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# STATUS OF ARTIST UPGRADE

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Digisonde 256s were installed in Argentia, Newfoundland, Wallops Island, Virginia, Bermuda, College, Alaska and Goose Bay, Labrador between 1986 and 1988.

Although the systems generally have run successfully at these stations, it was realized that additional developments would improve the resulting ionospheric data and the system reliability. The development work is in three categories:

- Improve scaling and true height profile analysis.
- Automate the measuring of drift data and recording data on magnetic tape.
- Exchange input/output operation and diagnostic programs for testing of communication ports.

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# 1.0 BACKGROUND

The AN/FMQ12 Digital Ionospheric Sounding System (DISS) is a Digisonde 256 system consisting of hardware and software designed to sense the radio-frequency properties such as absorption, reflection, and refraction of the ionosphere, analyze the ionograms to determine the ionospheric characteristics, extract the E- and F-traces for calculating the electron density profile, interface to communication systems, and provide service to peripheral equipment. The collective name for the software system is ARTIST. Most of the ARTIST program modules are written in FORTRAN 77. For the functions that cannot be accomplished by FORTRAN (e.g. interfacing communications, driving peripherals), 80286 assembly language has been used. The FORTRAN modules are compiled by Microsoft compiler version 3.3. ARTIST codes were completed in October 1986 for delivery which fulfilled the requirements specified in the Sacramento Air Logistics Center contract F04606-85-C-0810.

Since the delivery of the DISS system, the ARTIST code has undergone several updates and improvements. To distinguish the two codes in the text, the term ARTISTD will refer to the software for the DISS version, ARTISTSV will refer to the software for the ARTIST scientific version, and ARTIST will refer to the general hardware/software system.

## 2.0 ARTIST DEVELOPMENTS BEYOND THE DISS BASELINE

### 2.1 Introduction

Digisonde 256s (*) and the AWS version DISS (**) were installed in Argentia, Newfoundland;* Wallops Island, Virginia** in 1986; Bermuda in 1987;* College, Alaska** and Goose Bay, Labrador** in 1988. The systems generally have run successfully at these stations. Ionospheric data, tape and hard copy records and system status reports are available from these mid and high latitude stations. Given the more than two years experience with the baselined ARTIST, it was realized that additional developments would improve the resulting ionospheric data and the system reliability. The development work is in three categories:

- Improve scaling and true height profile analysis.
- Automate the measuring of drift data and recording data on magnetic tape.
- Input/Output operation improvement and diagnostic programs for testing communication ports.

The aforementioned contract required a performance evaluation of ARTIST. Manual and autoscaled ionospheric parameters [foF2, foF1, foE, foEs, fmin, h'E, h'F and M(3000)] for Argentia, Newfoundland for the period of October 13 to November 7, 1986 (about 560 ionograms) were compared to evaluate the performance of ARTIST. The autoscaled frequencies (except for foEs) were within 0.5 MHz accuracy of the corresponding manual scalings more than 90% of the time. The critical frequency of sporadic E was autoscaled to within 0.5 MHz of the manually scaled value approximately 82% of the time. While the contractual requirement of 80% was met for foEs, it was clear that improvements could be made to yield better results.

The study of many ionograms and the associated calculation of the true height profiles led to the identification of four areas where significant improvements could be made:

- Error checking to ensure continuous real time operation.
- Frequency gap filling as needed to ensure inversion (true height analysis) during most F1 layer occurrences.
- Search for roots in the E layer scale height function to avoid non-monotonically increasing profile solutions.
- Change in the layer boundary conditions (in frequency and virtual height) to avoid DISS rounding errors and attendant inaccuracies.

These true height calculation improvements are further discussed in Section 2.3.

A new program has been added to ARTIST to measure the ionospheric drift velocity and record the data on magnetic tape automatically (AUTODRFT). The program runs as one of the ARTIST tasks to monitor the ionosphere making use of the latest scaling results supplied by ARTIST. The algorithm is described in Section 2.4.

Additional changes were incorporated to improve the ARTIST input/output operations. The ARTIST output consists of a header, a list of autoscaled parameters, the listing of the autoscaled h'f trace, results of the true height analysis, and an ionogram. Figure 2.1 shows the scaled parameters for a typical ionogram. In DISS, the

| | | |
|---|---|---|
| ARGENTIA, NEWFOUNDLAND | LAT 47.3N LONG 54W | |
| | DIP 72, FH 1.4 MHz | |
| DIGISONDE 256 - VS.02.A | UNIVERSITY OF LOWELL, USA | |

| STATION | YEAR | DAY | H M | | OUT | OPT | B E | Q | CAB | XLIT | NAW | HEIG | PROGRAM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 | 1982 | 1 | 16:44 | UT | 0084100 | 00-11 | 1 | | 12E | 41D3 | 434 | 123C | A1 |

| FOF2 | FOF1 | H'F | H'F2 | M3000 | FMIN | FOES | MUF | FMINF |
|---|---|---|---|---|---|---|---|---|
| 8.2 | *** | 220. | **** | 3.14 | 1.3 | 3.0 | 25.8 | 3.0 |

| FXI | FMINE | FOE | H'E | H'ES | QF | QE | FF | FE |
|---|---|---|---|---|---|---|---|---|
| 9.1 | 1.3 | 2.8 | 103. | 103. | *** | *** | .2 | .2 |

AUTOSCALED TRACES (KM):

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3. | 228. | 220. | 226. | 226. | 231. | 231. | 236. | 246. | 246. | 251. |
| 4. | 251. | 256. | 256. | 256. | 256. | 256. | 256. | 256. | 256. | 261. |
| 5. | 261. | 261. | 261. | 261. | 261. | 261. | 266. | 266. | 266. | 271. |
| 6. | 271. | 271. | 276. | 276. | 281. | 286. | 286. | 291. | 291. | 296. |
| 7. | 301. | 306. | 311. | 316. | 321. | 326. | 336. | 346. | 361. | 381. |
| 8. | 406. | 446. | 511. | | | | | | | |
| 1. | ***** | ***** | ***** | 105. | 105. | 105. | 105. | 110. | 110. | 110. |
| 2. | 115. | 115. | 115. | 120. | 120. | 125. | 130. | 140. | 160. | |

NORMALIZED AMPLITUDE AS AT REFLECTION HEIGHT 100KM IN (DB)

| | TOPF | 2. | 3. | 4. | 5. | 6. | 7. | 8. |
|---|---|---|---|---|---|---|---|---|
| F | 29. | 0. | 57. | 68. | 67. | 65. | 60. | |
| E | 25. | 42. | | | | | | |
| ES | 12. | | | | | | | |

PROFILE - ULCAR

W = .0 KM

| | FSTART (MHZ) | PEAK HT (KM) | A0 (KM) | A1 (KM) | A2&DG (KM) | A3 (KM) | A4 (KM) | DEV (KM)/PT | ROOTS |
|---|---|---|---|---|---|---|---|---|---|
| E | .199 | 116.092 | -29.011 | 3.169 | -5.260 | | | 1.7 | - |
| F1 | | | | | | | | | |
| F2 | 2.899 | 265.851 | -120.227 | -20.456 | -8.962 | .488 | -.608 | 7.7 | - |

