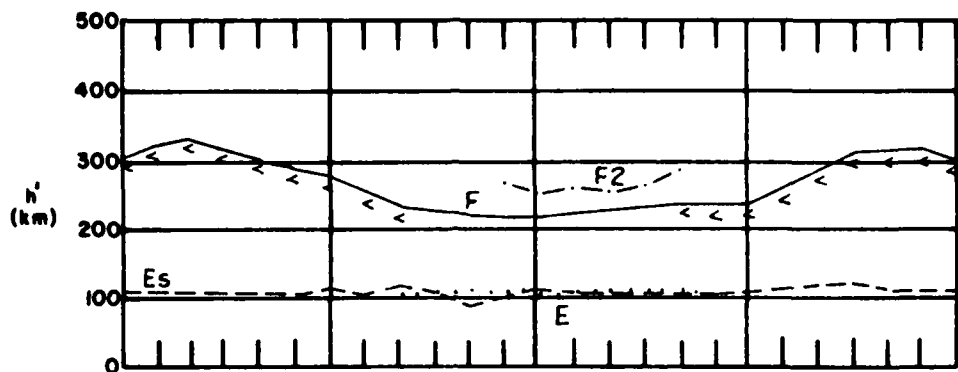
FEBRUARY 1978
GOOSE BAY, LABRADOR



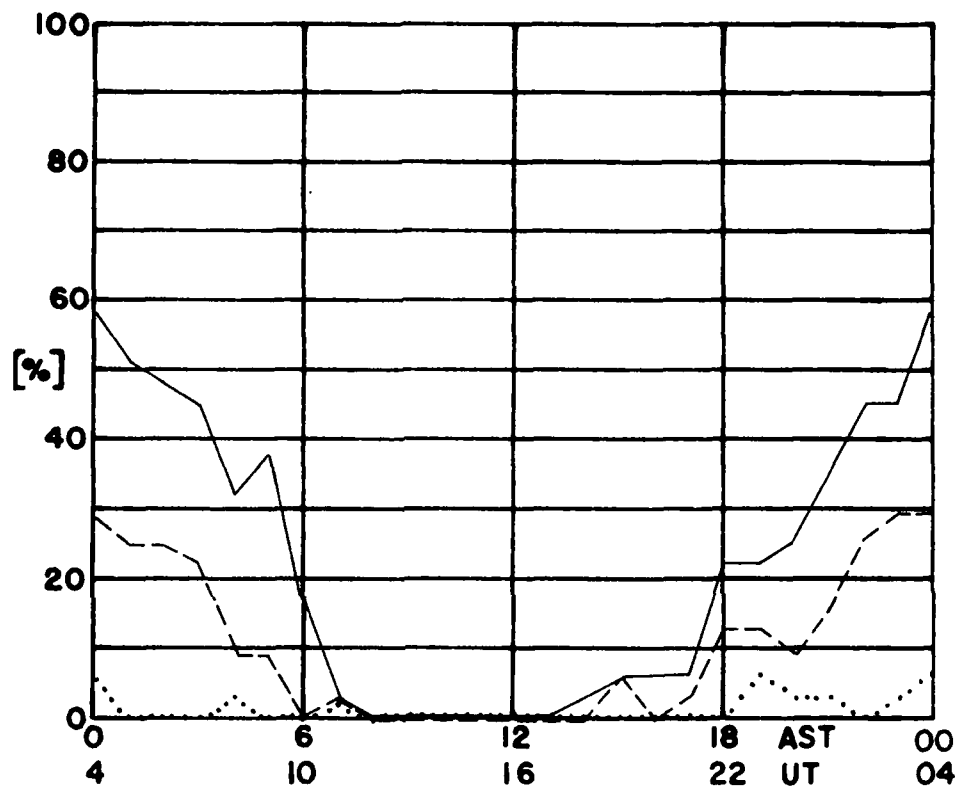
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF n' AND f_o AT GOOSEBAY, LABRADOR FOR FEBRUARY 1978



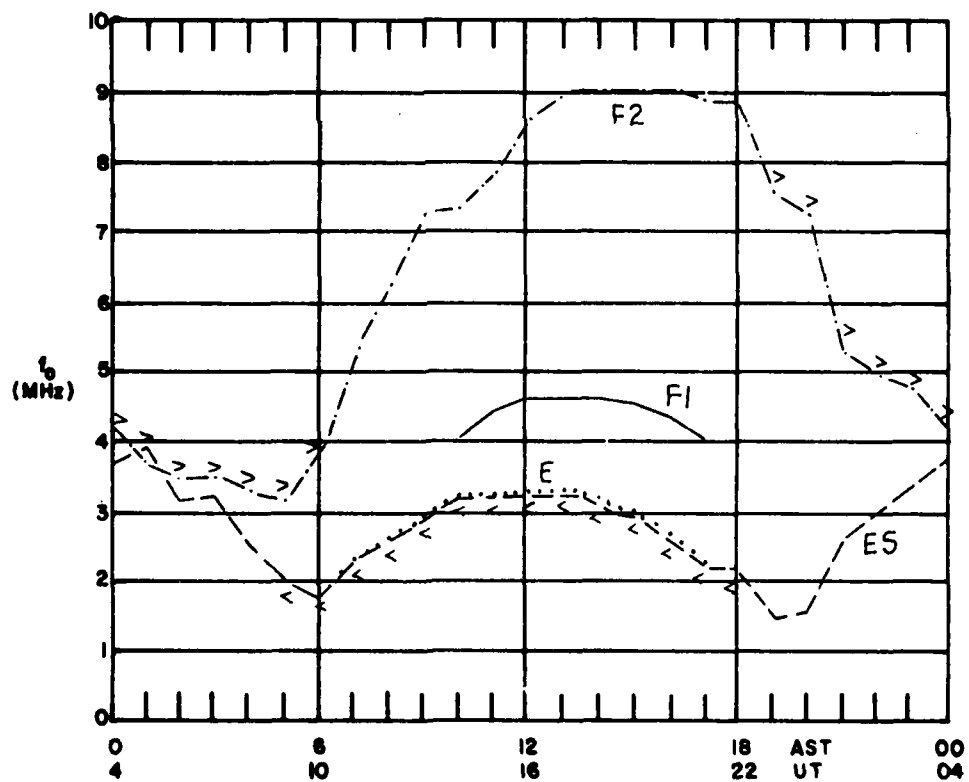
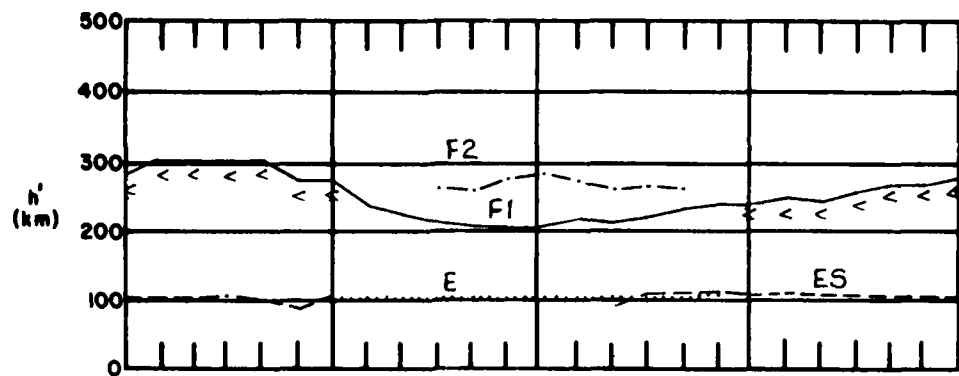
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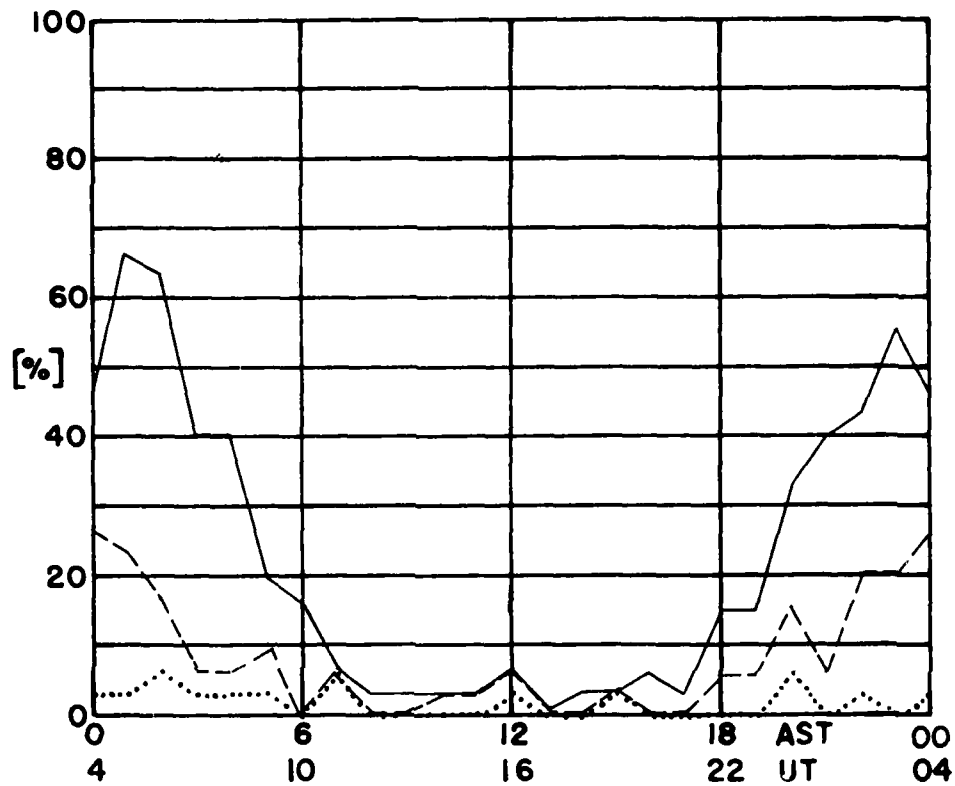
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF n' AND f_o AT GOOSEBAY, LABRADOR FOR MARCH 1978



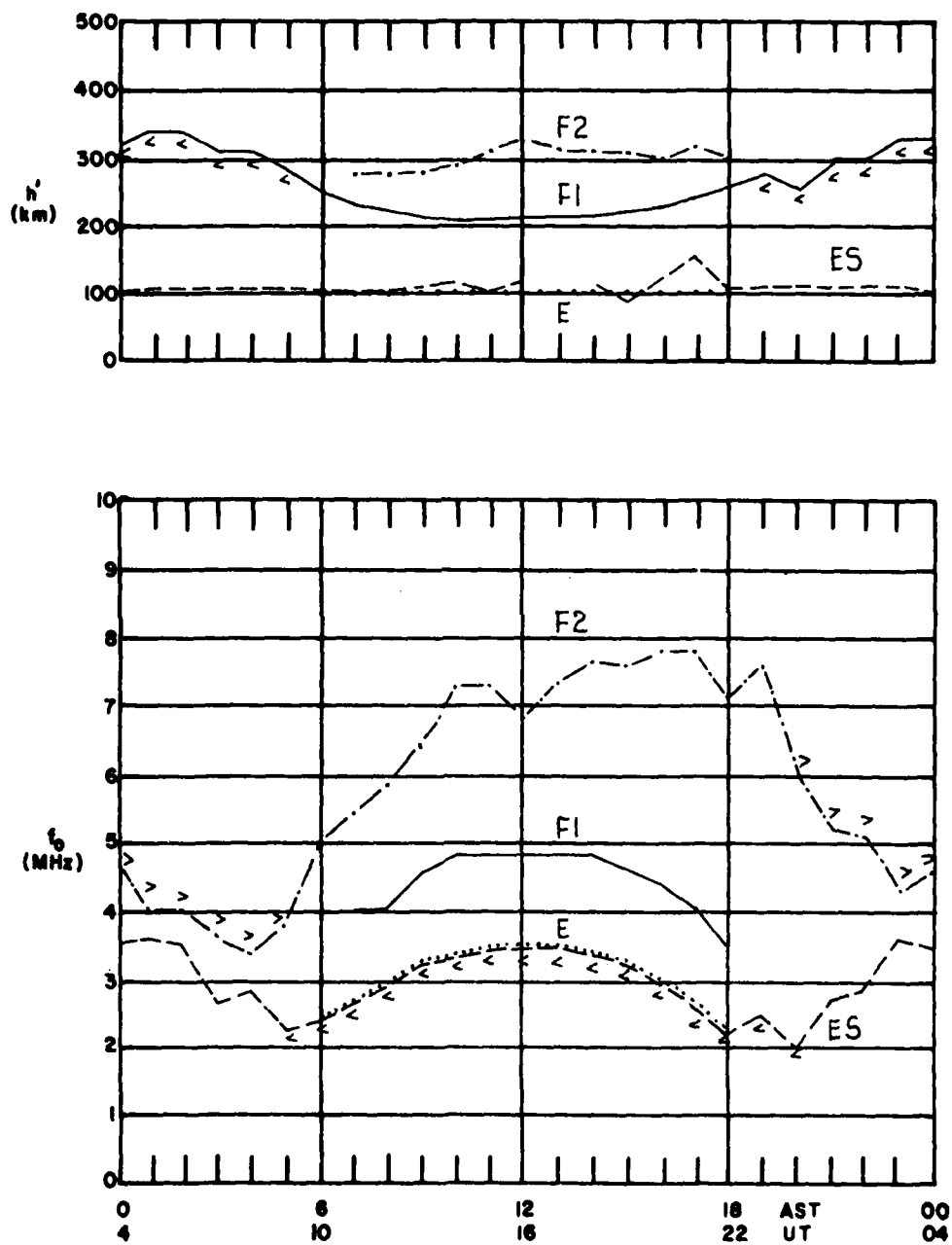
APRIL 1978
GOOSE BAY, LABRADOR



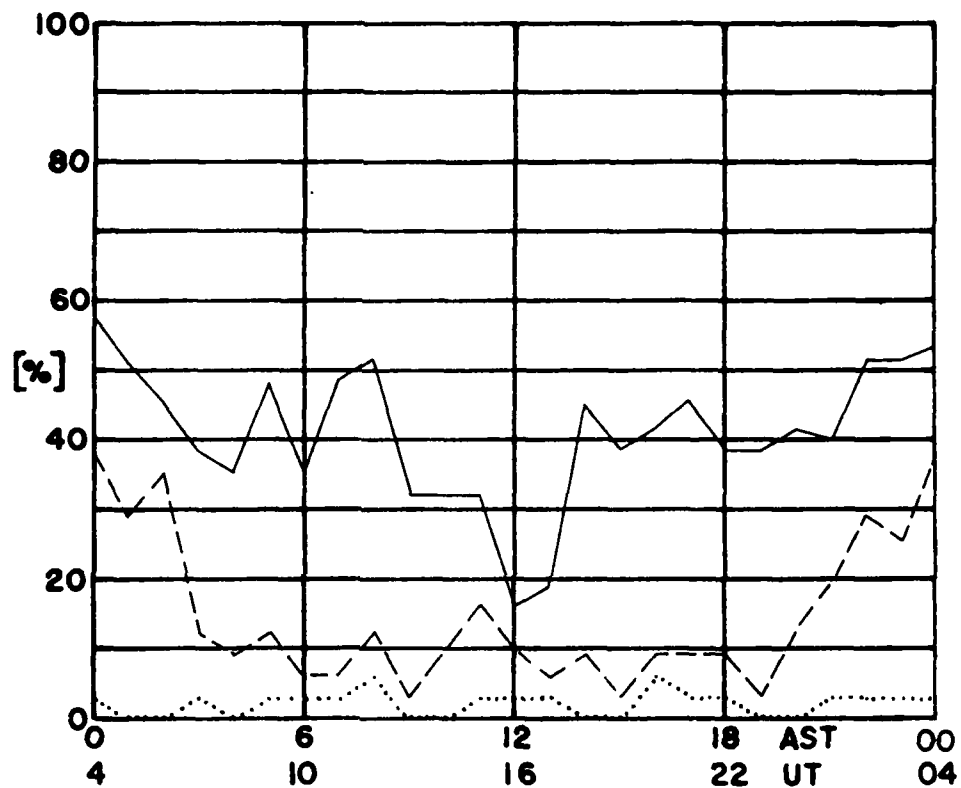
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR APRIL 1978