| FN(MHZ) | H(KM) | DENSITY(P.CC) | AUTO H' (KM) | THEO H' (KM) | |
|---|---|---|---|---|---|
| .20 | 85.1 | .495E+03 | 99.5 | 91.0 | 8.5 |
| .55 | 97.6 | .374E+04 | 100.3 | 103.6 | -3.3 |
| 1.30 | 101.6 | .209E+05 | 105.0 | 105.1 | -.1 |
| 1.40 | 101.9 | .243E+05 | 105.0 | 105.7 | -.7 |
| 1.50 | 102.3 | .279E+05 | 105.0 | 106.4 | -1.4 |
| 1.60 | 102.7 | .317E+05 | 105.0 | 107.3 | -2.3 |
| 1.70 | 103.1 | .358E+05 | 110.0 | 108.2 | 1.8 |
| 1.80 | 103.6 | .401E+05 | 110.0 | 109.3 | .7 |
| 1.90 | 104.1 | .447E+05 | 110.0 | 110.5 | -.5 |
| 2.00 | 104.7 | .495E+05 | 115.0 | 111.9 | 3.1 |
| 2.10 | 105.3 | .546E+05 | 115.0 | 113.6 | 1.4 |
| 2.20 | 106.0 | .599E+05 | 115.0 | 115.5 | -.5 |
| 2.30 | 106.8 | .655E+05 | 120.0 | 117.9 | 2.1 |
| 2.40 | 107.7 | .713E+05 | 120.0 | 120.8 | -.8 |
| 2.50 | 108.8 | .774E+05 | 125.0 | 124.7 | .3 |
| 2.60 | 110.0 | .837E+05 | 130.0 | 130.5 | -.5 |
| 2.70 | 111.8 | .903E+05 | 140.0 | 141.3 | -1.3 |
| 2.80 | 116.1 | .971E+05 | 160.0 | ****** | ****** |
| 2.90 | 116.2 | .104E+06 | 227.5 | 142.3 | 85.2 |
| 3.00 | 122.4 | .111E+06 | 227.5 | 222.0 | 5.5 |
| 3.10 | 128.1 | .119E+06 | 220.0 | 228.9 | -8.9 |
| 3.20 | 133.4 | .127E+06 | 226.0 | 232.3 | 6.3 |
| 3.30 | 138.2 | .135E+06 | 226.0 | 234.7 | -8.7 |
| 3.40 | 142.7 | .143E+06 | 231.0 | 236.8 | -5.8 |
| 3.60 | 150.8 | .160E+06 | 236.0 | 239.0 | -3.0 |
| 3.90 | 161.3 | .188E+06 | 251.0 | 242.8 | 8.2 |
| 4.20 | 170.2 | .218E+06 | 256.0 | 246.9 | 9.1 |
| 4.50 | 178.1 | .251E+06 | 256.0 | 251.2 | 4.8 |
| 4.80 | 185.1 | .285E+06 | 256.0 | 255.5 | .5 |
| 5.10 | 191.5 | .322E+06 | 261.0 | 259.9 | 1.1 |
| 5.40 | 197.3 | .361E+06 | [illegible] | 264.4 | -3.4 |
| 5.70 | 202.8 | .402E+06 | 266.0 | 269.1 | -3.1 |
| 6.00 | 208.1 | .446E+06 | 271.0 | 274.3 | -3.3 |
| 6.30 | 213.1 | .491E+06 | 276.0 | 280.2 | -4.2 |
| 6.60 | 218.1 | .539E+06 | 286.0 | 287.3 | -1.3 |
| 6.90 | 223.2 | .589E+06 | 296.0 | 296.3 | -.3 |
| 7.20 | 228.7 | .642E+06 | 311.0 | 306.6 | 2.4 |
| 7.50 | 234.8 | .696E+06 | 326.0 | [illegible] | -.6 |
| 7.80 | 242.3 | .753E+06 | 361.0 | 358.0 | 3.0 |
| 7.90 | 245.4 | .773E+06 | 381.0 | 375.7 | 5.3 |
| 8.00 | 249.1 | .792E+06 | 406.0 | 402.2 | 3.8 |
| 8.10 | 254.0 | .812E+06 | 446.0 | 453.0 | [illegible] |
| 8.20 | 265.9 | .832E+06 | 511.0 | ****** | ****** |

Figure 2.1 ARTIST Scaled Parameters

ionogram is output in ASCII format. The ASCII numbers 1 to 6, letters A to F represent O(ordinary)-echo amplitudes of the positive and negative Dopplers respectively; X represents the X(extraordinary)-echo and a period (.) indicates an oblique return. Figure 2.2 shows the ASCII ionogram from which the Figure 2.1 results were obtained. There is a two-fold disadvantage to the ASCII ionogram. The signal strength of the O-echo does not stand out clearly, and the oblique signal directions are lost as they are displayed as a period (.). Our objective is to output as much information as the hardware allows. Use of Optifont [Patenaude et al., 1973] allows the O-mode signal strengths to be printed in a optically weighted character set. In addition, oblique signal directions are indicated by arrows to indicate the sector from which the echo originates. The Optifont output format is discussed in Section 2.5.1. Figure 2.3 shows an Optifont ionogram.

In addition to the above changes, the ARTIST modules, both Fortran and assembly, were modified and upgraded to run with Microsoft Fortran Version 4.0. Version 4.0 allows better use of the system resources such as memory, higher flexibility in programming, and generates more efficient codes. The updated ARTIST, that differs from the DISS ARTIST (ARTISTD) program, is distinguished as ARTIST, Scientific Version (ARTISTSV).

## 2.2 Scaling Improvements

### 2.2.1 Critical Frequency of Sporadic E

In ARTISTD, the Es trace is scaled by searching for continuous O echoes beyond foE using a window of 3 × 3 frequency-range bins. In the ionograms where the Es trace is segmented by many X-echoes or interference, the search window may contain very few or no O-echo. As a result, ARTISTD decides that the end of the

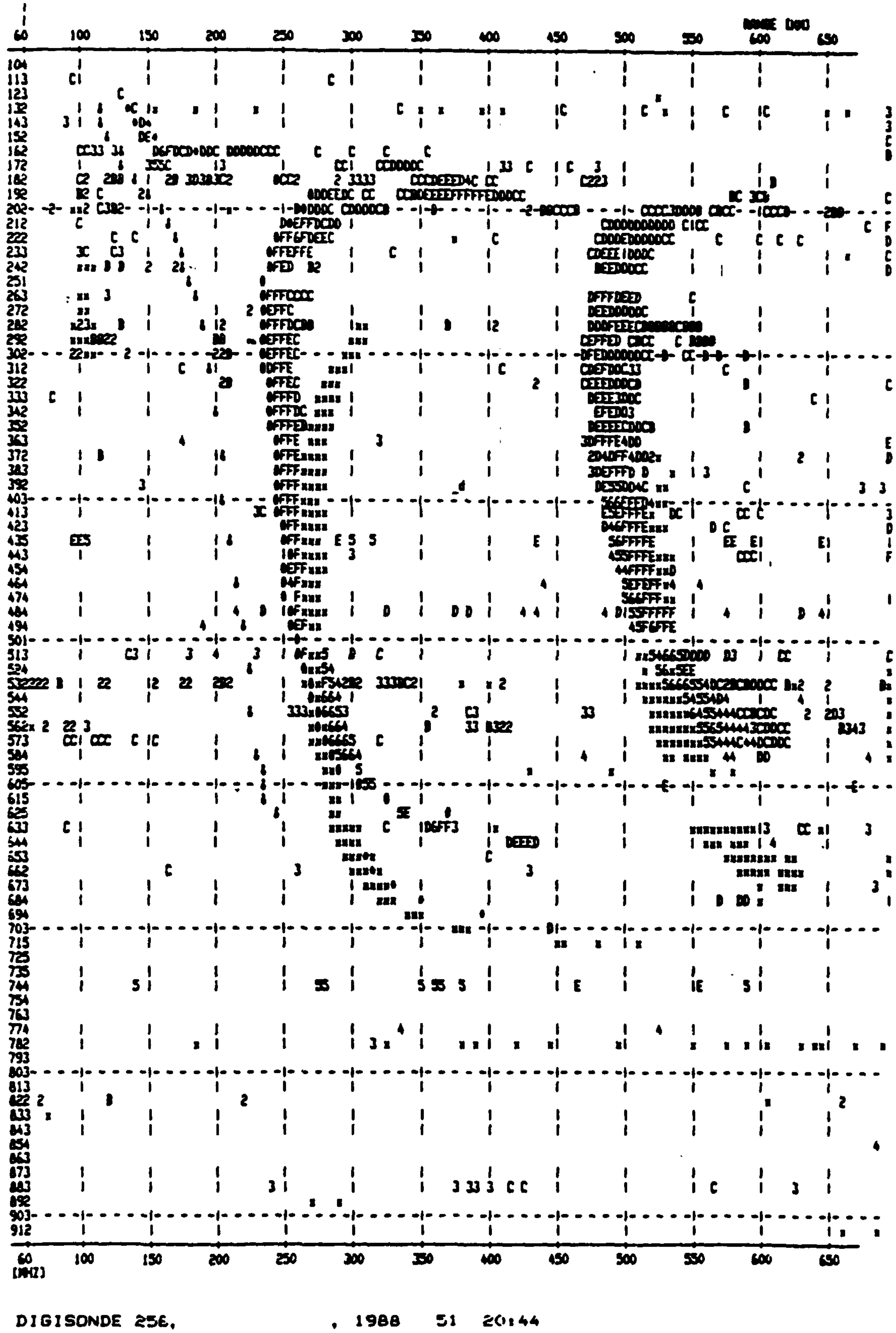


Figure 2.2 ARTIST ASCII Ionogram

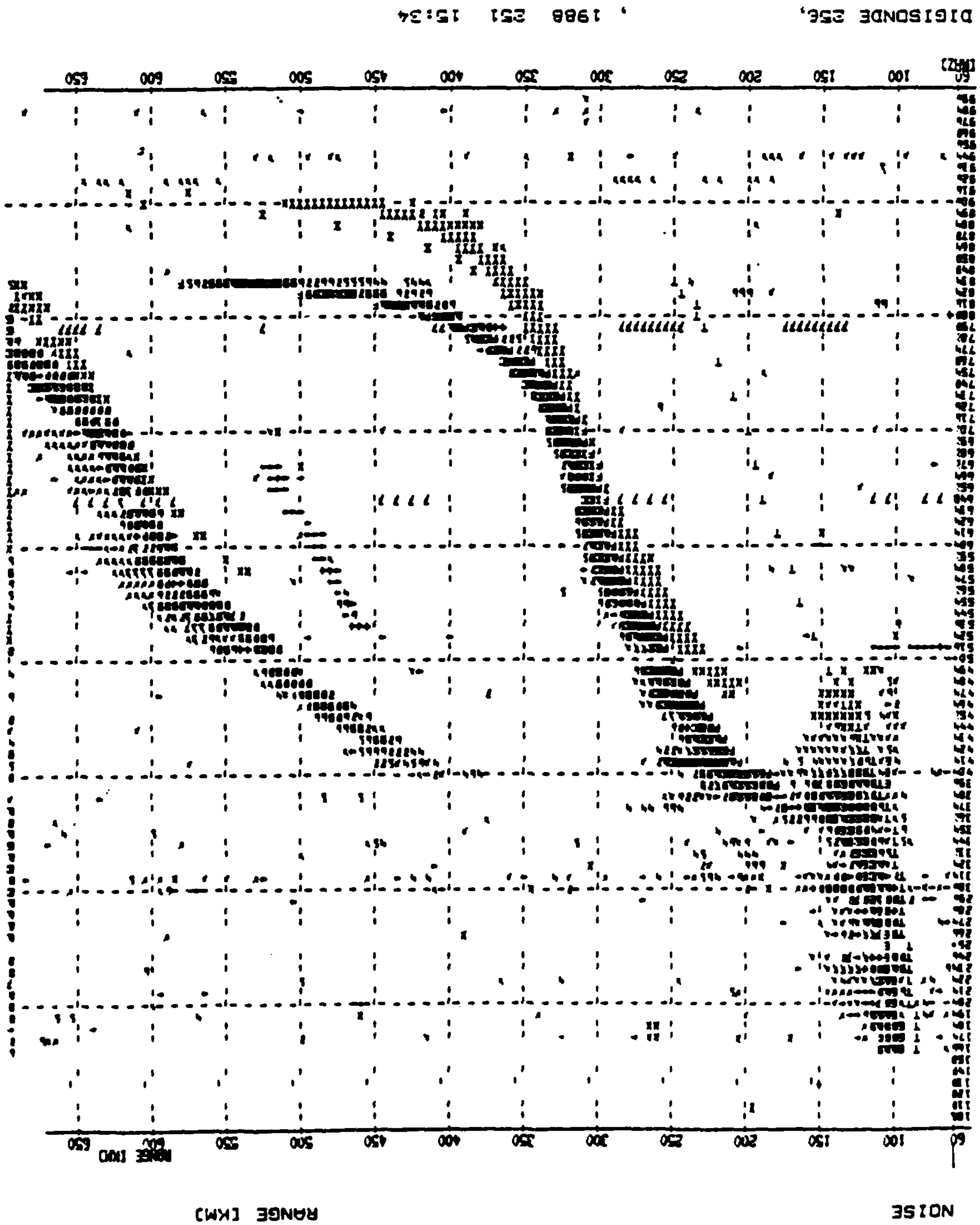


Figure 2.3 ARTISTSV Optifont Ionogram

trace has been reached and the foEs is scaled too low. Figure 2.4 shows an example of this phenomenon. Between 2.5 and 3.2 MHz, the Es-trace is constituted primarily of X-mode and oblique echoes. Ordinary-mode sporadic E echoes are detected again at higher frequencies.

The improved method determines the raw foEs first. Starting from the end of the ionogram, a search window is slid toward lower frequency searching for the first 3 × 3 window with a number of O-echoes. The same technique is used to locate the F trace center in ARTISTD. For the ionogram in Figure 2.4, the Es trace center is determined to occur between the foE and 6 MHz. Finally, the Es trace is linked between the center and the raw foEs. However, if there are no O-mode echoes found for three consecutive frequencies in the linking process, the highest frequency which has O-mode echoes, before the data gap, defines foEs. This is true even though the raw foEs has not been reached. The foEs scaling results have been improved using these techniques. Figure 2.5 shows the correctly scaled foEs obtained by the ARTISTSV program.

### 2.2.2 Use of CCIR foE Prediction to Replace the ARTISTD foE

Table

In ARTISTD, the foE is determined by searching the frequencies within 300 kHz of the predicted foE. The predicted foE is precalculated from a model, Ionospheric Communications Analysis and Prediction Program (IONCAP vs 78.03), and the monthly foE reference table is stored in the station personality file ARMENU. The reference and the current year sunspot number are required parameters.

In ARTISTSV, the foE is calculated using CCIR foE prediction equation, see Appedix A, during execution instead of using

| STATION | YEAR | DAY | H M | | OUT | OPT | B | E | Q | CAB | XLZT | NRW | HEIG | PROGRAM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 042 | 1987 | 207 | 3:14 | UT | 0084100 | 01- | 8 | 2 | | 12E | 41D3 | 434 | 123E | 1 |

| FOF2 | FOF1 | H'F | H'F2 | M3000 | FMIN | FOES | MUF | FMINF |
|---|---|---|---|---|---|---|---|---|
| 3.4 | *** | 318. | **** | 3.07 | 1.6 | 2.5 | 10.5 | 1.6 |

| FXI | FMINE | FOE | H'E | H'ES | QF | QE | FF | FE |
|---|---|---|---|---|---|---|---|---|
| 3.2 | *** | .7P | 90. | 103. | *** | *** | 1.1 | *** |