MAY 1978
GOOSE BAY, LABRADOR



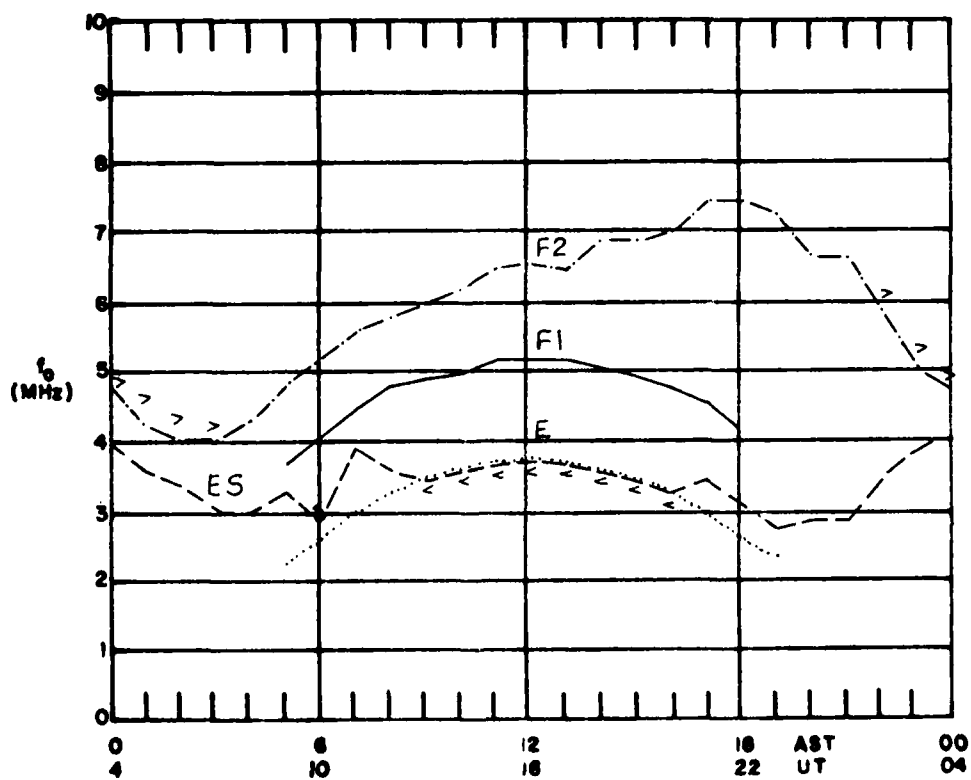
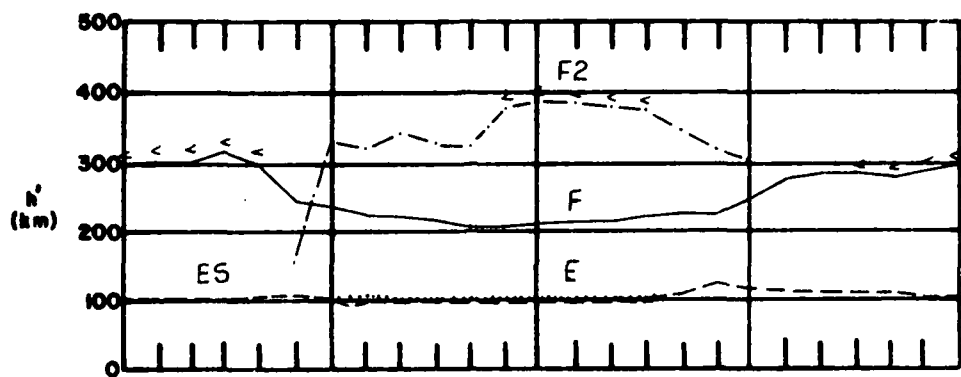
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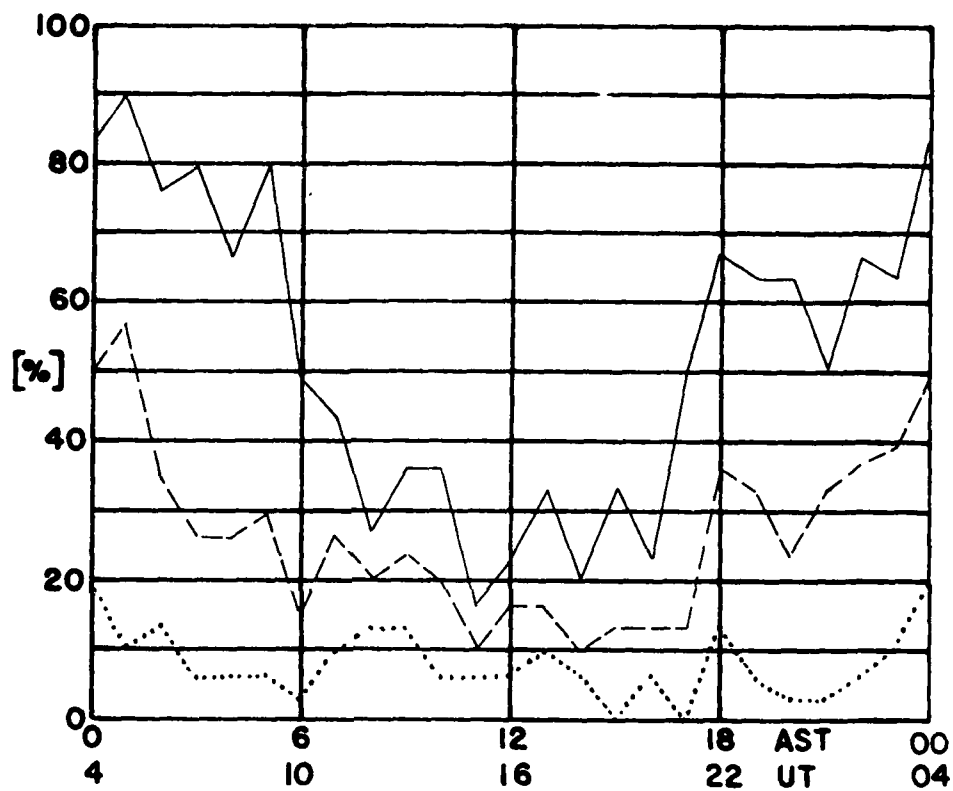
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF N' AND f_o AT GOOSEBAY, LABRADOR FOR MAY 1978



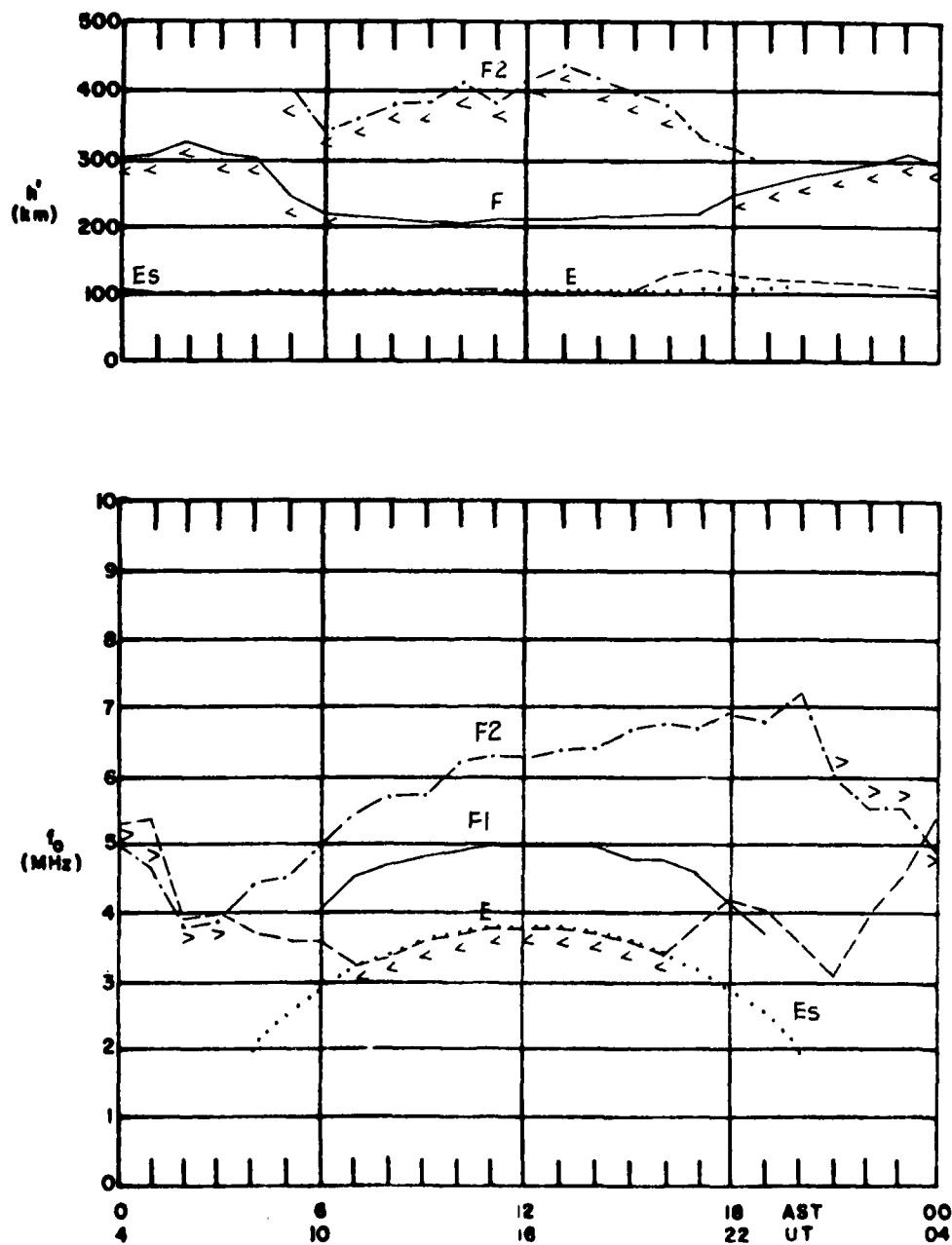
JUNE 1978
GOOSE BAY, LABRADOR



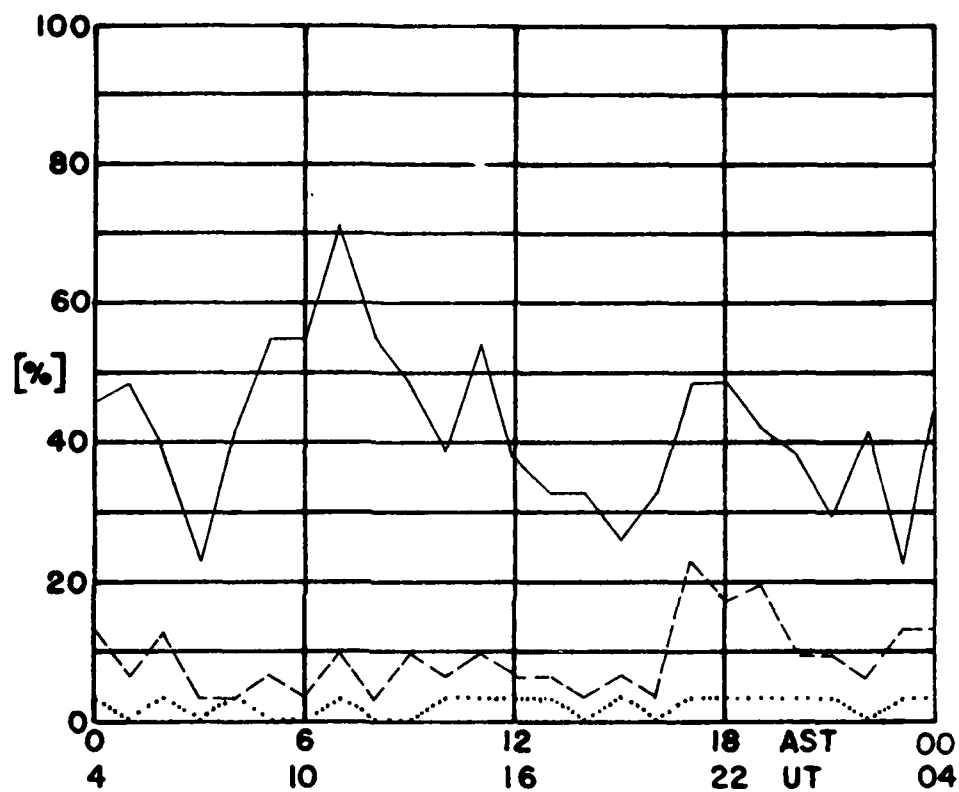
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF N' AND f_o AT GOOSEBAY, LABRADOR FOR JUNE 1978



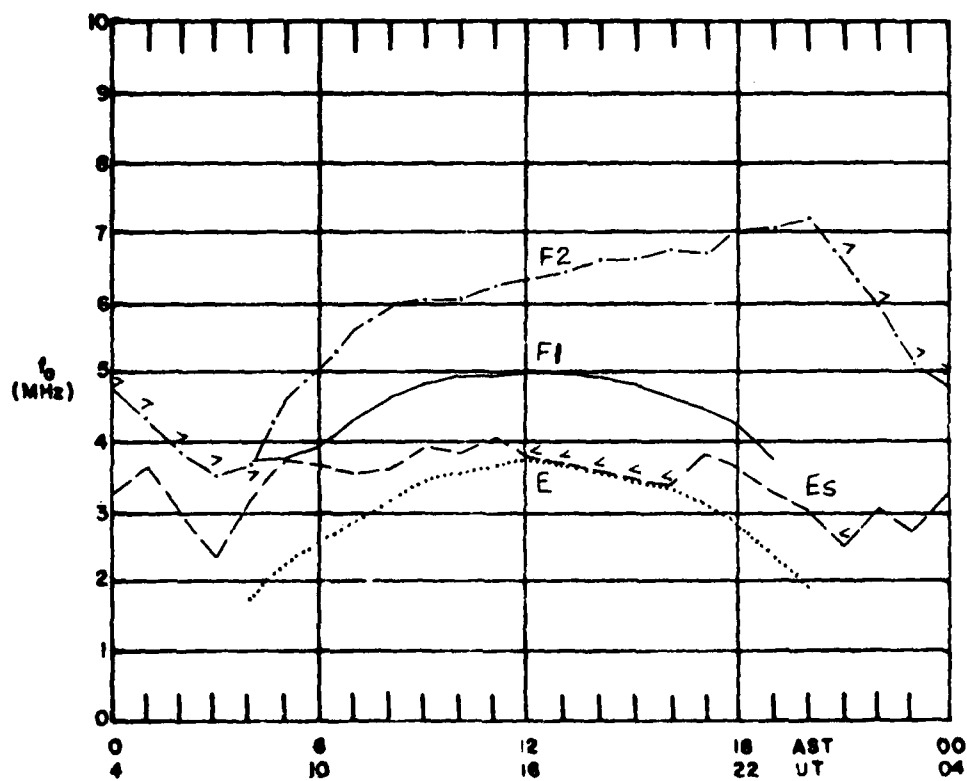
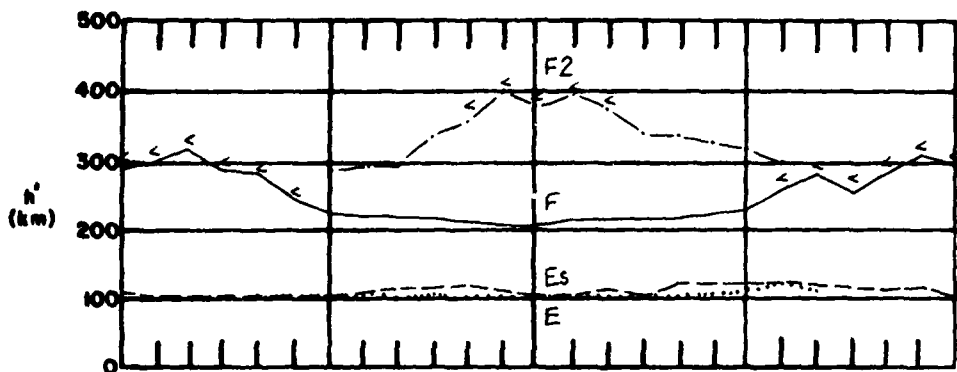
JULY 1978
GOOSE BAY, LABRADOR