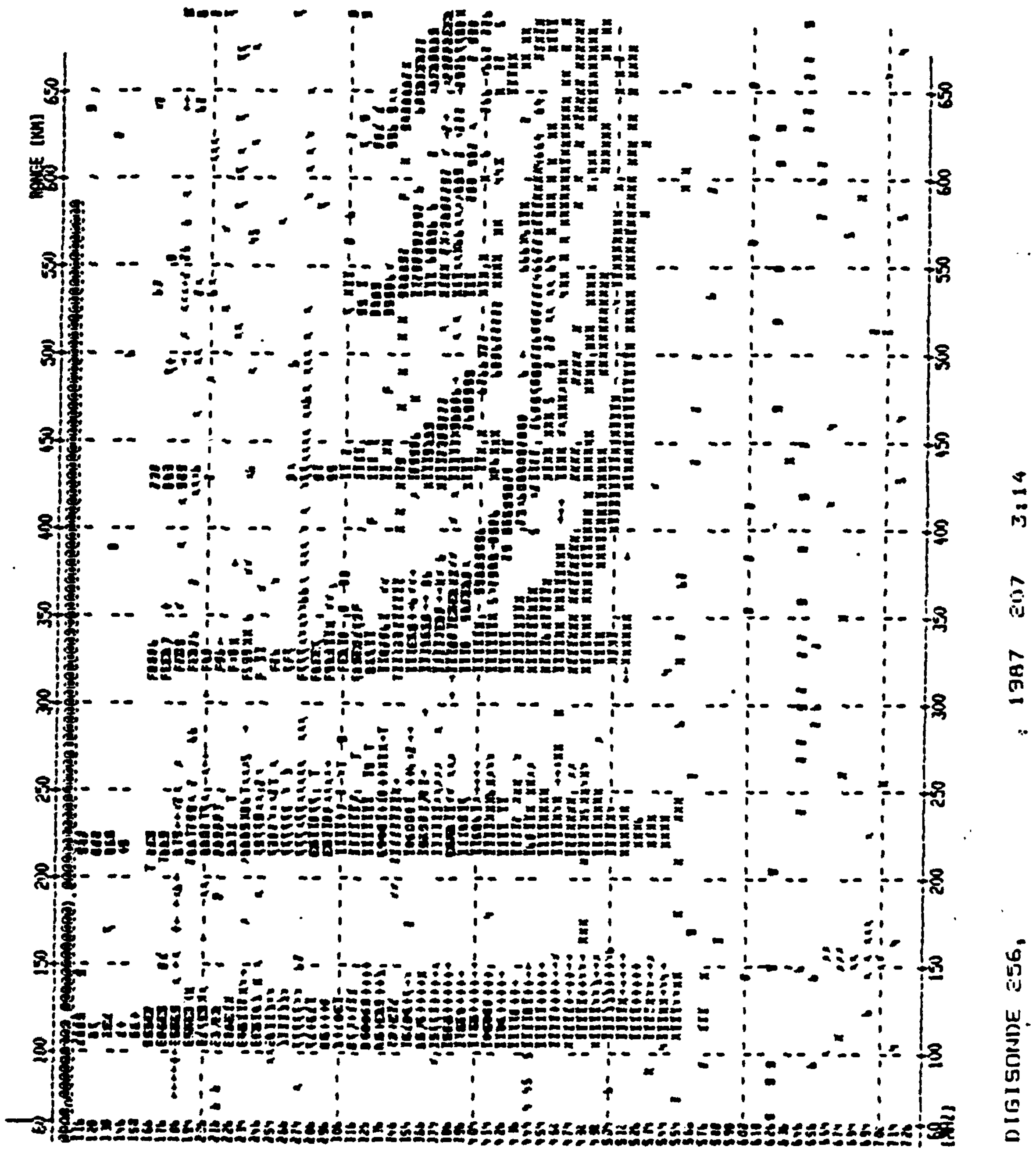


Figure 2.4 Autoscaling of Es Trace Before Improvement

| STATION | YEAR | DAY | H M | | OUT | OPT | B | E | Q | CAB | XLZT | NRW | HEIG | PROGRAM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 042 | 1987 | 207 | 3:14 | UT | 1084100 | 01- | 8 | 2 | 12E | 41D3 | 434 | 123E | | 1 |

| FOF2 | FOF1 | H'F | H'F2 | M3000 | FMIN | FOES | MUF | FMINF |
|---|---|---|---|---|---|---|---|---|
| 4.4 | *** | 315. | **** | 2.94 | 1.0 | 4.4 | 12.9 | 2.8 |

| FXI | FMINE | FOE | H'E | H'ES | QF | QE | FF | FE |
|---|---|---|---|---|---|---|---|---|
| 5.2 | *** | .7P | 90. | 97. | 5. | *** | .1 | *** |

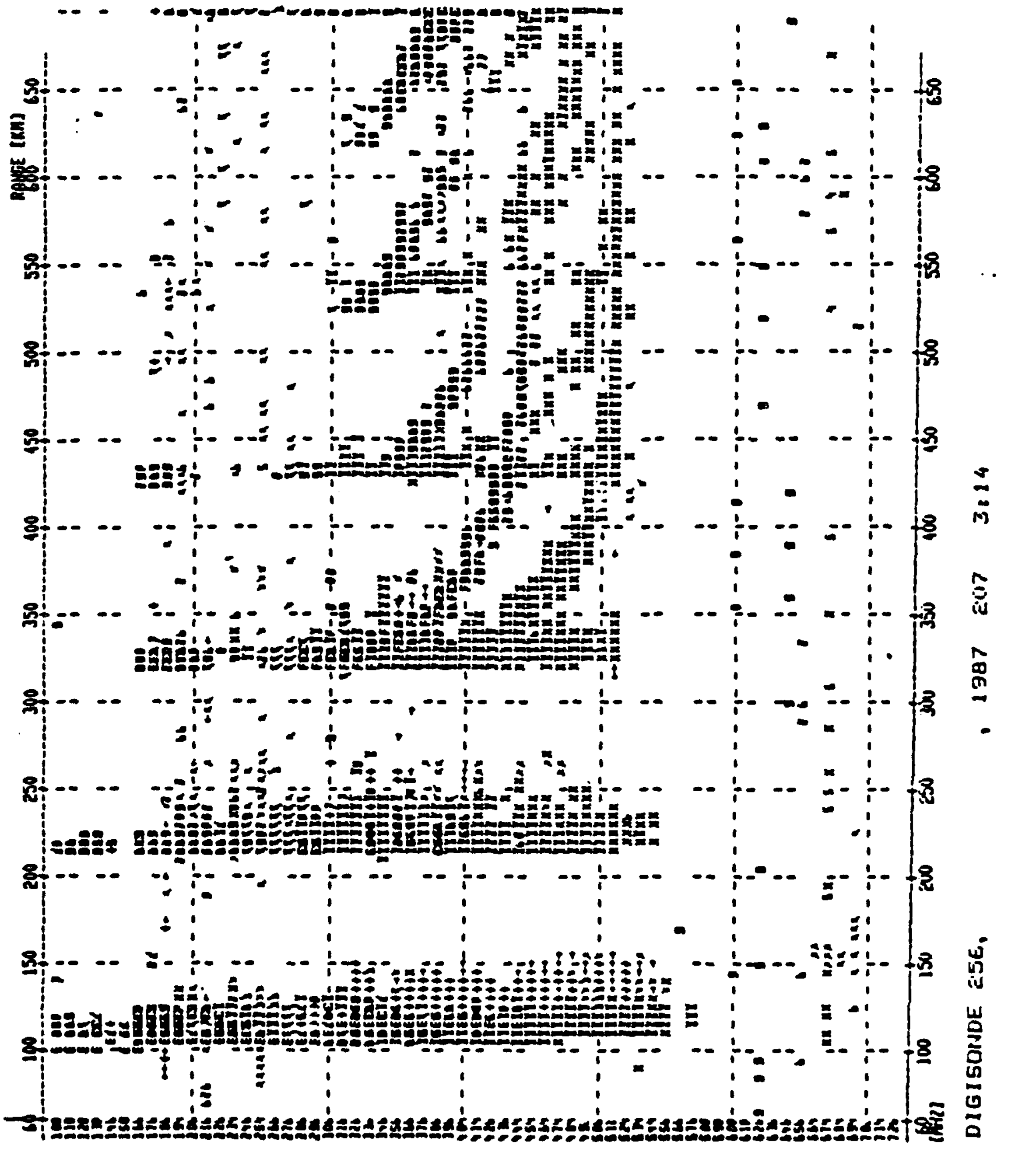


Figure 2.5 Autoscaling of Es Trace After Improvement

a table. In addition, the solar zenith angle is calculated for each ionogram. These changes ensure an improved predicted value of foE. Only the current year 12 month mean sunspot number is required. The elimination of the foE table in ARMENU makes the file shorter and simplifies the menu editing process described in the later text.

### 2.2.3 Modified Method to Determine MUF(3000)

In ARTISTD the modified secant law [Davies, 1969] is used to calculate the MUF. The equation is:

$$f_{ob} = k\, f_v \sec \phi \tag{1}$$

where k is the correction factor which value depends upon the distance. In the case of a curved earth and a plane ionosphere, $\phi$ is given by

$$\tan \phi = \frac{\sin \frac{1}{2} \theta}{1 + \left(\frac{h'}{a}\right) - \cos \frac{1}{2} \theta} \tag{2}$$

where a is the earth's radius (6370 km), $\theta$ is the angle at the center of the earth subtended by the transmission path, and h' is the virtual reflection height.

The value of k is difficult to calculate since it is a function of the distance and the electron density profile. The experimentally determined k factor graph [Wieder, 1955], shown in Figure 2.6, is used to obtain the k value for different distances. A single MUF is calculated for the selected distance in the ARMENU.

OBLIQUE PROPAGATION

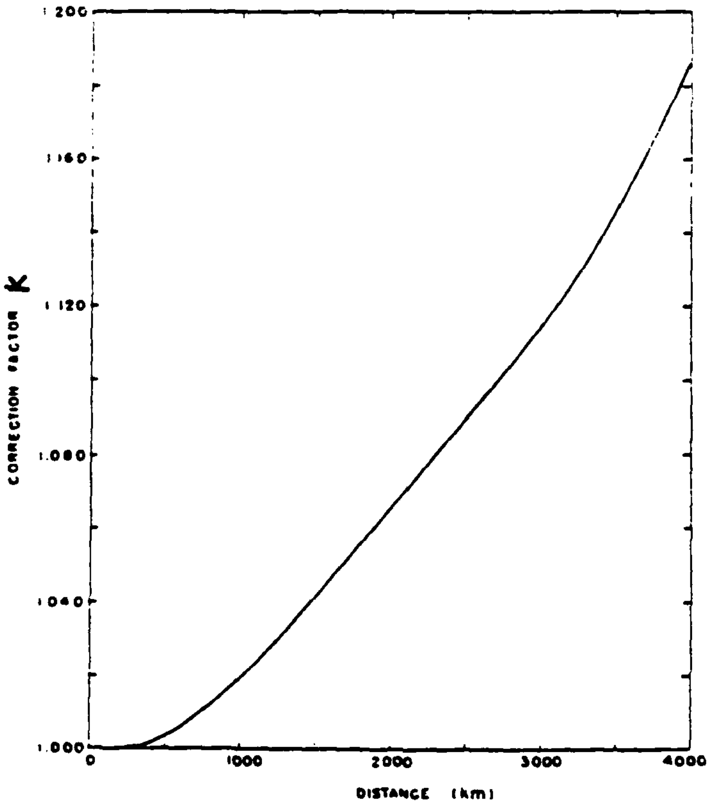


**FIGURE 4.8.** ***Variation of correction factor k with distance.***

**(After B. Wieder, 1955. Some results of a sweep-frequency propagation experiment over a 1100 km east-west path. J. Geophys. Res. 60, 395.)**

Figure 2.6 Variation of Correction Factor k With Distance

ARTISTSV adopts Paul's [1982] equation for a distance of D = 3000 km to determine the obliquity factor as:

$$\text{Obliquity Factor} = \frac{[67.654 - 0.0149\,(h')]}{\sqrt{h'}} \qquad (3)$$

where h' is the virtual height of reflection for the vertical frequency f and the oblique frequency $f_0$,

$$f_0 = f \bullet \text{Obliquity Factor.} \qquad (4)$$

This expression for $f_0$ is within 0.5% of the value given by Piggott and Rawer [1972]. This conclusion was reached from scaled DISS MUF values which are 0.05 too low compared to Paul (c.f. AFGL-TR-86-0098, Scientific Report Number 3).

The CCIR [1978] MUF equation is also used for skip distances between 0 and 4000 km

$$\text{F2(zero)MUF} = \text{foF2} + 1/2\, f_H \qquad (5)$$

where $f_H$ is the electron gyro frequency.

$$\text{F2(4000)MUF} = \text{F2(3000)MUF} \bullet 1.1 \qquad (6)$$

$$\text{F2(d)MUF} = \text{F2(zero)MUF} = M[\text{F2(4000)MUF} - \text{F2(zero)MUF}] \qquad (7)$$

where $M = 1.64 \times 10^{-7}\, d^2$ for $0 \leq d \leq 800$ km

and $M = 1.26 \times 10^{-14}\, d^4 - 1.3 \times 10^{-10}\, d^3 + 4.1 \times 10^{-7}\, d^2 - 1.2 \times 10^{-4}\, d$ for $800 \leq d \leq 4000$ km.

The advantage of equation (7) is that this simple expression can be used to calculate a series of MUF(d). This capability is not implemented yet in either ARTISTD or ARTISTSV.

## 2.3 Improvement in True Height Calculations

The true height inversion algorithm is being modified to improve and extend the functions of the program. These changes, incorporated with the scaling changes, comprise ARTISTSV.

For the true height inversion part of the program, the ARTISTD code is very similar to the code that is operating as ARTISTSV at this time. The differences between the current ARTISTSV and the ARTISTD version are discussed below.

### 2.3.1 Summary of the ARTISTD Profile Technique

The ARTISTD software forms the basis of what is called the ULCAR true height inversion method. In this method, the autoscaled trace of each ionospheric layer is inverted separately. The lowest layer is inverted first, so depending on the conditions this can be the E or F (nighttime) layer. The starting conditions of the next (upper) layer are adjusted using the information from the inversion of the lower layers. Thus the method proceeds from the start frequency of the ionogram to the end frequency (foF2). The starting height of the profile is determined from the data by the parabolic electron density profile that best reproduces the measured h'(f) data. In daytime, this is done on the E layer points. During the night (presently defined as the time when foE $< 0.6$ MHz) no E layer is considered and the F layer points are used in the extrapolation. A model valley region is employed to account for ionization between the E and F layers. The model consists of a slab of ionization with $f_c$ = foE where the width of the slab is determined by fitting the observed retardation at the start of the F trace to the model.

The profile for each layer is represented in terms of analytical functions. The functions chosen in this approach are the shifted Chebyshev polynomials [Snyder, 1966]. For each layer, the true height is presented as:

$$z - z(f_s) = A_{I+1} + g^{1/2} \sum_{i=0}^{I} A_i T_i^*(g) \tag{8}$$

where

$$g = \frac{\ln(f/f_c)}{\ln(f_s/f_c)}$$

and $0 \leq g \leq 1$;

f is the plasma frequency, $f_C$ the critical frequency, i.e. the plasma frequency at the layer peak and $f_S$ is the start frequency of the layer. In the current algorithm, the number of coefficients selected for each layer is 3 for the E-layer (i = 0, 2), 5 for the F1-layer (i = 0, 4) when present, and 5 for the F2-layer. Details of the ULCAR inversion method that is incorporated in the ARTISTD are given in Reinisch and Huang [1983], Huang and Reinisch [1982] and Gamache et al. [1985].

### 2.3.2 Objectives of Changes

The scientific program has several improvements over the ARTISTD. The changes that were made represent either improvements in the inversion method or help to ensure continuous operation of ARTIST. Some of the problems addressed were conditions where F1 is present with a gap between foE and the start frequency of the F1 layer, non-monotonic E layer polynomial solutions, and ill-defined boundary conditions for the polynomial solutions.

### 2.3.3 Description of Changes

#### 2.3.3.1 Error checks for continuous operation

Error checking has been added to the ARTISTSV to ensure continuous operation in real time. The errors that stop execution are either numerical type errors, e.g. taking the square root of a negative number, or errors in the trace to be inverted. Some of the trace errors that stop execution are traces too short for inversion, data gaps of two or more frequencies between traces, and large oscillations in the virtual height trace after underlying effects have been removed. There are also frequency range errors, start height errors, oscillating profile solutions, or underlying layers that are too thick and cause unrealistic results in the upper layer. The reasons that these conditions occur are the variability of the data and the fact that results of the autoscaling procedure are sometimes incomplete or unrealistic. To eliminate the possibility of the inversion program being terminated by these conditions the following checks have been added.

All square roots are computed in a function routine which first checks for negative arguments. If found, the inversion is stopped, an error message issued and control returned to the autoscaling routine. A similar test is done for natural logarithms of the type:

$$\ln\left[\frac{f_{critical}+f}{f_{critical}-f}\right] \qquad (9)$$

which occurs several times in the true height algorithm. The routines PROF and SIK check variable ranges that could cause termination of the program. When out of range, the calculation of the true height is stopped, a message printed, and control returned to the calling program. Without the checks, these errors would cause the ARTISTSV to stop execution.

2.3.3.2 Frequency gap filling for F1 conditions

The true height of reflection, z, as a function of frequency can be obtained from the virtual height trace of an ionogram by inversion of the integral equation

$$h'(f) = \int_0^{z(f)} n'\left(f, f_N, f_H, \Theta, \nu\right) dz \tag{10}$$

In this equation $f_H$ is the electron gyrofrequency, θ is the angle between the vertical and the geomagnetic field, ν is the electron collision frequency, $z_r(f)$ is the reflection height at operating frequency f, and fN is the plasma frequency. Assuming negligible collision frequency, the group refractive index, μ', becomes a real double valued (ordinary and extraordinary) function m' of f and fH. Inversion of equation (10) is sometimes complicated by the presence of gaps in the trace data (virtual heights not reported at particular frequencies) (see Figure 2.7). Under these conditions the true height profiles become approximate. If too much of the trace is missing, the results from inverting equation (10) become less meaningful.