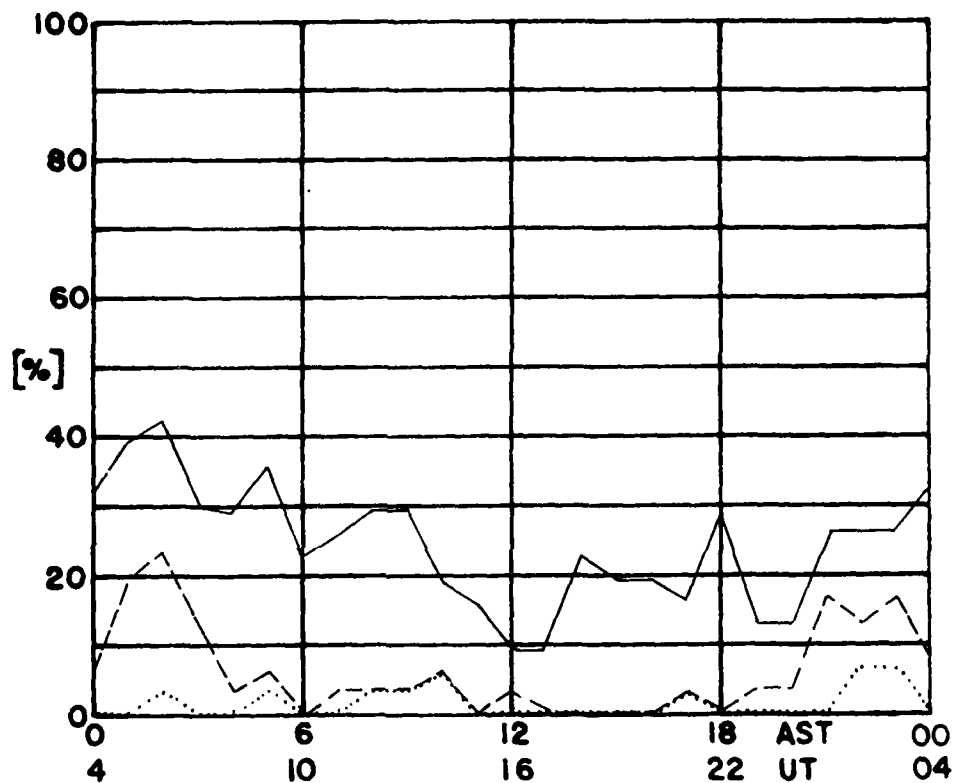
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR JULY 1978



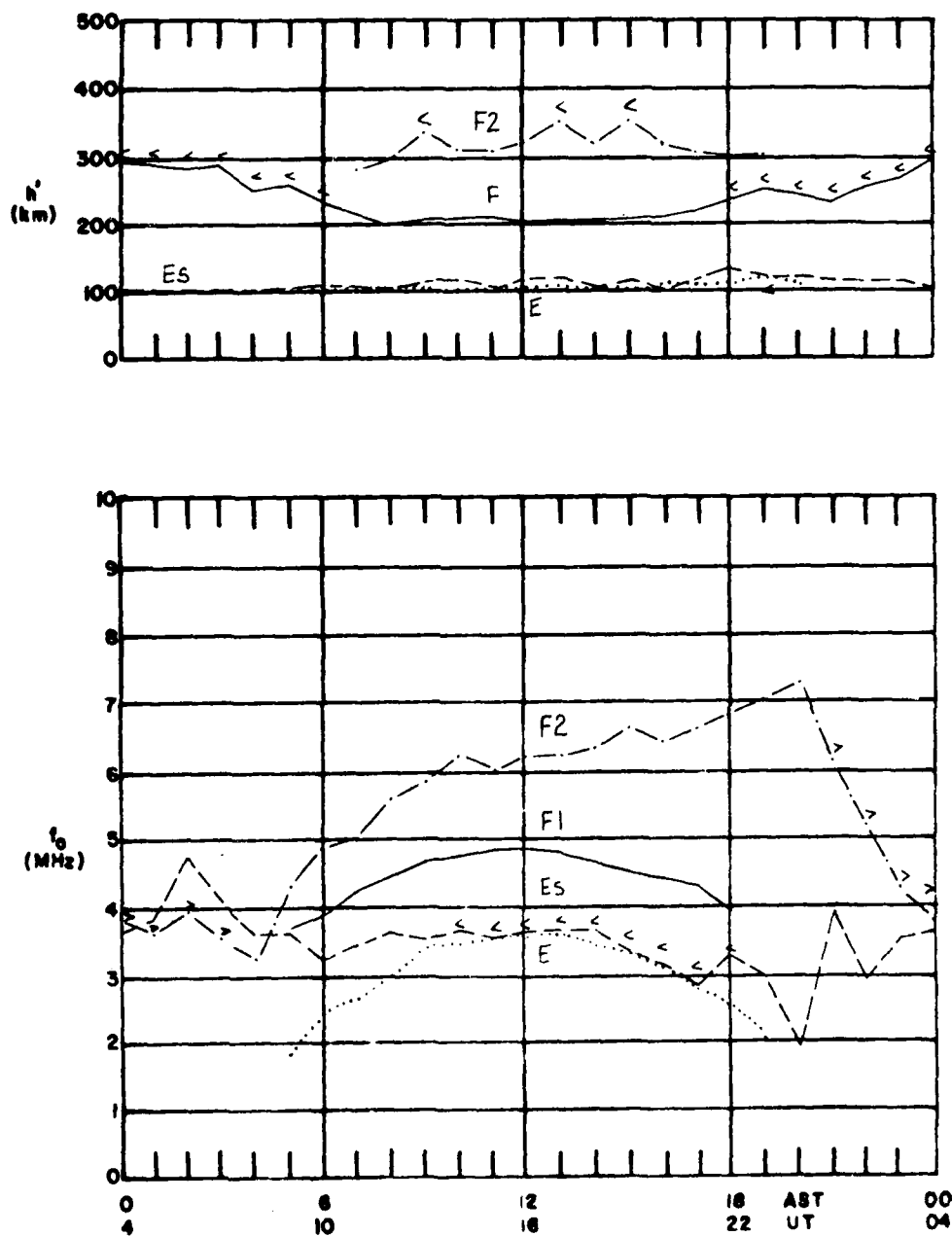
AUGUST 1978
GOOSE BAY, LABRADOR



LIMITING FREQUENCY = 3MHz —————
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF n' AND f_o AT GOOSEBAY, LABRADOR FOR AUGUST 1978



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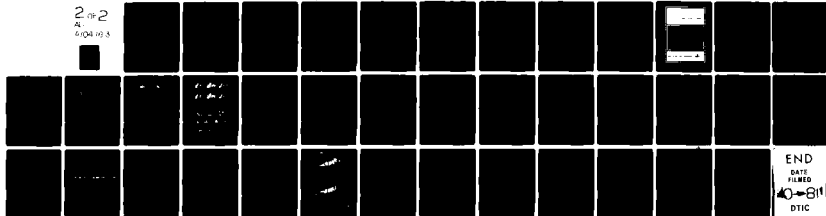
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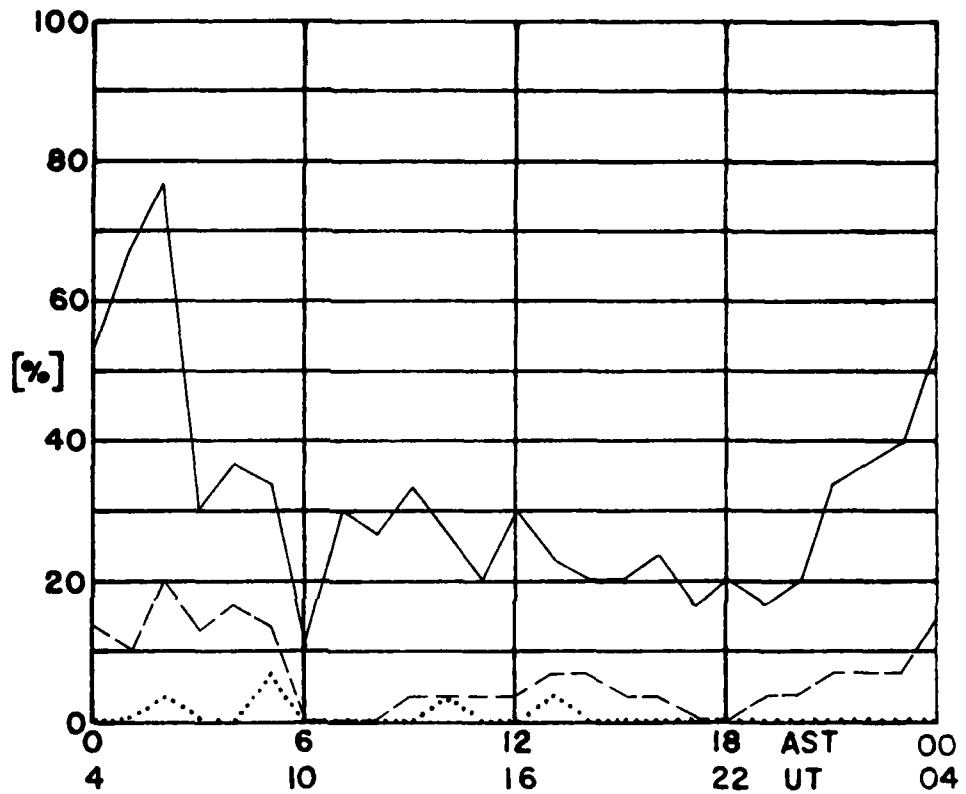
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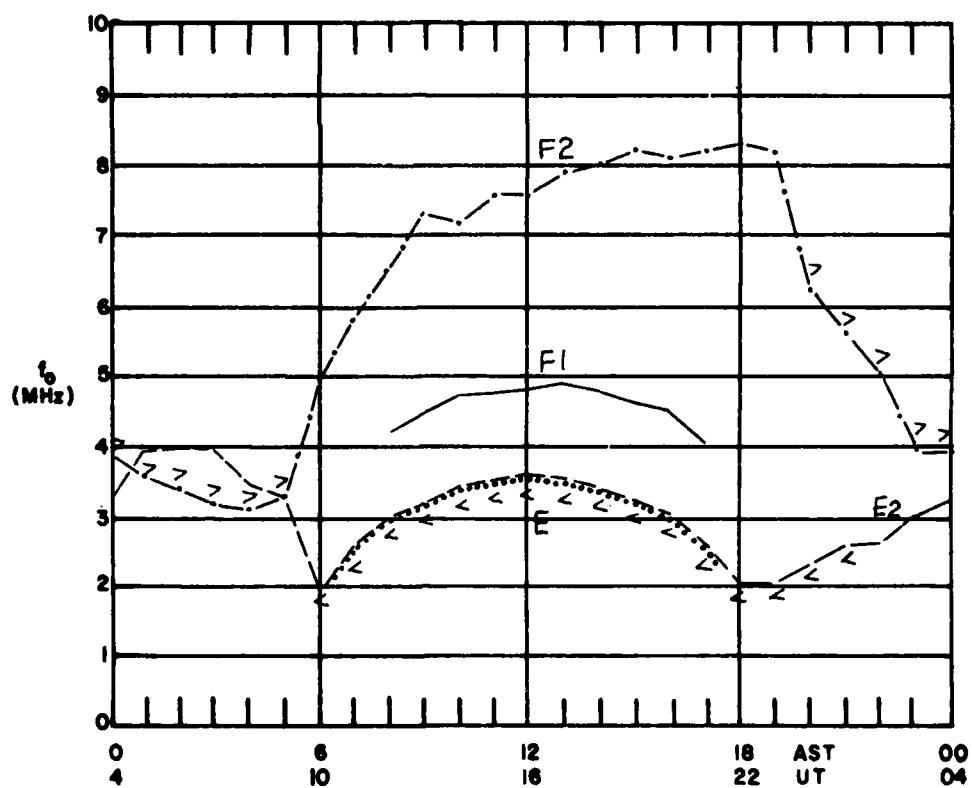
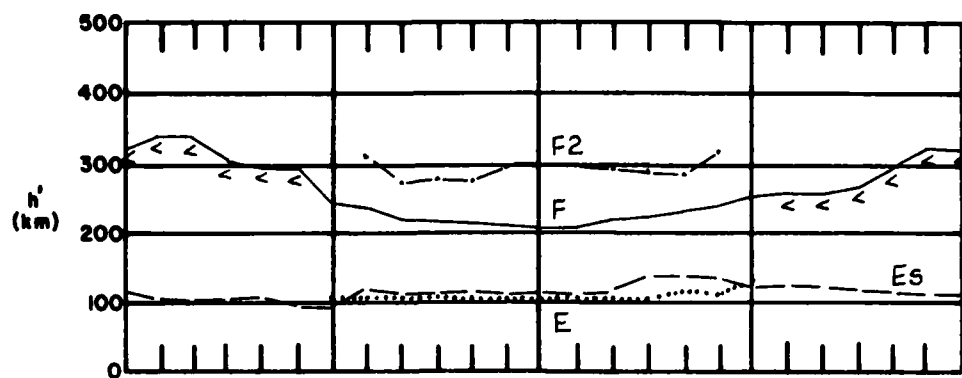
SEPTEMBER 1978
GOOSE BAY, LABRADOR



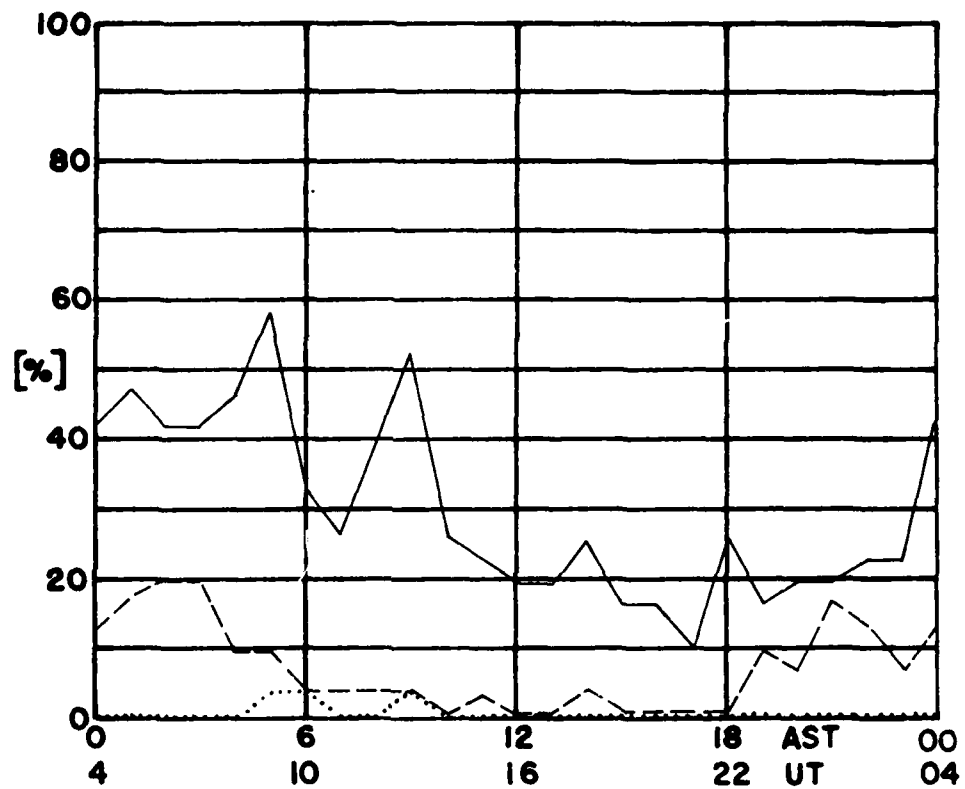
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PERCENTAGE OF TOTAL TIME DURING WHICH
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MEDIAN VALUES OF n' AND f_o AT GOOSEBAY, LABRADOR FOR SEPTEMBER 1978



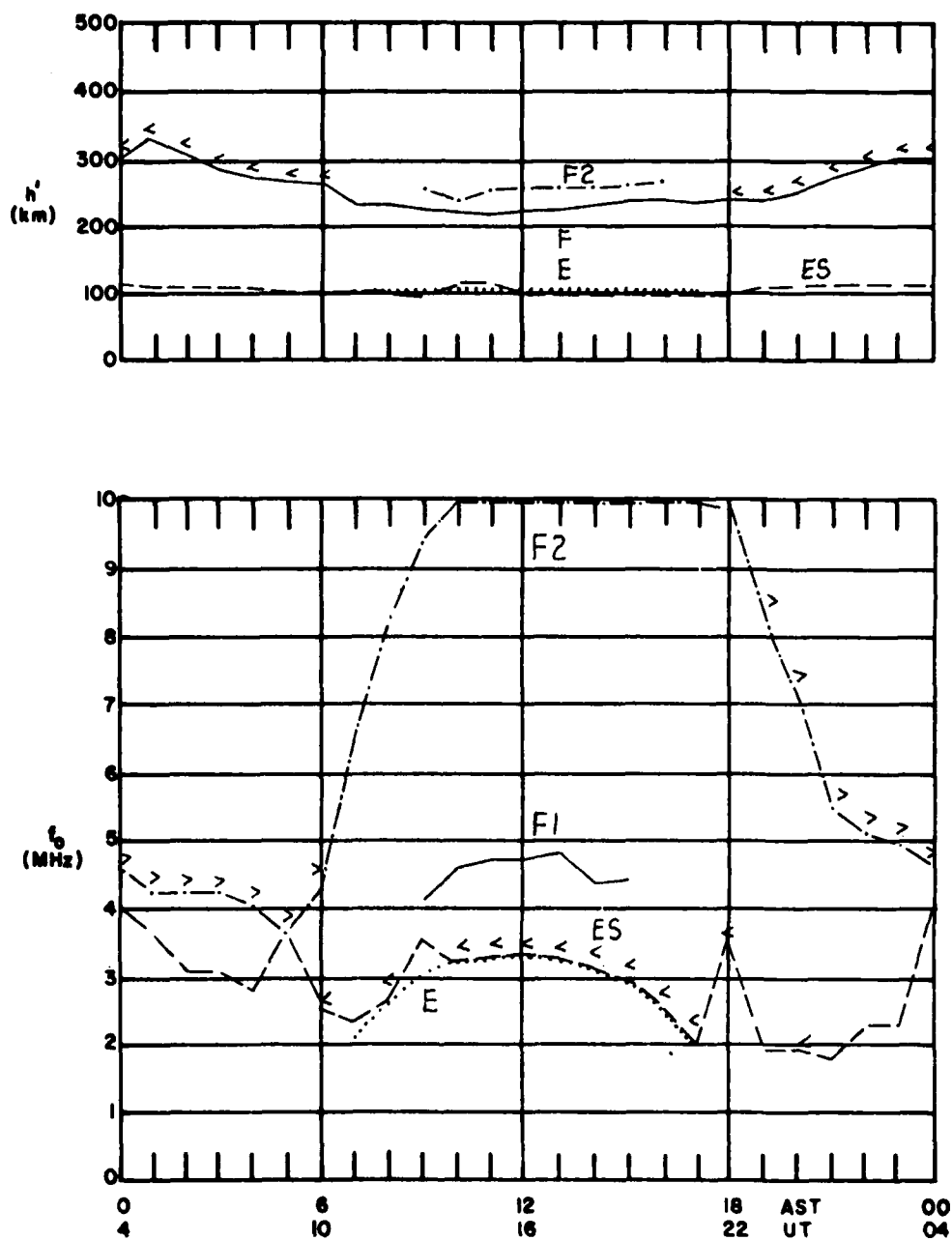
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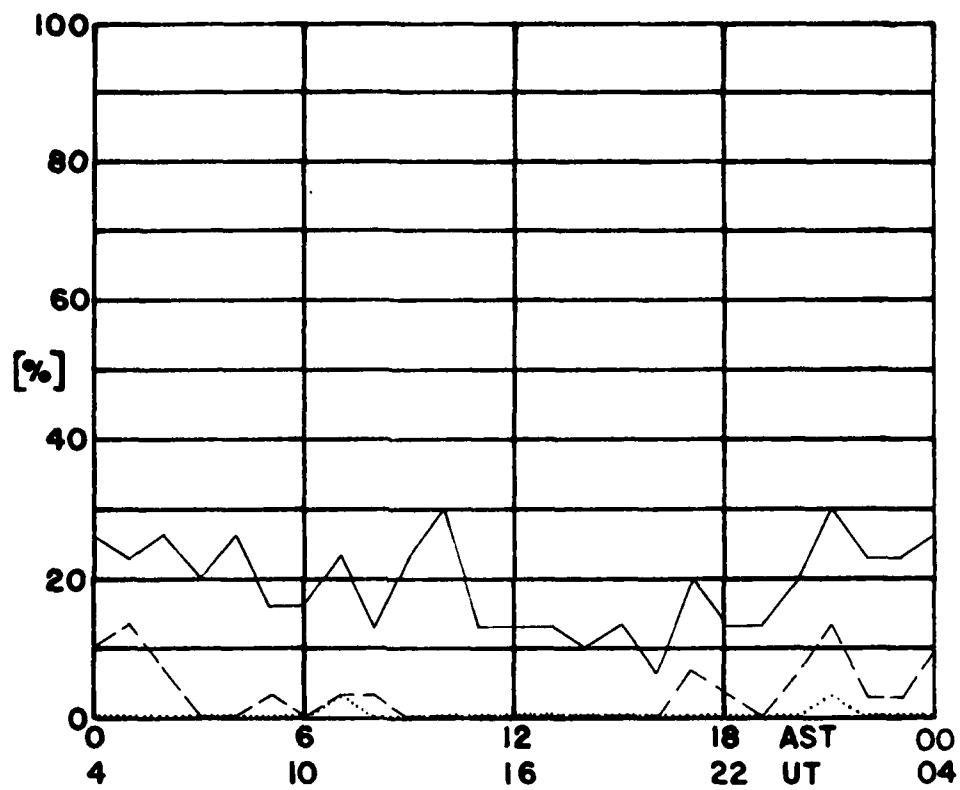
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MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR OCTOBER 1978



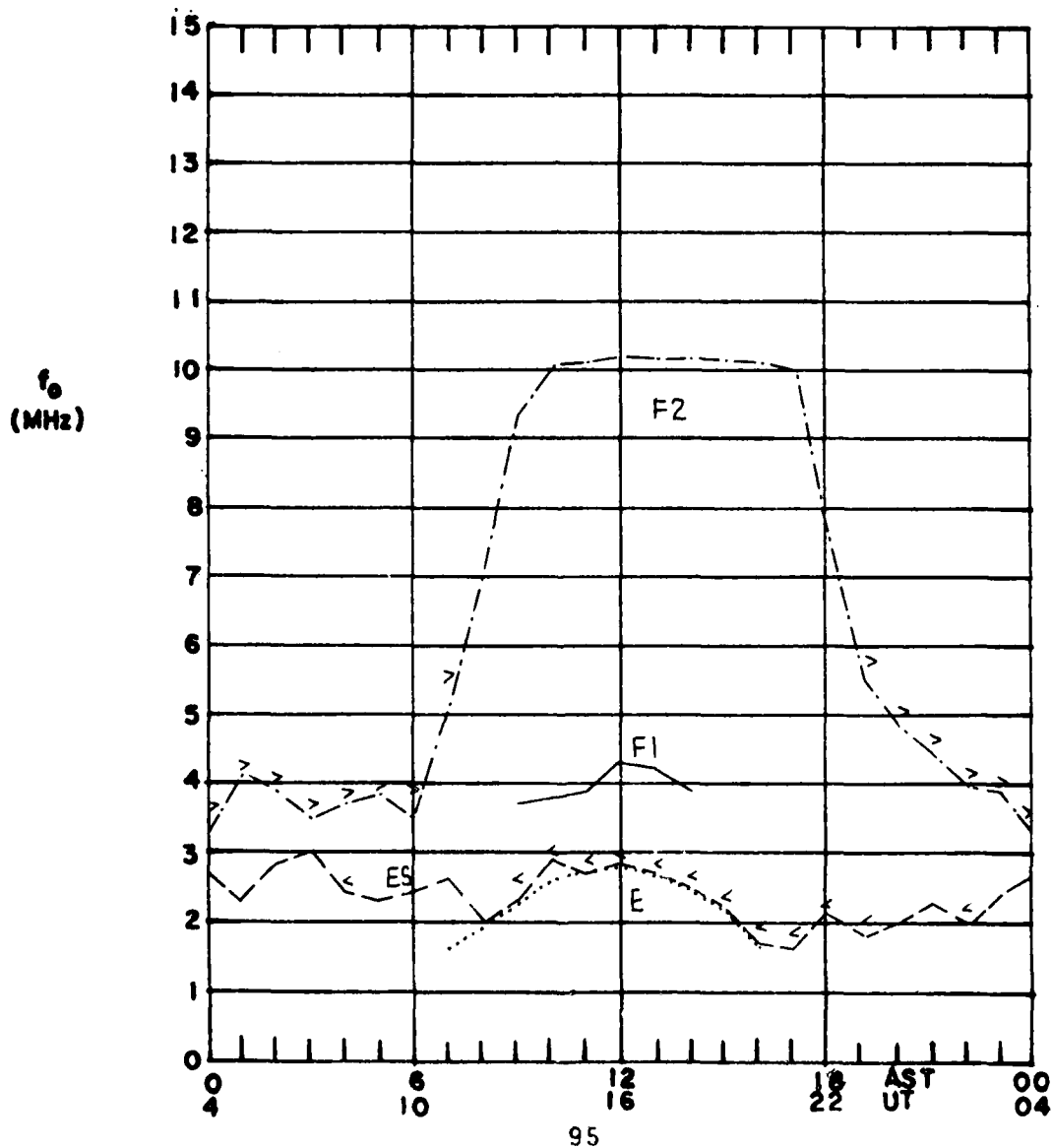
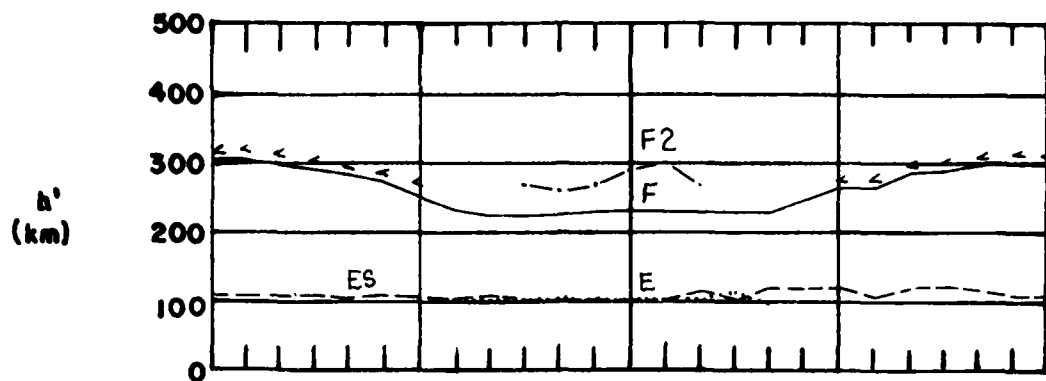
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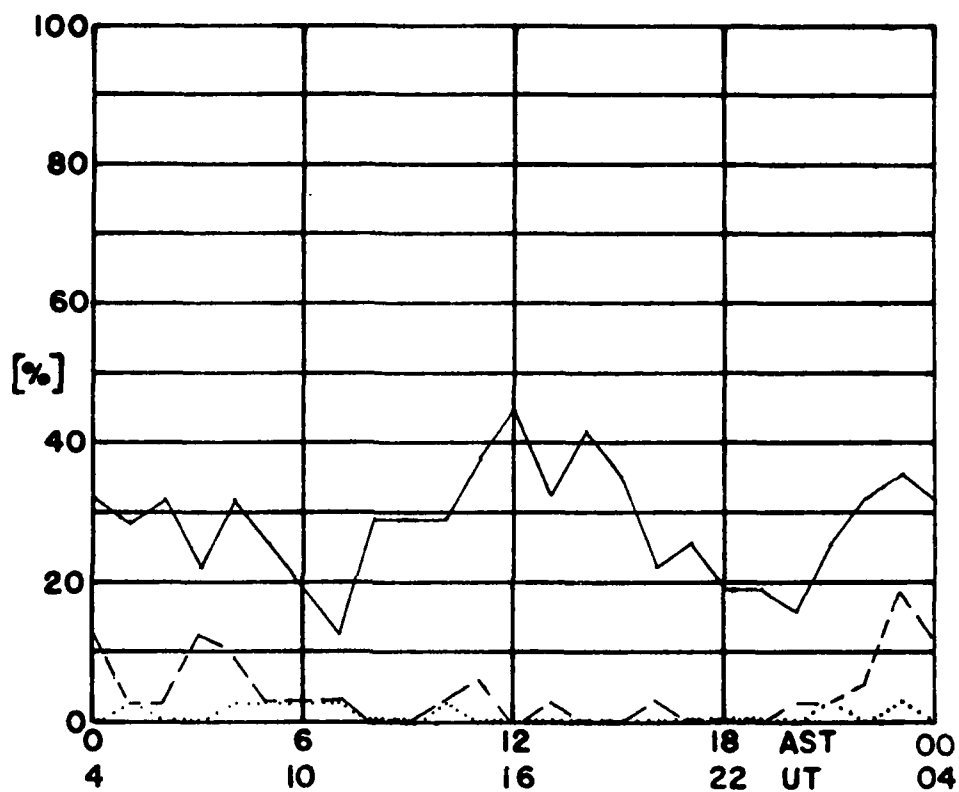
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PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES of h' AND f_o AT GOOSE BAY, LABRADOR FOR
 NOVEMBER 1978