When points are missing in the autoscaled traces they usually occur between the E and F layers (i.e. the start of the F trace). When this occurs, the true height algorithm attempts to fill in the missing points before inverting the trace. If there are too many points missing, the filling methods and the resulting electron-density profile become questionable. In scme instances execution errors can occur. To avoid this situation, the autoscaled traces are checked for missing data (no scaled h'(f) data at a particular frequency). When too much data is missing, the traces are not inverted. The check developed in ARTISTD is to consider the ratio of the number of frequency points with no h'(f) data at the start of the trace (the gap) to the number of points in the F trace (foF2-fminF). When this ratio is ≥0.3, the ionogram is not inverted. This criterion was developed

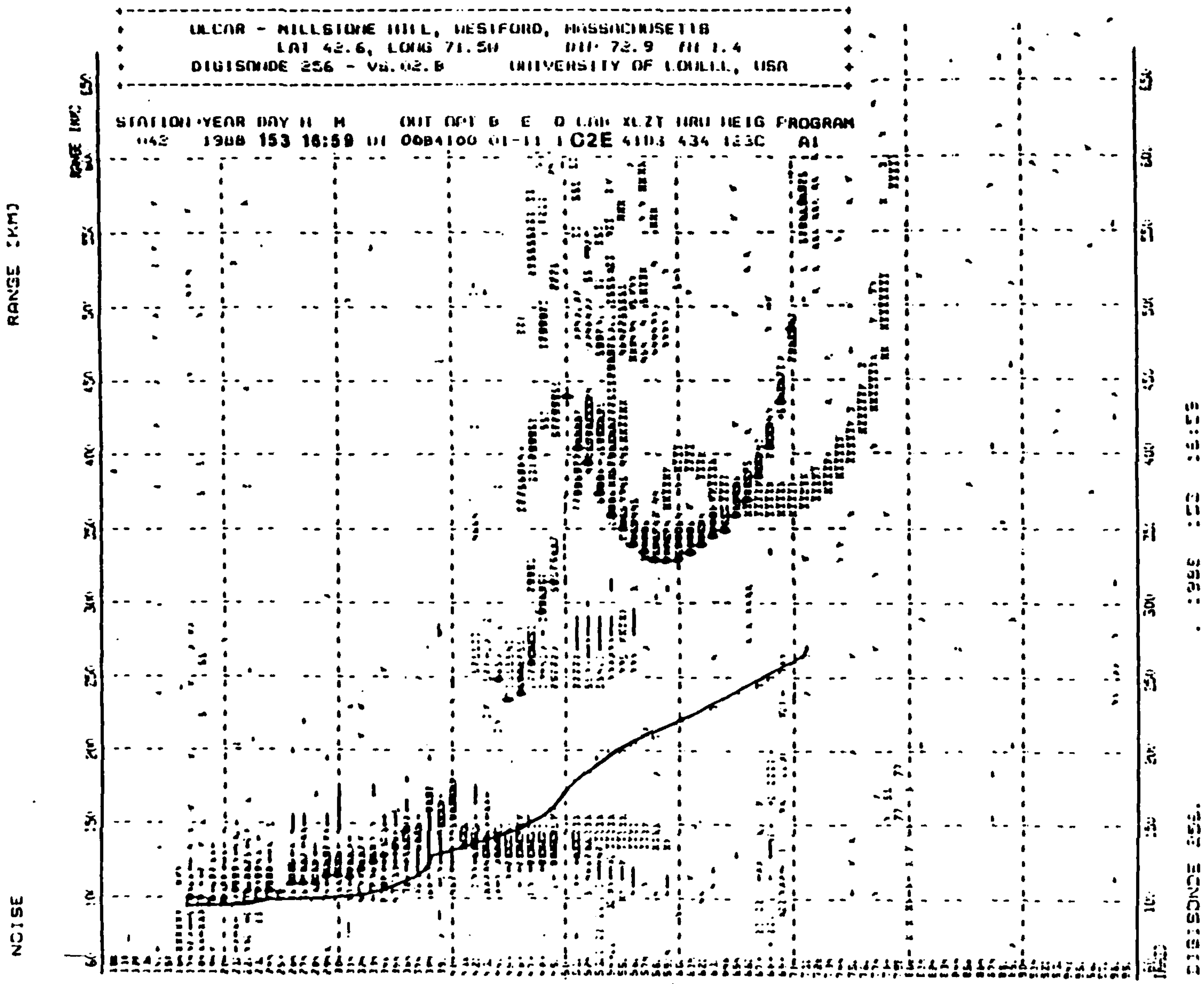


Figure 2.7 Ionogram With E/F1 Frequency Gap Filling

from studies of E-F2 gaps. With the presence of the F1 layer, the ratio taken is the gap to the number of F1 trace points (foF1-fminF). For ionograms with F1, the ratio criterion can be fulfilled by traces with small (2 or 3 point) gaps. To prevent elimination of such traces, the gap criterion was modified.

In the ARTISTSV, separate gap criteria are used for ionograms with and without F1 layers. For ionograms with no F1 layer, the ratio criterion developed for E-F2 conditions (≥0.3) is used. When the F1 trace is present, the ratio of gap to F1 trace is allowed to go to 0.6 before the solution is halted. This change allows profile solutions for traces that are skipped by ARTISTD (e.g. Figure 2.8).

In addition to this modification, the routine that fills the gap now checks that the filling process adds only heights in the correct range. The ARTISTD routine does not consider blanks in the trace which appear as heights at 999.9 km.

### 2.3.3.3 Non-monotonic E layer profile solutions

The polynomial inversion solution for the E layer is now checked that it meets the requirement of being monotonically increasing. This is accomplished by checking that the plasma scale height function, defined by

$$H \equiv \frac{N}{dN/dz} = \frac{1}{2} f_N \frac{dz}{df_N} \qquad (11)$$

is positive for all values of g in the interval $0 \le g \le 1$. Roots in the function H indicate that the electron-density will not be monotonically increasing but will oscillate. When oscillations occur, the profile cannot be used to determine the E layer contribution to