DECEMBER 1978
GOOSE BAY, LABRADOR



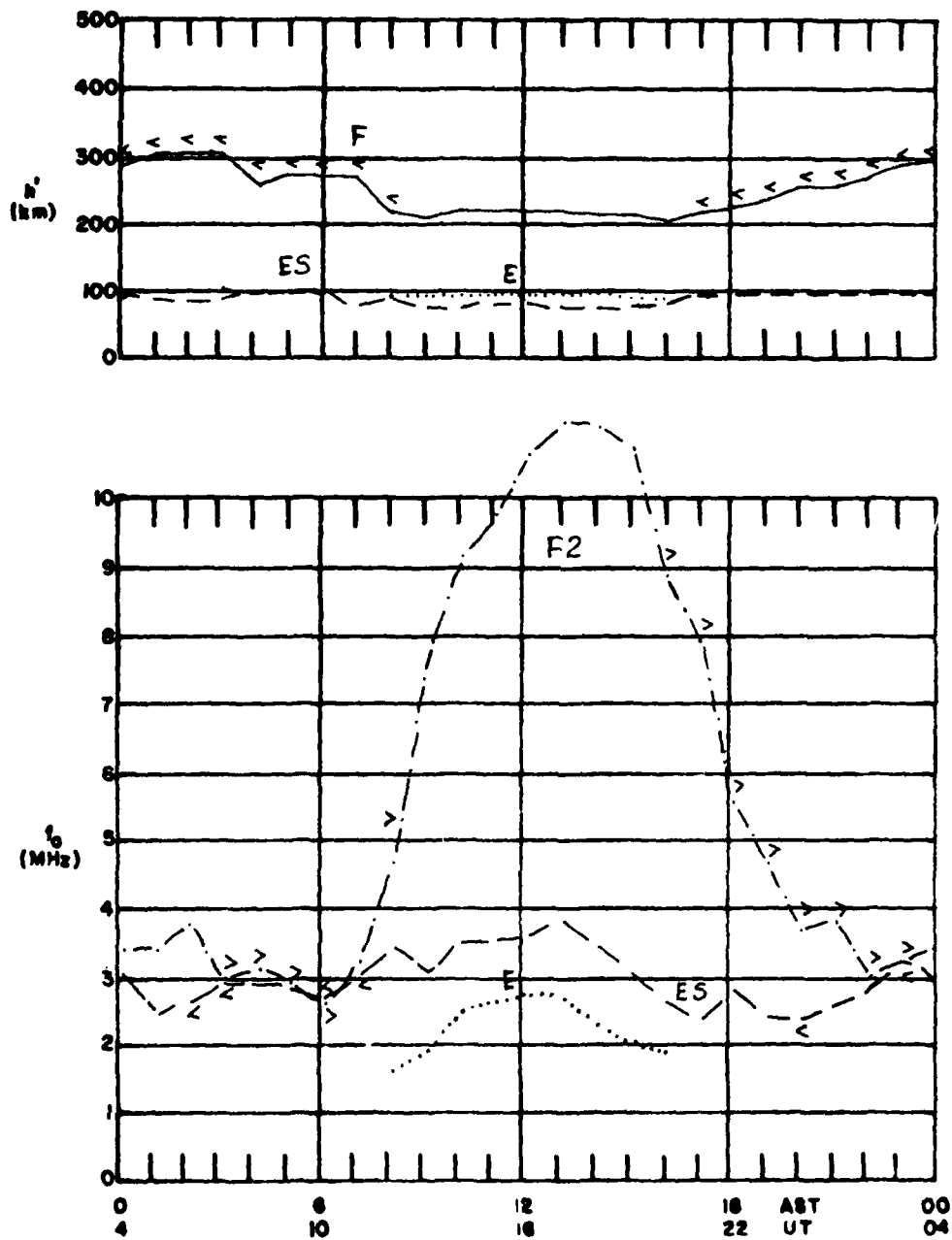
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LIMITING FREQUENCY = 7MHz

PERCENTAGE OF TOTAL TIME DURING WHICH
 $f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF N' AND f_o AT GOOSEBAY, LABRADOR FOR DECEMBER 1978



A P P E N D I X B

PAPERS AND ABSTRACTS

Papers and Abstracts which were in part supported under Contract F19628-78-C-0085 and the preceding Contract F19628-77-C-0024 and had not been officially submitted to the Air Force.

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SPECIAL TOPICS IN HF PROPAGATION

NORTH ATLANTIC TREATY ORGANIZATION



DIGITAL ON-LINE PROCESSING AND DISPLAY OF MULTIPARAMETER HF TRANSMISSION DATA

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Center for Atmospheric Research
Lowell, Massachusetts, U.S.A.

SUMMARY

Amplitude, phase, angle of arrival, polarization, frequency shift and signal travel time of a radio wave are simultaneously measured as functions of time and frequency in a new digital ionosonde, the Digisonde 128PS.

For the study of the structure and motions of the ionosphere and its influence on Over-the-Horizon detection systems, on sea-state measurements, on direction and location finding methods and on communication systems a selection of the measurable parameters is recorded and displayed in real time with the necessary resolution. Two main modes of operation are described, the ionogram mode using a Maximum Amplitude scheme for data compression and the Doppler-Drift mode using preselected frequencies and range bins for data compression.

Many applications in new fields are anticipated in addition to the thorough understanding of the ionosphere, its sources and its forces.

1. INTRODUCTION

Radio waves are characterized by amplitude, phase, angle of arrival, polarization, frequency shift and signal travel time. All these wave parameters are measured as functions of time and frequency and displayed in real-time in a new digital ionosonde, the Digisonde 128PS. For the study of the structure and the motion of a dispersive medium, like the ionosphere, and for a full analysis of the influence of the ionosphere on Over-the-Horizon detection systems, on sea-state measurements, on direction and location finding methods and on communication systems a digital radio sounder is employed with pulsed carrier frequencies scanning in steps through a large frequency band. Frequency scanning adds an important parameter to the wave characteristics of a conventional Radar system.

2. SYSTEM DESCRIPTION

As a scientific instrument, but useful for many operational tasks, we have developed a digital ionosonde which uses a large antenna array in a scanning or in a beam-forming mode. The Digisonde 128PS (K. Bibl and B. W. Reinisch, 1978) simultaneously integrates the echo amplitudes in a phase coherent mode at many Doppler frequencies, and for all chosen antennas or beam-directions. Echoes from 24 antennas can at once be spectrum analyzed in 128 coherent channels, or 16 spectral lines can be monitored for 128 range bins. Many other combinations of range windows, frequencies, polarizations, spectral channels and incidence angles can be processed simultaneously. Using the time between the transmitted pulses to measure complex spectrum amplitudes in up to 256 range bins (time sectors) requires a very fast on-line spectrum analyzer. The Processing Controller of the Digisonde forms the products between the sine and cosine samples of the high frequency (HF) signal and the trigonometric spectral function (of three averaged spectral lines) at a rate of 1 MHz. But such a large amount of data can not be handled on a continuous basis. We therefore operate the system in one of two data compression schemes: the Ionogram Mode with the Maximum-Amplitude Method, and the Doppler-Drift Mode with limited frequencies and ranges.

2.1 Maximum Amplitude Mode

The Maximum Amplitude Mode is used for recording of digital ionograms. For each of the 128 range bins of the more than 100 carrier frequencies the largest amplitude of the 24 possible channels is selected. The amplitude is recorded together with a status character, indicating the selected channel number. Since the signals arriving from different directions with different Doppler travel along different paths, they mostly have different travel time. Thus the maximum method does not suppress essential information.

In the contrary this differential method, selecting the strongest amplitudes, enhances the main features of the investigated propagation medium, as shown on the right side in Fig. 1. With frequency as the abscissa and range as ordinate the amplitudes (on the bottom) or the status characters (on top) form patterns from the numerical presentations as the third dimension (K. Bibl, 1974). Different features are clearly distinguishable simultaneously. While one area of reflection (showing large values of the status indicator on the top of the picture) moves toward the observation station, the older ionization, forming the lower pattern, with numerical values below 8, moves away. While the presence of the "4" bit (numbers between 5 and 7 or 13 and 15) indicates high Doppler speed, the numbers 1, 5, 9, 13 indicate one direction, 2, 6, 10, 14 another and the numbers 3, 7, 11 and 15 a third direction of the arriving echoes.

A different method of data presentation, the split-screen technique, is presented in Fig. 1a. Here two complementary data sets, echoes with ordinary and with extraordinary polarization, are presented in two separate ionograms. Splitting into several ionograms is possible by an on-line microcomputer (Fig. 2). On the bottom of the figure the total of the recorded data is presented first in the form of amplitude ionograms and above those as status ionograms. On top of these two ionograms the data are broken down into three practically independent amplitude ionograms which show echoes arriving from three different directions. Since the interference is split in the same way a substantial reduction in interference appearance is achieved that way. To increase the number of scanned directions the receiver antenna beam is looking into different directions in sequential ionograms which are corresponding to the left or the right side of Fig. 2. This is done to increase the number of reflection areas with the same range displayed simultaneously and to increase the sensitivity of the differential selection in the Maximum Amplitude mode which overcomes the limitations caused by the large beam width of the receiver antenna array. Thus the ionogram showing the vertical echo also includes echoes from directions not separated by the split screen method. Therefore the consecutive "vertical" ionograms appear somewhat different and must be further cleaned in the microcomputer to include only common echoes. Similarly two additional directions: north and south can be constructed by extracting echoes common in the NW and NE or SW and SE ionogram respectively. Thus it will be possible to construct false color ionograms indicating six different directions as six different colors plus overhead as white and still maintain amplitude and/or Doppler information as numbers. A third method is the suppression of unwanted echoes, as shown in Fig. 3. This method finds application mainly in automatic compression and analysis of large data series where one magneto-ionic component or oblique echoes should be suppressed (Fig. 4). But the switching between ionograms with and without suppression of specific echoes shows surprises even to experienced data analysts, specifically in the aurora region where oblique echoes are often interpreted wrongly. Thus the digital tagging of the echo properties is significant also for the manual data analysis as inputs for world-wide mapping.

2.2 Doppler-Drift Mode

In the Doppler-Drift Mode a full complex spectrum analysis is executed in real time during the measurement. The build-up of the spectra can be observed for any and all of the 24 independent channels by the programmable test features. Guided by the survey provided by the Maximum Amplitude Mode six frequencies and ranges can be chosen for the scanning of four antennas simultaneously. Rather than processing a multitude of frequencies and ranges, the signals from up to 24 antennas are spectrum analyzed simultaneously. This interlaced spectrum analysis is necessary if low Doppler frequencies have to be studied and the propagation conditions provide barely consistent data during the integration period. In contrast to the Fast Fourier Transform procedure used in most computers our Direct Discrete Fourier Transform algorithm with Hanning weighting by averaging the spectral phase function provides a continuous consistency check of the data. Fig. 5 shows that the complete multi-dimensional spectrum analysis is executed while the data are digitized as quadrature samples of the Intermediate Frequency (IF).

3. APPLICATION

A wide field of actual and possible applications for this instrument can be envisioned. The first system has been used to study the equatorial spread-F phenomenon in the ionosphere which heavily affects satellite-ground communication and navigation up to several GHz during many nights. Similar phenomena are studied in the aurora region of the ionosphere. We further applied the Digisonde to measurements of the sea-state of the oceans by direct and ionospherically reflected scatter and bistatic radio propagation experiments.

3.1 Gravity Waves and Fine Structure in the Ionosphere

Incidence angle measurement on spectrum-analyzed monostatic and bistatic pulse radio signals have shown that the structure of the ionosphere is multidimensional. Only rarely can the ionosphere be considered a plane reflector with an effective reflecting surface of the size and shape of the first Fresnel zone. In most cases the surface of constant electron density is two-dimensionally curved.

Therefore it is not always possible to find an area of perpendicularity but sometimes more than one perpendicular area can be found. The requirement of perpendicularity is related to the requirement of constant phase by the Fresnel condition which permits coherent integration of all contributions within the Fresnel zone.

Although spectrum analysis diminishes the area which can contribute to a coherently integrated signal it does simultaneously ease the condition of perpendicularity. Under the assumption of an almost constant drift of all irregular structure over the surface of constant electron density the spectrum analysis cuts out a band from this surface. The width of the band is determined by the drift speed and by the spectral resolution to comprise all reflection points with the same Doppler frequency. The length of the band is given by the Fresnel condition and is only extensive if the surface is perpendicular at least in the direction along the band (which is oriented perpendicular to the drift velocity).

But the perpendicularity requirement across the band is substantially relaxed because a change by one-half wavelength in phase path can be admitted for the width of the reflecting surface band if the roughness of the surface is sufficient to produce specular reflection. Under reasonable assumptions of drift speed and spectral resolution the reflecting surface band has a width in the order of 500 m (for F-region heights) which permits coherent addition of returns from all points of the surface if the inclination of the surface is less than 6° at 3 MHz probing frequency. Similar deviations from perpendicularity are permitted in the F-region since some of the changes in parameters compensate each other.

This Doppler-induced quasi-perpendicularity condition makes a large part of the constant electron density surface visible simultaneously and permits determination of its three-dimensional structure and motion at least in the time sequence of the "sky maps" which indicate the locations of all the reflection areas for all Doppler frequencies present at the sampling time (Fig. 6).

In transionospheric transmissions from satellites and reflections from targets fading, scintillation and positioning errors are caused by multimode propagation. Although the spacing of the different propagation paths is small compared with those of the vertical or oblique reflection case, effects of the multimode propagation might become important since higher accuracy for the incidence angle determination is required. Not always does the higher operation frequency compensate for the more stringent accuracy requirements. Therefore a good three-dimensional model is necessary for the correction of incidence angle errors. It can be produced by either multi-antenna complex spectral analysis of known satellite signals or by extrapolation from vertical sounding experiments not too far (<500 km) from the subionospheric point of the expected satellite propagation path.

3.2 Sea-Surface Waves

In March 1973 a Digisonde was used for the radio Doppler probing of the ocean surface in Eglin, Florida (Fig. 7). At a radio frequency around 6 MHz the energy scattered back showed Doppler offsets of ± 0.25 Hz. These observations are in good agreement with the theoretically predicted Bragg scatter lines, but show many additional features and unexpected events. Nevertheless even the motion of the water parallel to the wave motion can be resolved.

3.3 Future Applications

The precision of the digital direct frequency synthesis, and the large antenna array permit accurate angular measurements for radio-interferometry in the frequency range of 20 to 40 MHz. Solar, planetary and galactic sources can be studied with this system. A combined acoustic-electromagnetic sounding of the non-ionized atmosphere is very promising. Acoustic scanning in medical and material research requires only little modification. Scanning of the sea-bottom (after conversion to acoustical waves) and underground radio communication and structure research should also be possible with this system.

We are developing a prototype for a topside digital ionosonde with very low output data rate (300 bits/sec). Such a system can also be used as a unmanned station on an island or a buoy in the ocean, on-board of a ship or in the arctic or antarctic. This sounder will broadcast the significant information of the preceding ionogram during the following ionogram to another Digisonde station in a distance of up to 3000 km for remote recording via an ionospheric propagation path (K. Bibl and B. W. Reinisch, 1976). This method has the advantage that the ionospheric conditions at the location of the ionospheric reflection can be monitored simultaneously. Data from several stations can be recorded simultaneously. Such a system can form an emergency radio propagation prediction network in case that satellite communication is interrupted. But for normal conditions simpler and more reliable satellite links can be used for collecting the low rate data from remote unmanned Digisonde stations.

ACKNOWLEDGEMENTS

The development of this instrument has been supported in part by DNA under Contract No. DNA001-77-C-0187 and by AFGL under Contract No. F19628-77-C-0024. The first on-line spectrum analyzer was integrated into a Digisonde for the U.S. Army Electronics Command under Contract No. DAAB07-75-C-A176.

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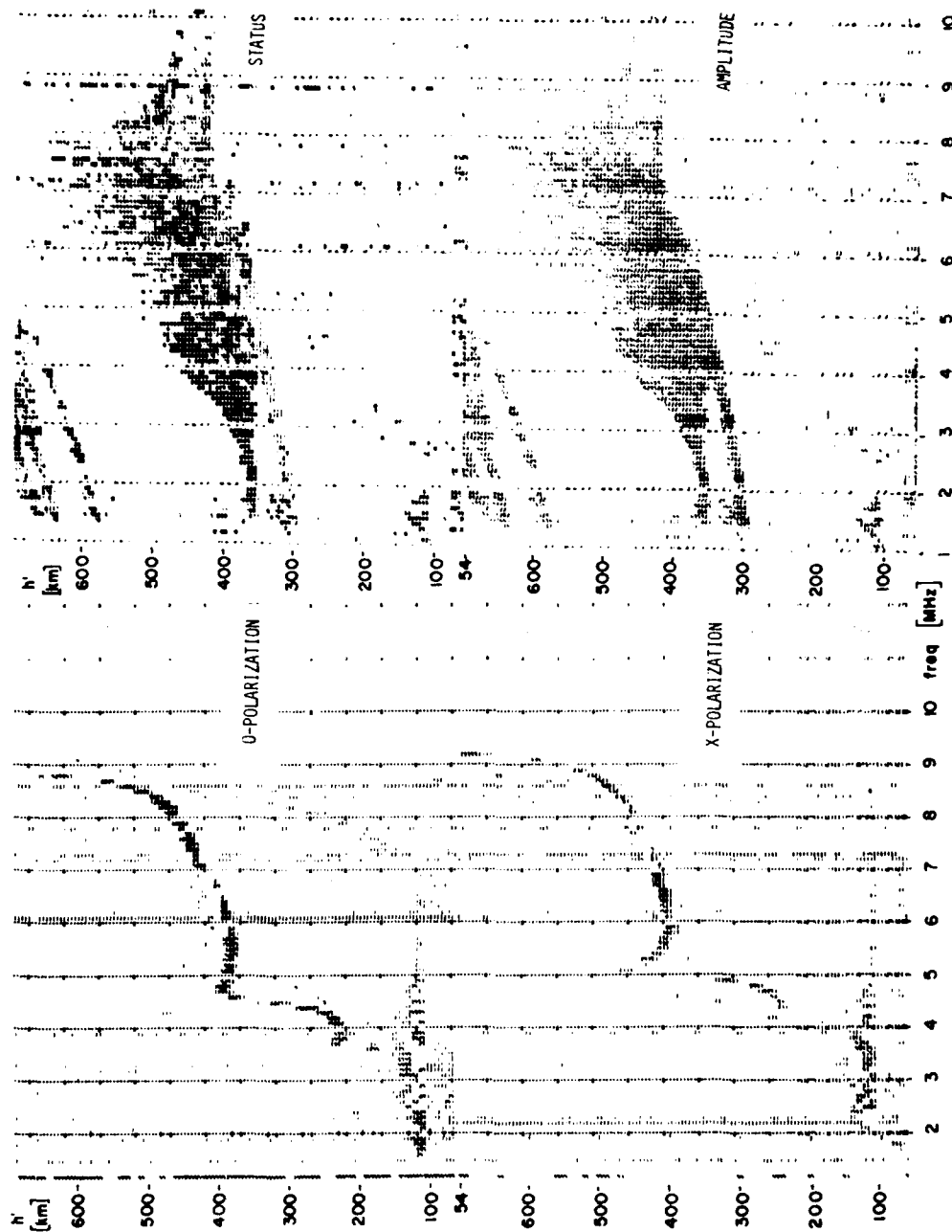


Fig. 1a SPLIT ICNOGRAM

Fig. 1b AMPLITUDE, AZIMUTH AND DOPPLER

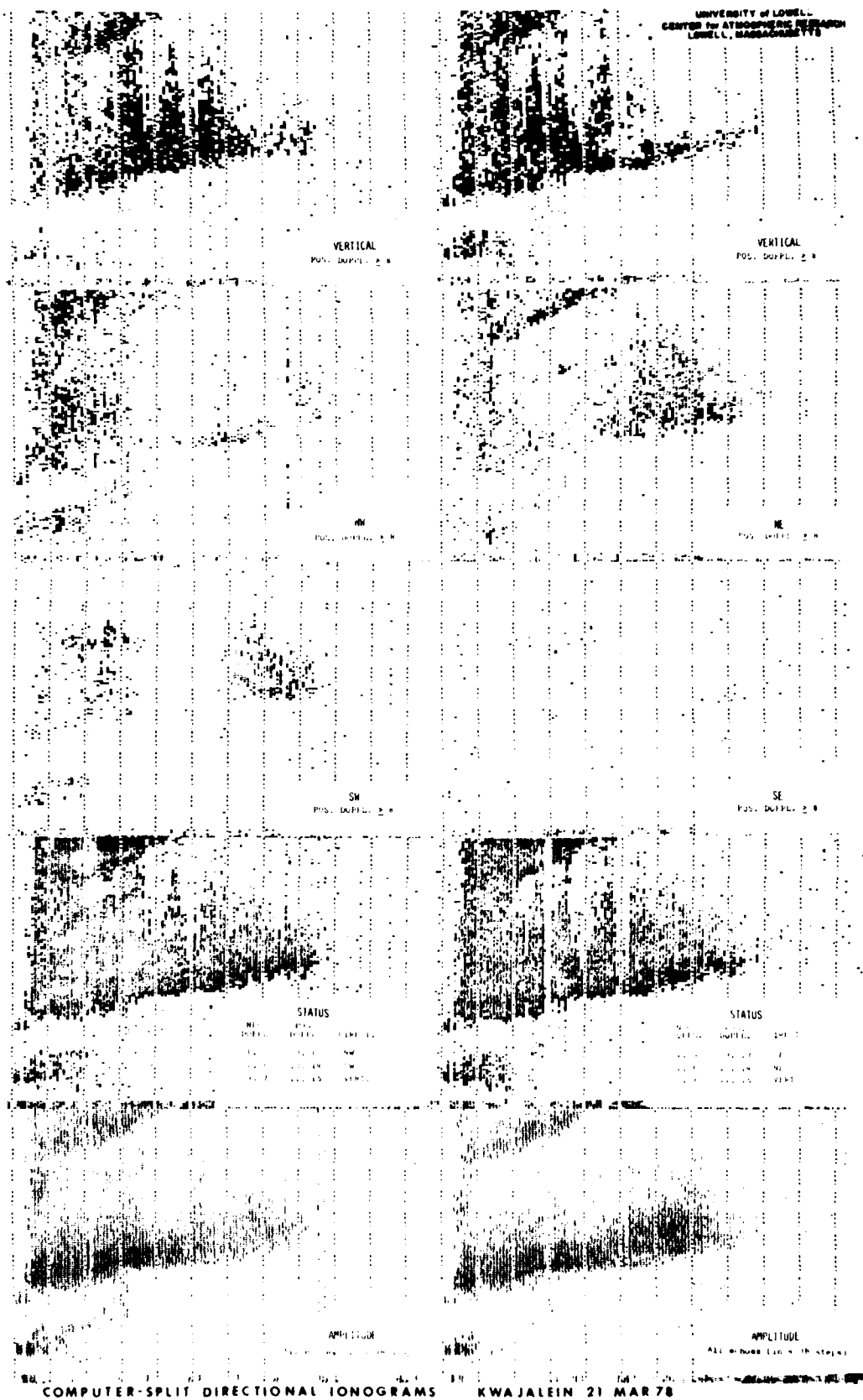


FIG. 2 COMPUTER-SPLIT DIRECTIONAL IONOGRAMS

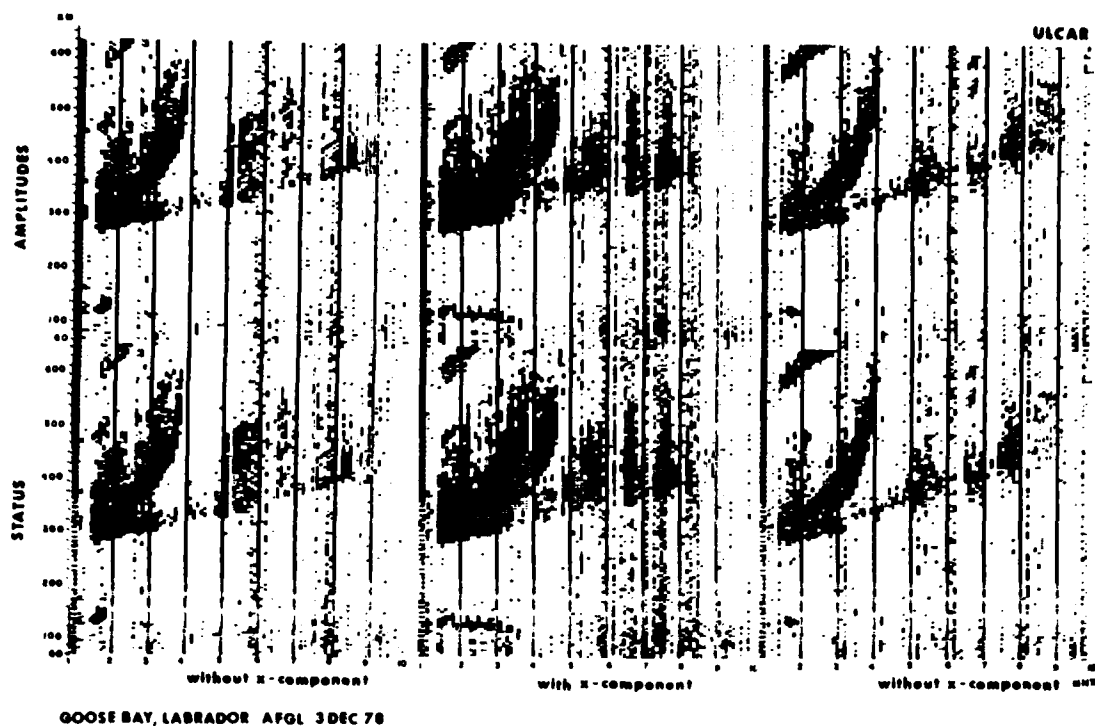
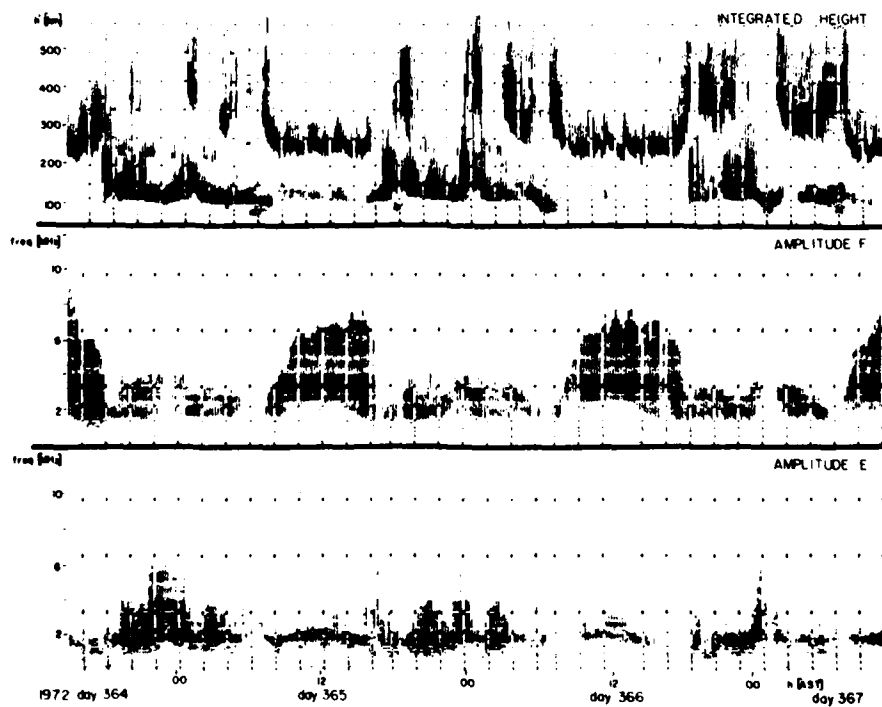
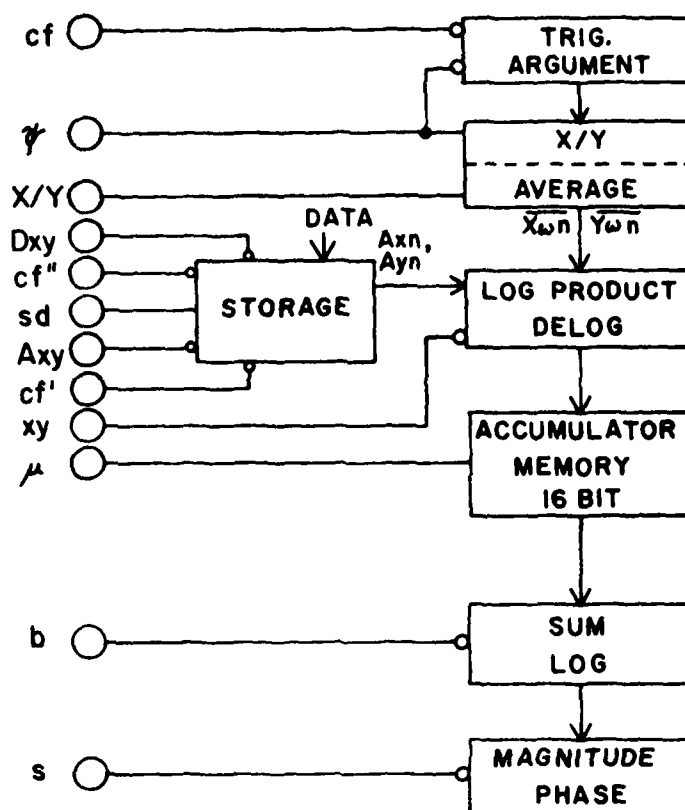


Fig. 3 DIGITAL SUPPRESSION OF THE EXTRAORDINARY COMPONENT



AIR6
VERTICAL IONOGRAMS
GOOSE BAY, LABRADOR

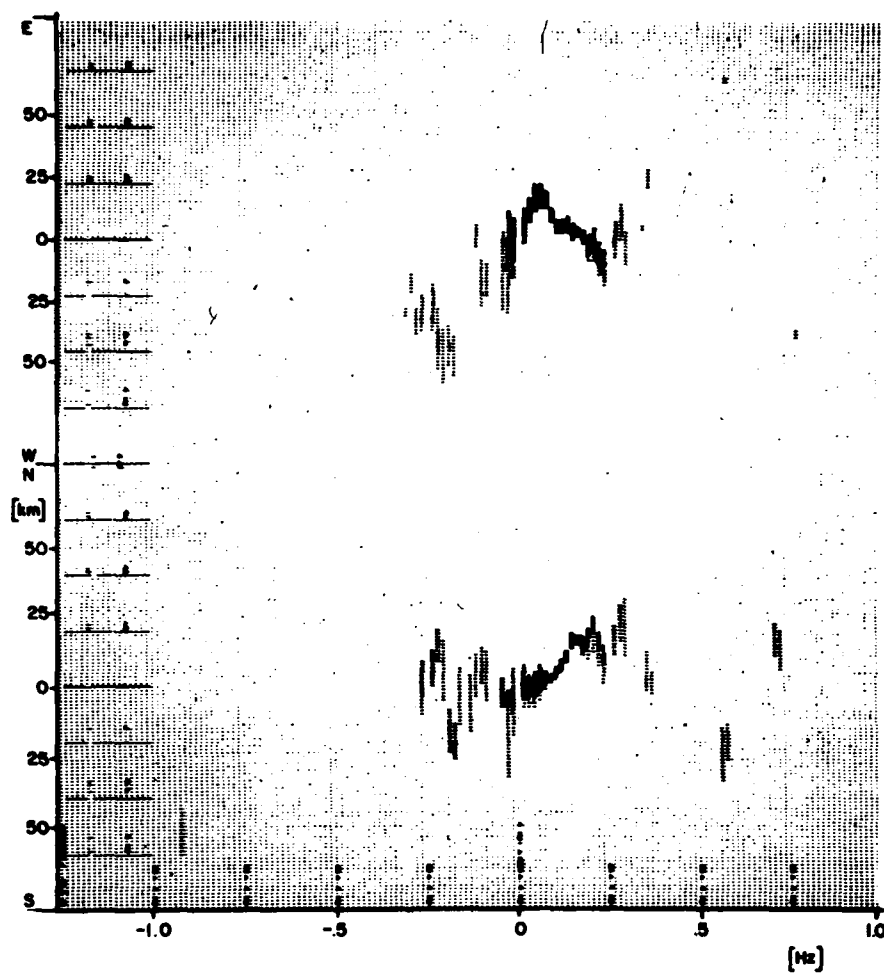
Fig. 4



$$\begin{aligned}
 \sum_{n=1}^N (A_{xn} \cdot \overline{X_{\omega n}} + A_{yn} \cdot \overline{Y_{\omega n}}) &= R^+_{\omega} \\
 \sum_{n=1}^N (A_{yn} \cdot \overline{X_{\omega n}} - A_{xn} \cdot \overline{Y_{\omega n}}) &= I^+_{\omega} \\
 \sum_{n=1}^N (A_{xn} \cdot \overline{X_{\omega n}} - A_{yn} \cdot \overline{Y_{\omega n}}) &= R^-_{\omega} \\
 \sum_{n=1}^N (A_{yn} \cdot \overline{X_{\omega n}} + A_{xn} \cdot \overline{Y_{\omega n}}) &= I^-_{\omega}
 \end{aligned}$$