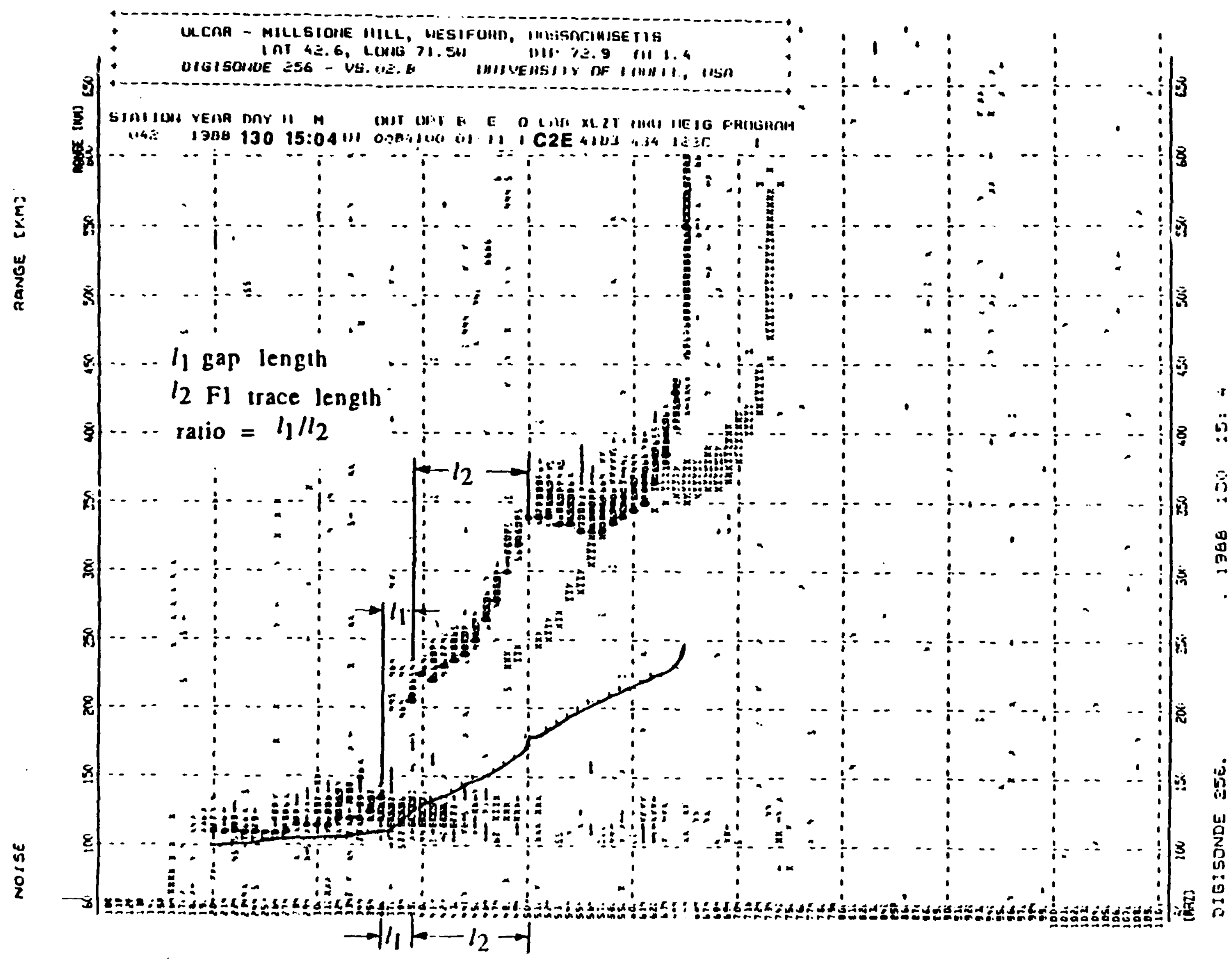


Figure 2.[illegible] [illegible]am that Would not be Inverted by ARTISTD

retardation (the retardation function is defined as DHE in the program) at frequencies above foE. Integration of such profiles is unstable, produces unrealistic retardation functions, and sometimes causes stoppage of execution.

The ARTISTSV uses the solution for the E layer electron-density as input to decide how the retardation function will be evaluated. When there are no roots in the plasma scale height function, the profile is integrated directly (via the polynomial coefficients) to produce DHE. When roots occur, the profile is investigated for the severity of the non-monotonic behavior. When the profile decreases (with increasing frequency) by less than 5 km, it is assumed that the general features of the profile are useful. Here the peak height, HoE, and the semi-thickness, YE, of the layer determined from inversion are used with foE to define a parabolic model E layer

$$z(f) = HoE = YE \left( 1 - \frac{f^2}{foE^2} \right)^{1/2} \tag{12}$$

to calculate DHE. For these cases, the coefficients of the polynomial for the E layer profile are not reported; instead the parabolic parameters are recorded. When the non-monotonic behavior is greater than 5 km, the inversion solution is not used. The algorithm defaults to model values of the peak height and semi-thickness [Dandekar, 1982], i.e. HoE = 110 km and YE = 20 km, to use in the model parabolic E layer for calculating DHE.

In the ARTIST routine, the integration that is done over the E profile is also checked to ensure that array boundaries are not exceeded.

### 2.3.3.4 Layer boundary conditions for inversion

The last change is the adoption of more reasonable boundary conditions for the inversions. The ARTISTD program takes the point fmin for the layer as the starting point and the scaled critical frequency for the endpoint. In the ARTISTD autoscaling routines, the scaled foF2 point is found and rounded down to the nearest tenth of a megahertz. This underestimates the critical frequency. It was found that this could result in peak heights of the layer that are 20-40 km too low. Similarly the autoscaled foE and foF1 values are reported as the last point in the particular trace and not where the trace approaches infinite height. Thus, these points are underestimated as well. ARTISTSV considers this and adds a shift of 10% of the frequency increment (i.e. 0.01 MHz if the frequency step is 0.1 MHz) to the critical frequency for the E and F1 layer end points. The foF2 value obtained from autoscaling by fitting a hyperbola to the F2 cusp is directly taken as the endpoint of the F2 layer, before it is rounded down to the 100 kHz frequency resolution, required by the URSI analysis procedure for foF2.

The starting point of a layer uses information from the underlying layer. A more consistent solution would take the starting point just above this underlying layer. The new routine sets the starting frequencies at foE + 0.02 MHz for the F1 layer and foF1 + 0.01 MHz for F2 layers. These changes to the boundary conditions result in electron density profiles that are more consistent with the theory. With these changes, the data at the critical frequencies are used in the inversions (as they should be) and the output table contains height values at these frequencies as well.

2.3.3.5 Miscellaneous changes

Other minor changes between the two versions include: the storage of and subsequent output of the number of roots found in the plasma scale height of each layer and the correct starting and ending frequencies for each layer. This allows one to recalculate the true height from the polynomial coefficients at later times and to reproduce the results of the ARTISTSV inversion routine.

## 2.4 Automatic Drift Measurement

To monitor the ionospheric drift motion, the Digisonde provides a drift mode sounding. The drift mode sounding supports a maximum of four frequencies with corresponding height range and gain settings. The signals from the seven (or optionally four) receiving antennas on the four frequencies are Fourier transformed in the Digisonde and stored on magnetic tape as one drift case (4096 bytes). The Digisonde transmission is repeated and a new drift case is generated until terminated by the operator or the start of an ionogram. Refer to Dozois [1983] for a summary of the plasma drift analysis using Digisonde data.

The operator must select the four frequencies, height ranges and gain settings at the beginning. Once the drift measurement has begun, one has to adjust the height range and gain settings to follow any changes in the ionosphere from one drift case to another. This procedure is time-consuming and requires constant attention from the operator during the entire drift measurement period.

An automatic drift measurement feature (AUTODRFT) was implemented in the ARTISTSV to permit monitoring of ionospheric drift without human assistance. AUTODRFT selects the frequencies at which the drift is to be measured and sets the initial sampling ranges. Routine, fully automatic drift measurements are now feasible.

In the automatic drift measurement mode, the four frequencies are divided into two pairs of identical frequencies with different range and gain settings. The AUTODRFT examines the last scaled ionogram from the ARTISTSV and selects the two most interference free frequencies from the scaled F trace. The first frequency is chosen from the upper half of the F trace while the second one is picked from the lower half. Frequencies near fminF and foF2 are not used to avoid rapid height changes. Currently the critical frequency foF1 is not excluded in the frequency selection process. Once determined, these frequency pairs are kept constant until the next ionogram is scaled. However, the period for continuous drift measurement should be limited to a few minutes due to possible noise contamination in the channels. Furthermore, the selected frequencies may become inappropriate due to changes in the ionosphere. A five or ten minute ionogram sequence, with drift measurements between, has been found acceptable.

Within each pair of frequencies, the two height ranges are separated by 10 km. The appropriate starting heights for the frequencies are determined from the ionogram h'(f) trace. For each drift case, the AUTODRFT compares the spectral amplitudes within each pair and follows the maximum amplitude by changing the height range of the weaker echo. A + or - 20 km adjustment is added to the height ranges of the smaller returns before the next transmission begins. Hence, the two groups of height ranges (with a 10 km separation) will hover around the optimal height ranges from one drift case to the other following the changes in the ionosphere.

The gain controls are automatically adjusted during the drift measurement. The starting gain controls are set to a value of 2 to avoid saturation. Then the gains are increased or decreased to maintain maximum signal returns (10 dB below the system limit) without saturating the receiver of the Digisonde.

A sample automatic drift measurement setup follows:

| | | PPPPPPP (1234567) | SSQUU | CAB | XLZT | NRW | HEIG |
|---|---|---|---|---|---|---|---|
| PROGRAM | A1 | 0484200 | 02108 | C2E | 41D1 | 534 | 1239 |
| PROGRAM | G1 | 05A330E | 00000 | 12E | 0B80 | 525 | 0000 |
| | | | | | | (7 ANTENNAS) | |
| | G1 | 05A330E | 00000 | 12E | 0980 | 625 | 0000 |
| | | | | | | (4 ANTENNAS) | |
| AUTO SCHEDULE | 06A | 9 19 29 39 49 59 | | | | | |
| AUTO SCHEDULE | 06G | 9 19 29 39 49 59 | | | | | |
| "O" PARAMETER | O=6 | | | | | | |

The AUTODRFT is activated by setting the 8th bit of P3 in the G program. Usually, a 10 minute sequence of ionogram-drift soundings (with P3 = 8) is entered into one of the Digisonde automatic schedules. The corresponding "O" parameter in the DISplay mode must be turned on to start the automatic sounding operation.

The P7 value in a drift program selects different automatic features of AUTODRFT. The automatic adjustments of height, gain and the selection of sounding frequencies are enabled by setting the proper bits of P7 as defined below:

| Bit | Function |
|---|---|
| 8 | enable frequency selection |
| 4 | enable gain adjustment |
| 2 | enable height range adjustment |
| 1* | select f(MUF) frequency selection |

*Least significant bit

When the 1-bit in P7 is activated, AUTODRFT selects the two sounding frequencies f(MUF) and f(MUF) - 8%, where f(MUF) is the vertical sounding frequency reflected at the same virtual height as the oblique signal at frequency MUF over distance D (usually 3000 km, unless otherwise specified). In other words, f(MUF) is the frequency at which the conventional MUF overlay curves touch the F-trace.