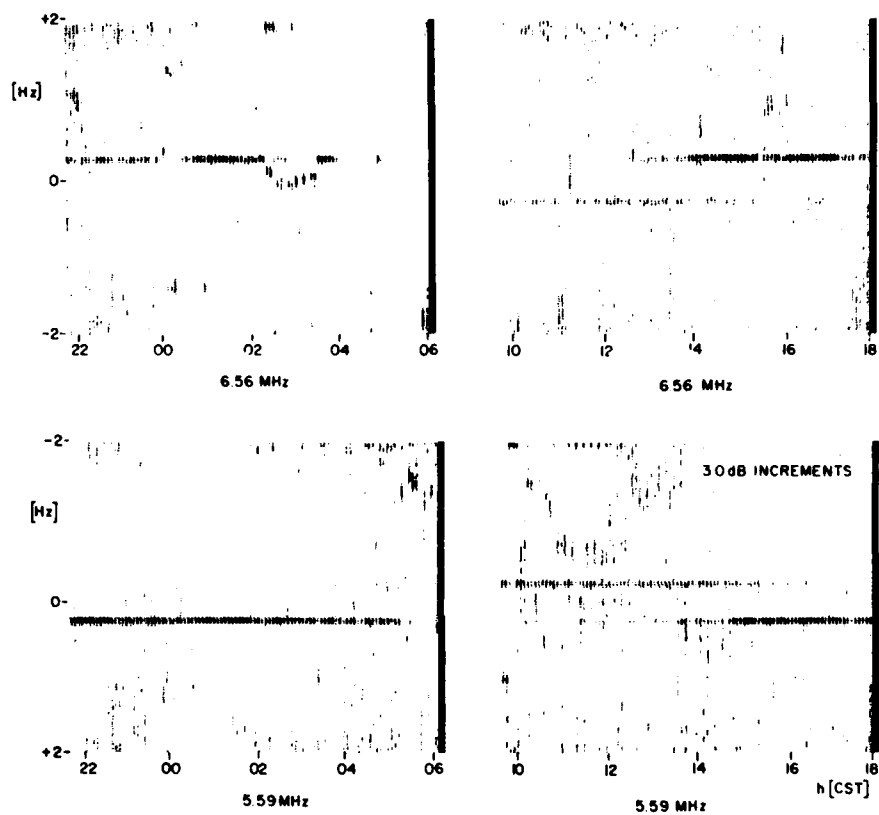
REAL-TIME SPECTRUM ANALYSIS

Fig. 5



DAASM DISPLAY
4 APRIL 72
EGLIN, FLA.
2.01 MHz-105 km

Fig. 6



SEASCATTER DOPPLER SPECTRUM
17-18 MARCH 1973
EGLIN, FLA.

Fig. 7

UNIVERSITY OF LOWELL
COLLEGE OF PURE AND APPLIED SCIENCE
CENTER FOR ATMOSPHERIC RESEARCH
Lowell, Massachusetts

REAL-TIME SPECTRA FOR INCIDENCE ANGLE SPREAD IN
MULTIPATH PROPAGATION CAUSED BY IONOSPHERE

by

Bodo W. Reinisch

Klaus Bibl

Presented at

URSI
International Symposium on Measurements in Telecommunications
October 3-7, 1977
Lannion, France

REAL-TIME SPECTRA FOR INCIDENCE ANGLE SPREAD IN
MULTIPATH PROPAGATION CAUSED BY IONOSPHERE

by

B. W. Reinisch and K. Bibl
University of Lowell, Lowell, Massachusetts, U.S.A.

Abstract

Electromagnetic signals from a set of receiving antennas are individually processed, the complex spectrum is determined for each antenna j , $F_{j\ell} = \{A_{j\ell}, \phi_{j\ell}\}$. The spectral composition is resolved in 128 lines, i.e. ℓ goes from -63 to +64. Cross-correlation of the frequency spectra and subsequent transformation into the spatial domain finds the incidence angles of each spectral component. The frequency-wave-number power density

$$P_{k\ell} = \sum_j \sum_{j'} F_{j\ell} F_{j'\ell}^* \exp i \underline{k} \cdot (\underline{a}_j - \underline{a}_{j'})$$

determines the power and spectral content for each "looking vector" $\underline{k}$. Actually, $\underline{k}$ is the wave vector and the vectors $\underline{a}_j$ point to the individual antennas. This method separates the multipath components for ionospherically reflected radio waves and for satellite-to-ground signal paths.

1.0 INTRODUCTION

Radio waves are characterized by amplitude, phase, wave vector, wave polarizaiton, frequency and signal travel time. All these wave parameters are measured in real-time in a new digital ionosonde, the Digisonde 128PS. We want to concentrate here on the measurement of the Doppler shifts and the

angular spectra of radio signals that are reflected at the earth's ionosphere. The same technique is applicable, however, for transionospheric propagation.

Direction finding for dekameter waves is not an easy task in case of multiple sources, or multiple paths. Unless very large receiving antenna arrays are used the beam width is normally too wide to resolve neighboring paths. It is easy to visualize that radio signals reflected from a moving ionosphere will have a Doppler frequency that is proportional to the carrier frequency, the speed of the reflector, and the angle between the velocity vector $\underline{v}$ and the electromagnetic wave vector $\underline{k}$, $d = (1/\pi) \underline{k} \cdot \underline{v}$.

2.0 PATH SEPARATION BY DOPPLER MEASUREMENT

A transmitted radio wave illuminates a certain area of the ionosphere for vertical (monostatic) as well as for oblique (bistatic) sounding. Reflection occurs at several points or areas in the ionosphere, depending on the structure of the ionization, in such a way that signals will propagate along different paths carrying slightly different Doppler frequencies (Bibl et al, 1975). Figure 1 illustrates the geometry for the case of monostatic operation. Echoes from two neighboring points differ in their Doppler frequency by

$$\delta d = \frac{1}{\pi} k v \delta(\cos\psi)$$

where ψ is the angle between $\underline{v}$ and $\underline{k}$. Using the angles of Figure 1, where $\underline{v}$ was assumed to be horizontal, we write:

$$\cos\psi = \sin\theta \cos(\phi - \phi')$$

and

$$\delta(\cos\psi) = \cos\theta \cos(\phi - \phi') \delta\theta - \sin\theta \sin(\phi - \phi') \delta\phi.$$

When looking in the direction of the velocity vector, i.e. $\phi = \phi'$, the variation in Doppler becomes:

$$\delta d = \frac{1}{\pi} k v \cos \theta \delta \theta .$$

For a given spectral resolution δd the angular resolution is therefore:

$$\delta \theta = \frac{\pi \delta d}{k v \cos \theta} = \frac{\lambda \delta d}{2 v \cos \theta} .$$

Substituting some typical values for the Digisonde, $\delta d = 0.03$ Hz, $\lambda = 50$ m (6 MHz) and $v = 100$ m/s, one obtains for small angles θ

$$\delta \theta = 7.5 \cdot 10^{-3}$$

corresponding to a source separation of 1.5 km in 200 km altitude. By storing the energy from such closely spaced sources in different spectral channels we can determine their location even in the presence of other strong sources with different Dopplers. When looking in the direction of $\underline{v}$, sources with $\delta \theta = 0$ separated by a small angle $\delta \phi$ have the same Doppler and can only be resolved by a sufficiently large antenna aperture.

3.0 DISCRETE FOURIER TRANSFORM

To obtain the Doppler shifts, the Digisonde converts the radio signals from an array of receiving antennas to an intermediate frequency of 255 kHz, digitizes in the quadrature method the logarithmically compressed IF signal and applies a discrete Fourier transform. The complex transform is calculated for each of the up to 24 antenna signals by making direct use of the quadrature samples X and Y. In general, the receiving antennas are scanned at a rate of 24 per quarter second. For the j -th antenna the transform can be written:

$$\begin{aligned}
F_{j\ell} &= \frac{1}{T} \sum_n [X_j(n\Delta t) + iY_j(n\Delta t)] \exp -i(2\pi\ell n\Delta t/T) \\
&= \frac{1}{T} \sum_n [X_{jn} \cos \beta_{\ell n} + Y_{jn} \sin \beta_{\ell n}] \\
&\quad + \frac{i}{T} \sum_n [-X_{jn} \sin \beta_{\ell n} + Y_{jn} \cos \beta_{\ell n}]
\end{aligned}$$

where ℓ is the Doppler line, T is the length of the time window and $\beta_{\ell n} = 2\pi\ell n\Delta t/T$. While the initial multiplication of the time samples with the trigonometric functions is carried out in the logarithmic domain, the final summation is, of course, performed in the linear domain. Hanning weighting is applied in the frequency domain by averaging three adjacent spectral lines with weights of 1-2-1. The result of the 24 channel Fourier analysis are 24 number arrays of the form

$$j = 1, \dots, 24$$

$$F_{j\ell} = \{M_{j\ell}, \phi_{j\ell}\}$$

$$-63 \leq \ell \leq 64$$

where $M_{j\ell}$ are the logarithmic spectral amplitudes (64 dB range in 1 dB increments, or 32 dB with 1/2 dB) and $\phi_{j\ell}$ are the corresponding phases with a resolution of $2\pi/512$.

For the Digisonde operation it was necessary to develop a method of calculation that requires no extra time beyond the last time sample, since between the time windows we allow only one second for recording of the spectra on magnetic tape for later computer processing. Directly following digitization the quadrature pair is multiplied by all 128 time-adjusted values of $\cos\beta_{\ell n}$ and $\sin\beta_{\ell n}$, respectively, and the 256 spectral samples thus obtained are added to the previous 256 samples. After the last time sample the final four sums $\sum_n X_{jn} \cos\beta_{\ell n}$, $\sum_n X_{jn} \sin\beta_{\ell n}$, $\sum_n Y_{jn} \cos\beta_{\ell n}$ and $\sum_n Y_{jn} \sin\beta_{\ell n}$ are suitably combined for each j -channel to form the real and imaginary parts of the spectra.

4.0 ANGULAR SPECTRA

The complex Fourier spectra are converted in real-time into an angular power spectrum. The aim is to find for each Doppler component the corresponding incidence angle, or possibly several angles if wave energy of the same Doppler frequency is arriving from different directions. In our initial approach we limited ourselves to four receiving antennas for the real-time processing. But this limit was arbitrary and there is no difficulty in expanding it to 12 antennas.

For a given angle of arrival, specified by the wave vector $\underline{k}$, the frequency-wavenumber power density is calculated (Sales et al, 1975):

$$P_{\ell k} = \sum_j \sum_{j'} F_{j\ell} F_{j'\ell}^* \exp -ik \cdot (\underline{a}_j - \underline{a}_{j'})$$

where $F_{j\ell}$ is the Fourier spectrum for antenna j , and the $\underline{a}_j$'s are the antenna distance vectors. By substituting for

$$F_{j\ell} = A_{j\ell} \exp i \phi_{j\ell}$$

the power density can be written as

$$P_{\ell k} = \left| \sum_j A_{j\ell} \exp i(\phi_{j\ell} - \underline{k} \cdot \underline{a}_j) \right|^2$$

Depending on the observational program, monostatic, bistatic or transionospheric, the receiving array will be arranged correspondingly and an adequate format must be selected to present the angular spectra. For the case of vertical sounding we expect echoes from within a cone of about 90° solid angle. Each direction is represented by its x, y coordinates with $x = r \cos \phi \sin \theta$ and $y = r \sin \phi \sin \theta$, r is the echo range. The Digisonde calculates the power densities for equal increments in x and y . These increments are selected as function of r . A sky map of 40×40 points is generated this way.

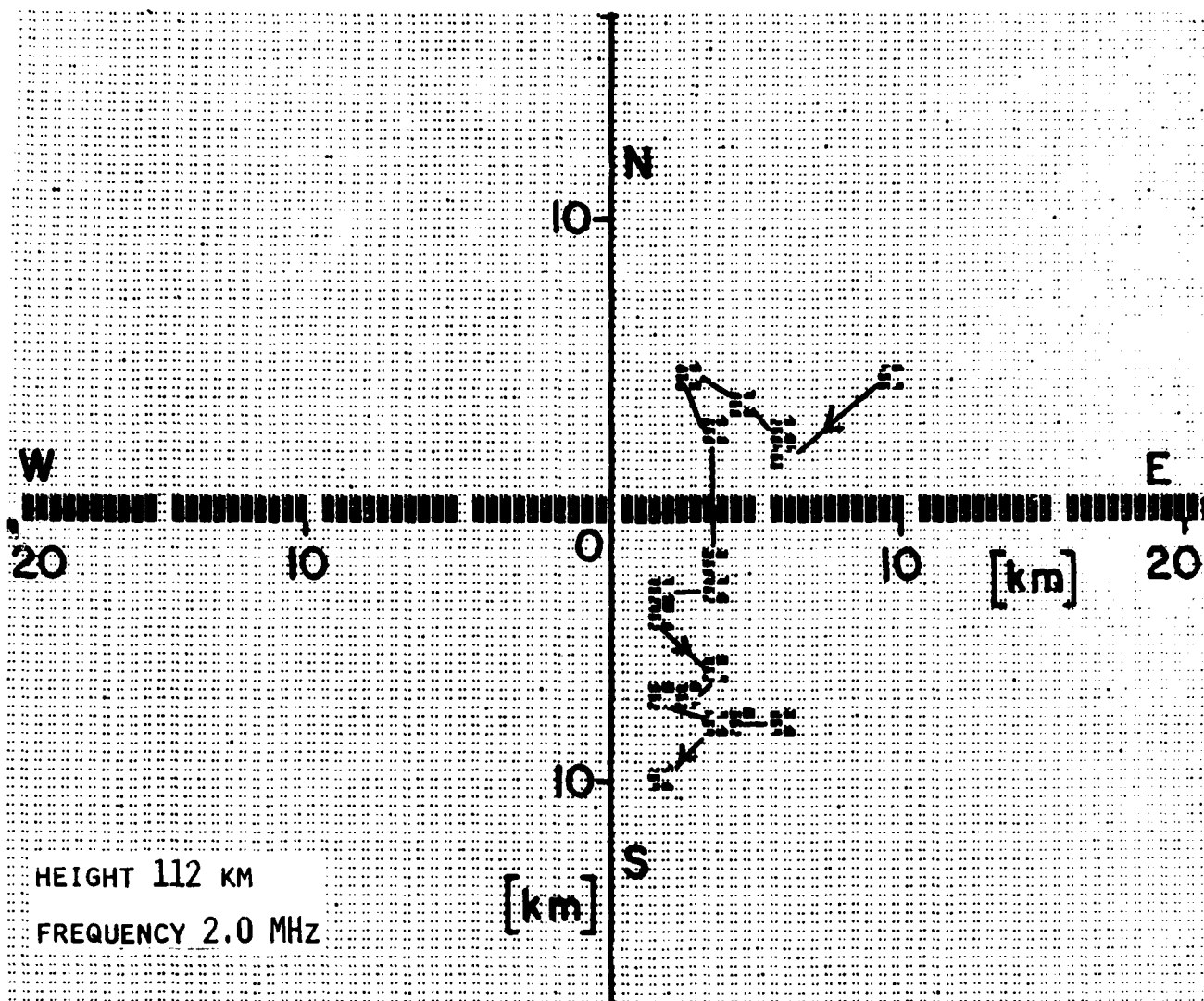
So far, each x, y point contains a complete spectrum P_{lk} . A sorting algorithm finds for each spectral component the x, y position with the maximum power density. The resulting sky map displays, therefore, the power density together with the spectral component number l . An example of a sky map is shown in Figure 2 where the reflection points are connected by an arrowed line pointing in the direction of increasing Doppler frequency. The sorting algorithm is essentially a differential method in that it searches for a maximum in spectral density as function of x and y . This overcomes the limited resolution of the array directivity. As a further improvement it is considered to search for more than one discrete maximum for each spectral component.

5.0 ACKNOWLEDGEMENT

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SKY MAP

FIGURE 2

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DIGITAL PREPROCESSING, ON-LINE PROCESSING
AND DISPLAY OF MULTIPARAMETER TRANSMISSION DATA

by

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1.0 INTRODUCTION

Simultaneous recording and display of all parameters of a radio wave propagated through a highly dispersive medium is possible with digital processing. For the measurement of the structure and the motion of the dispersive medium and for a full analysis of the radio propagation properties of communication links digital radio sounders can be employed with pulsed carrier frequencies scanning in steps through a large frequency band.

Frequency scanning adds an extra parameter to the wave characteristics of a conventional Radar system: amplitude, phase or Doppler frequency, range, incidence angle and polarization.

2.0 DATA PREPROCESSING

As a scientific instrument, but useful for many operational tasks, we have developed a digital ionosonde which uses a large antenna array in a scanning or a beam-forming mode. The Digisonde 128PS (K. Bibl and B. W. Reinisch, 1977) integrates the echoes coherently at many Doppler frequencies simultaneously for all antennas or all beam-directions. Echoes from 24 antennas can at once be spectrum analyzed in 128 coherent channels, or 16 spectral lines can be monitored for

128 range bins. Many other combinations of ranges, frequencies, polarizations, spectral channels and incidence angles can be processed simultaneously. Using the time between the transmitted pulse to measure complex spectrum amplitudes in up to 256 range bins (time sectors) requires a very fast on-line spectrum analyzer. The Processing Controller of the Digisonde forms the products between the sine and cosine samples of the high frequency (HF) signal and the phase function of three averaged spectral lines at a 1 MHz rate during the measurement. But such an amount of data is too large for any institute to handle on a continuous basis. We therefore operate the system in one of two compression modes.

3.0 MAXIMUM AMPLITUDE MODE

The Maximum Amplitude Mode is used for recording of digital ionograms. For each of the 128 range bins of the more than 100 carrier frequencies the largest amplitude of the 24 possible channels is selected. The amplitude is recorded together with a status character, indicating the selected channel number. Since the signals arriving from different directions with different Doppler travel along different paths, they mostly have different travel time. Thus the maximum method does not suppress essential information.

In the contrary this differential method, selecting the strongest amplitudes, enhances the main features of the investigated propagation medium, as shown in Fig. 1. With frequency as the abscissa and range as ordinate the amplitudes or the status characters form patterns from the numerical presentations as the third dimension. Different features are clearly distinguishable simultaneously. While one area of reflection (showing large values of the status indicator on the top of the picture) moves toward the observation station, the

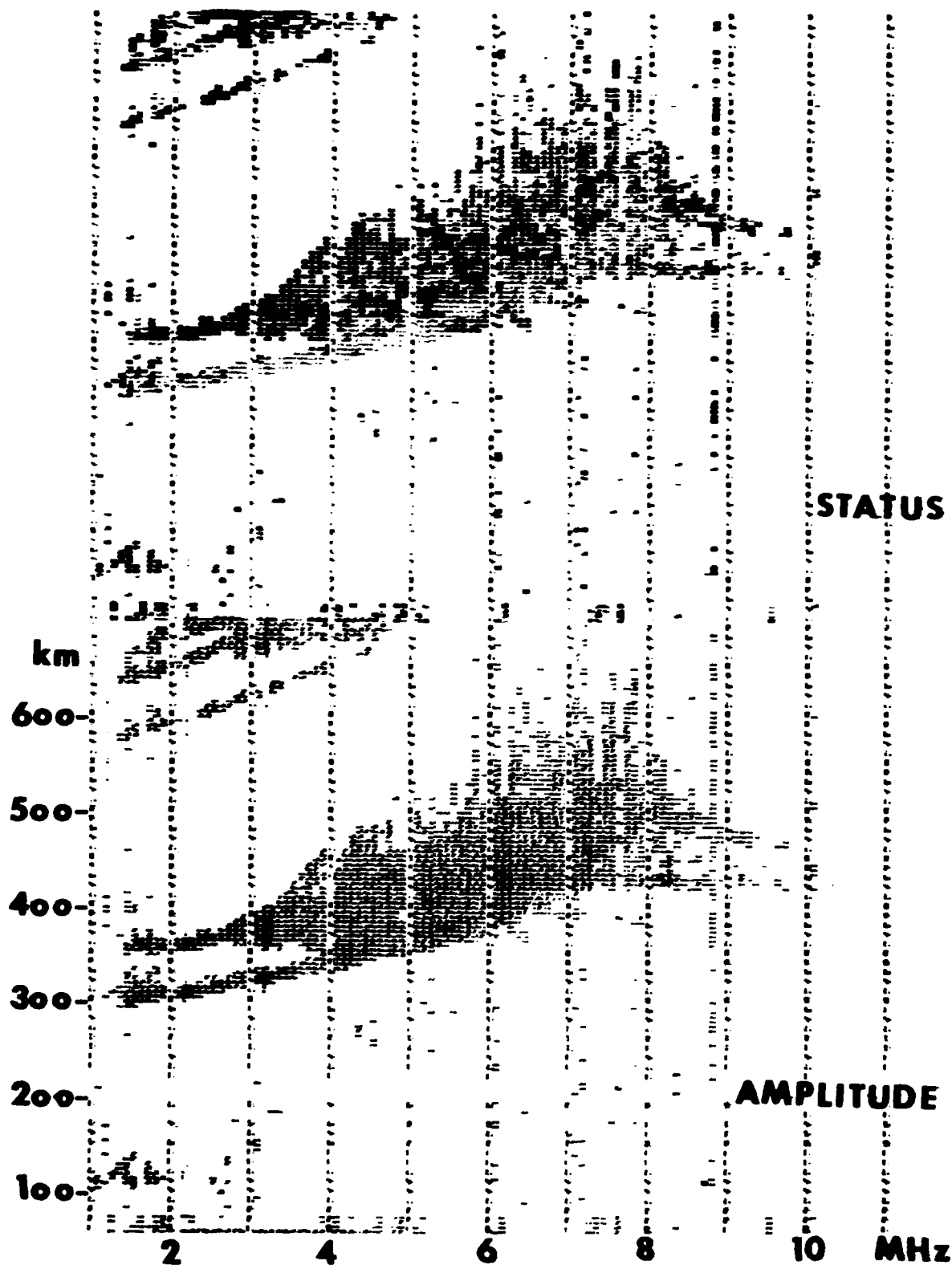


Fig. 1 AMPLITUDE, AZIMUTH AND DOPPLER AS
FUNCTIONS OF RANGE AND FREQUENCY

older ionization, forming the lower pattern moves away. In Fig. 2 the echo trace with ordinary polarization is characterized by the "4" bit in the status character, while the other bits indicate the Doppler speed (numbers larger than 8 indicate positive Doppler).

4.0 DOPPLER-DRIFT MODE

In the Doppler-Drift Mode a full complex spectrum analysis is executed in real time during the measurement. The build-up of the spectra can be observed for any and all of the 24 independent channels by the programmable test features. Guided by the survey provided by the Maximum Amplitude Mode six frequencies and ranges can be chosen for the scanning of four antennas simultaneously. Four decimal digits in frequencies, three decimal digits in range and one octal digit in receiver gain can be independently selected. All this information plus 20 additional operational parameters (pulse repetition rate, pulse width, antenna selection and sequences, number of samples, etc.) are stored together with date and time in an 80 character preface which is repeated for each record and updated for every measured case. Rather than processing a multitude of frequencies and ranges, the signals from up to 24 antennas can be spectrum analyzed simultaneously. This interlaced spectrum analysis is necessary if low Doppler frequencies have to be studied and the propagation conditions provide barely consistent data during the integration period. In contrast to the Fast Fourier Transform procedure used in most computers our Direct Discrete Fourier Transform algorithm with Hanning weighting by averaging the spectral phase function provides a continuous consistency check of the data.

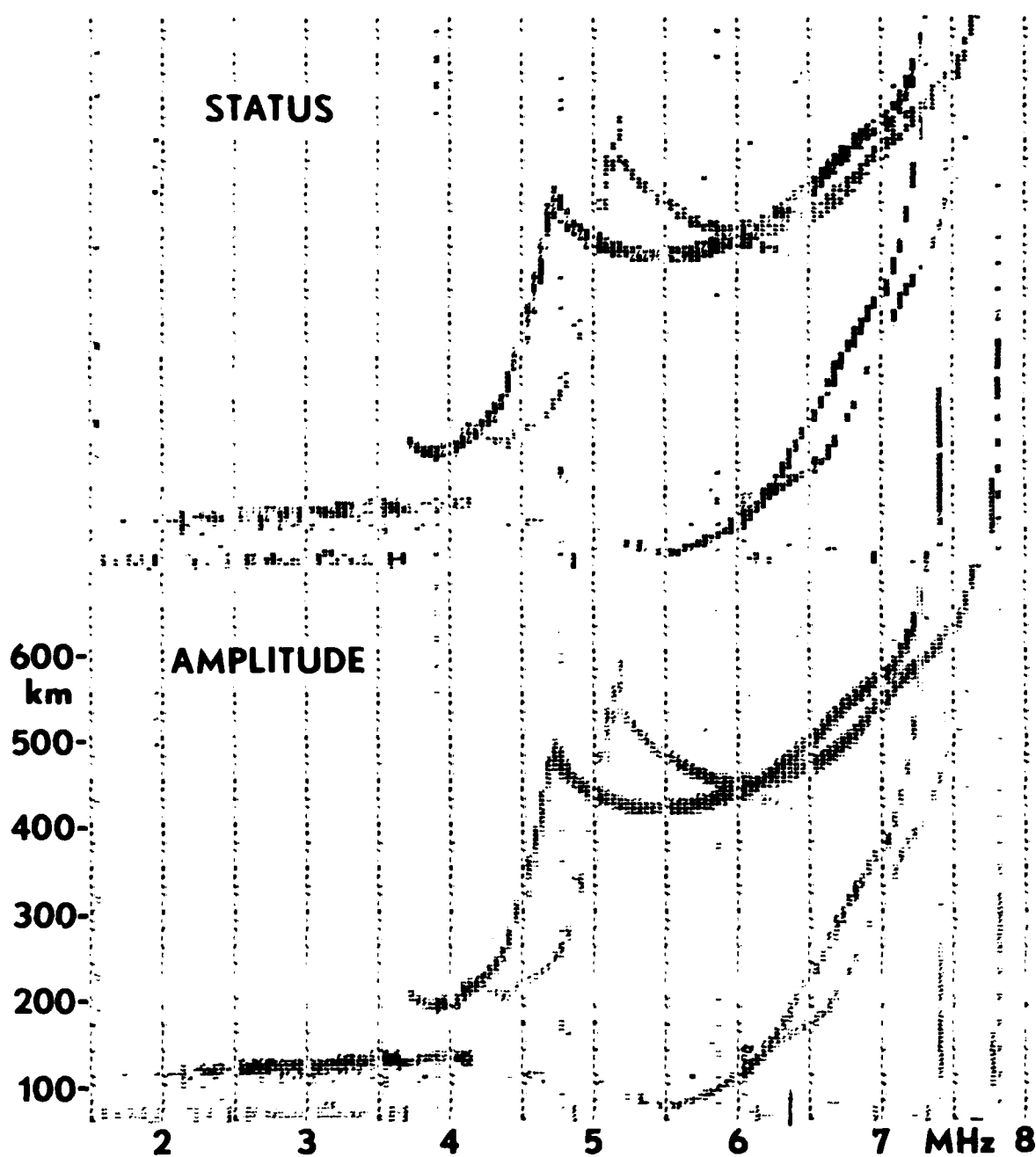


Fig. 2 AMPLITUDE, POLARIZATION AND
DOPPLER AS FUNCTIONS OF RANGE
AND FREQUENCY

5.0 DIGITAL DISPLAY

The three-dimensional digital display, as shown in Figures 1 and 2, is an important feature of our system. Special fonts for the numbers have been introduced (J. Patenaude et al, 1973) to make the number of dots of which they consist proportional to the value of the number. Dependent on the importance of a parameter for the investigation, the selection of the respective bits in the status flags can be chosen to emphasize specific features: like polarization, high Doppler rate or special incidence directions. Areas with similar numbers form patterns and, with some training, more than three dimensions can be visualized, avoiding the false color presentations which are so expensive to reproduce and difficult to interpret.

6.0 ON-LINE PROCESSING

With the help of special-purpose circuitry many provisory analyses can be executed on-line, like the selection of the important parameters for display, the measurement of incidence angles from the Doppler phase-differential between the different antennas, the profile and the fine structure of the dispersive propagation medium and an interactive terminal for display and programming. Because of the limited speed of a mini-computer an adequate formatting of the raw data, including full information of all operational parameters in a preface, is a precondition for its successful and flexible use as a sequential on-line processing device.

7.0 APPLICATION

We see a wide range of actual and possible applications for this instrument.

At this time the first system is used to study the equatorial spread-F phenomenon in the ionosphere which heavily affects satellite-ground communication and navigation up to 1000 MHz during many nights.

Similar phenomena are studied in the aurora region of the ionosphere. We further applied the Digisonde to measurements of the sea-state of the oceans by direct and ionospherically reflected scatter and bistatic radio propagation experiments.

The precision of the digital direct frequency synthesis and the large antenna array permits accurate angular measurements for radio-interferometry in the frequency range of 20 to 40 MHz. Solar, planetary and galactic sources can be studied with this system.

A combined acoustic-electromagnetic sounding of the non-ionized atmosphere is very promising. Acoustic scanning in medical and material research requires only little modification. Scanning of the sea-bottom (after conversion to acoustical waves) and underground radio communication and structure research should also be possible with this system.

8.0 ACKNOWLEDGEMENT

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EQUATORIAL SPREAD F OBSERVATIONS USE INCIDENCE ANGLE
AND DOPPLER MEASUREMENTS

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As part of DNA's Equatorial Wideband Program ground-based ionospheric observations are conducted at Kwajalein, Marshall Islands, with a new ionosonde, the Digisonde 128PS. To analyze the spread F phenomenon it is necessary initially to inspect the entire ionogram rather than relying on single frequency, single range measurements. By rotating the beam of the receiving antenna array from NW to SW to SE to NE and to vertical for each transmitted frequency we found a complicated angular pattern. The main F-trace is often composed of vertical echoes, while the spread echoes can be vertical and oblique. In some cases the majority of the spread echoes come from overhead, i.e. from within a cone of 5° , and the observed range spread of several hundred kilometers can only be explained by deep holes in the bottom-side F-region and multiple scatter. More frequently, the spread echoes simultaneously arrive from several directions (the antenna beam is 15° off vertical), for example, from NE and SW for the high frequencies (8 MHz) and from NW for the lower frequencies (2 MHz). The sign of the signal doppler shifts indicates the direction of motion of the reflecting irregularities. Several case studies are discussed.

DIGITAL IONOSPHERIC SOUNDING WITH DOPPLER MEASUREMENTS
AND DIRECTION FINDING

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A new type of ionosonde, the Digisonde 128PS, presently in operation at Kwajalein, Marshall Islands, and aboard an aircraft, collects new data previously not available. All characteristic parameters of the ionospheric radio echoes are measured to extract the maximum information on the ionosphere. The system measures the following signal parameters: complex spectrum, i.e. spectral amplitudes and phases, angle of arrival, polarization and, of course, group travel time. System operation alternates between two complementary modes of observation, (1) ionograms and, (2) drift-doppler measurements. A small computer postprocesses the data and generates sky maps from the drift-doppler observations and electron density profiles from the ionogram traces. Also, the computer can control the sounding operation. Recordings from Kwajalein and from the aircraft illustrate the system capabilities.

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