The AUTODRFT program was extensively tested at Qaanaaq, Greenland during the AURORAL ARCS campaign in October 1986. The program functioned without interruption during the experiments. AUTODRFT was found to reliably select interference free frequencies, representative F-region heights and automatically adjust the height gates and the receiver gains to ensure efficient, reliable acquisition of drift data. AUTODRFT has continued to operate successfully since that time.

## 2.5 Input/Output and Operation Enhancement

### 2.5.1 Optifont Ionogram

As noted previously, ARTISTD outputs ASCII ionograms. To print an Optifont ionogram, the printer driver is modified to interpret the ARTISTSV 8-bit output data and translate the data into Optifont characters. The modified driver is installed at the scientific stations at Argentia, Newfoundland, Goose Bay, Labrador, and Millstone Hill, Massachusetts. These stations routinely print Optifont ionograms. In the ARTISTSV Optifont output format, the Optifont numbers represent amplitudes of the O-echoes, with even numbers identifying signals with positive Doppler shift and odd numbers negative Doppler shifts (c.f. Table 2.1). X is used to indicate extraordinary mode echoes. Oblique signals are indicated by arrows that point in the direction from which the return signals come. The Optifont representation of oblique signals is shown in Figure 2.9. For further detail, refer to the DIGISONDE 256 Operator's Manual [Bullett, 1988].

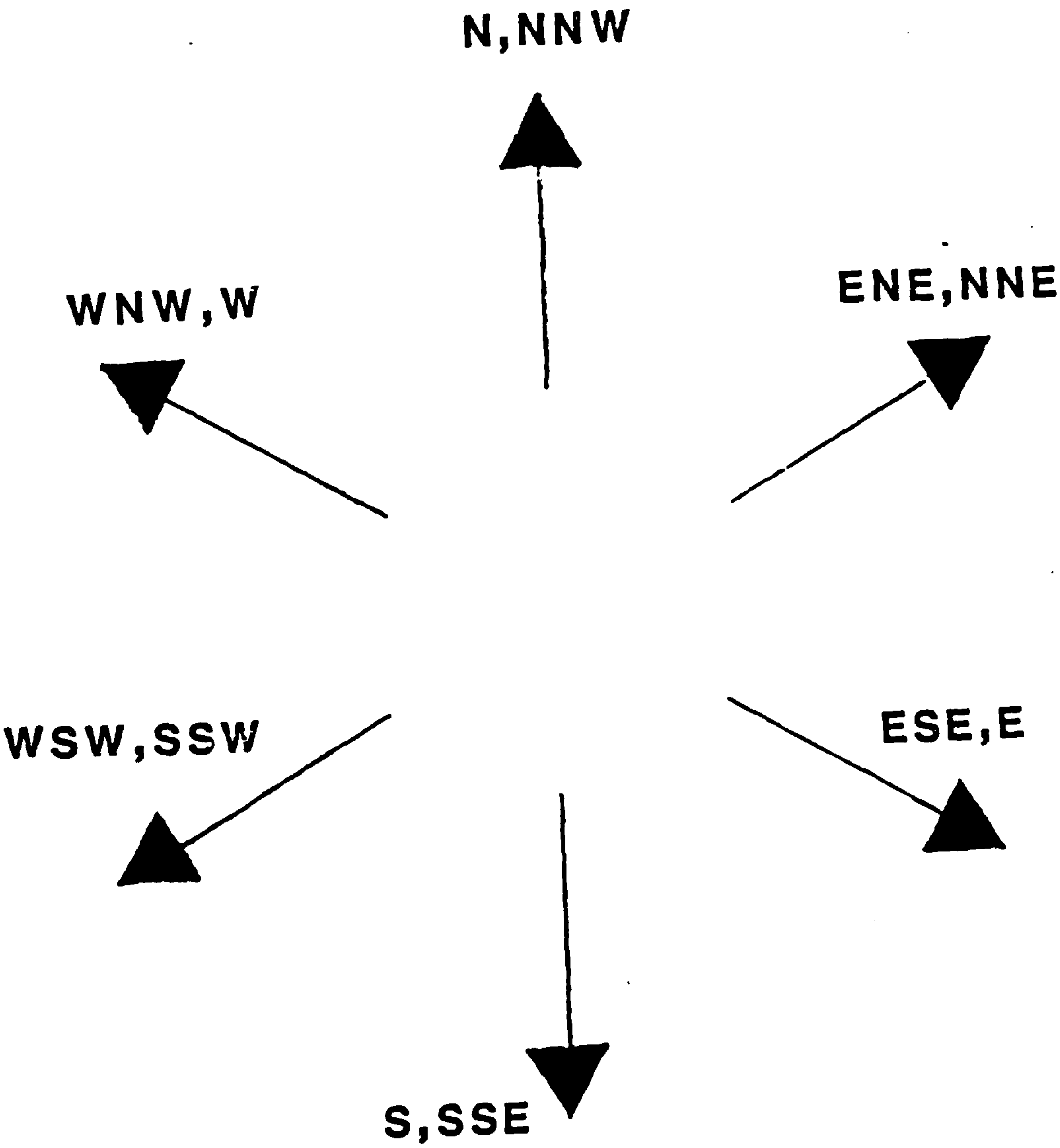


Figure 2.9 ARTISTSV Optifont Oblique Signal Indicators

ARTIST Amplitudes

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Optifont - | 0 | 2 | 4 | 6 | 8 | A | C | E | <- Positive Doppler |
| | 1 | 3 | 5 | 7 | 9 | B | D | F | <- Negative Doppler |
| Amplitude - | 12 | 24 | 36 | 48 | 60 | 72 | 84 | 96 | (dB, $Z < 8$) |
| | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | (dB, $Z \geq 8$) |
| ASCII - | 1 | 2 | 3 | 4 | 5 | 6 | | | <- Positive Doppler |
| | A | B | C | D | E | F | | | <- Negative Doppler |
| Amplitude - | 14 | 28 | 42 | 56 | 70 | 84 | | | (dB, $Z < 8$) |
| | 9 | 18 | 27 | 36 | 45 | 54 | | | (dB, $Z > 8$) |

Table 2.1. ARTIST Amplitudes for ASCII and Optifont

### 2.5.2 Magnetic Medium Archival of ARTIST Results

In ARTISTD, the results are stored only on magnetic tape. ARTISTSV allows user selection of storing the results on hard or floppy disk through a selection offered in ARMENU. If the available disk space is less than the threshold, which is set by the user in ARMENU, a reminder message will be displayed on the screen to alert the user to insert a new disk. The default threshold is 400 kilobytes. Each ARTIST ionogram requires four kilobytes. This means that the reminder message will appear after each disk write when the disk is 40 ionograms (or less) away from being full. Data stored on tape or disk have identical formats. Disk storage provides for rapid data access since the data are stored in a direct access file. Tape, on the other hand, has to be read sequentially. Another obvious advantage is that disks are easy to carry and to mail.

A utility Fortran program AROUTPUT was developed to unpack the data stored either on disk or tape. The output of AROUTPUT is identical in format to the ARTIST real-time printout.

### 2.5.3 Editing the Personality File ARMENU

The personality file contains site adaptation data and variable values pertaining to the solar and/or geophysical environments which are normally static for a given site. When ARTIST is initialized, the ARMENU file residing on disk is read into memory. The user may change the variable values in ARMENU to satisfy specific needs. Examples include updating the sunspot number or the output options.

In ARTISTD, the utility program EDMENU changes the input options in ARMENU but it must be activated in the Disk Operating System (DOS). This requires the ARTIST computer to be reset each time an option is changed. Within ARTISTSV, the user may edit ARMENU after ARTISTSV is loaded into memory. There are two operating modes in ARTIST. One is the DGS mode obtained by depressing the ALT 1 keys. The second is the ART mode obtained by depressing the ALT 2 keys. To edit the menu, the user must be in ART mode and then type 'EDITMENU'. The edited input options replace the previous ones, and ARTISTSV will process the next ionogram with these new values. The recommended time to edit the menu is between ionograms. Editing the menu at the recommended time allows the user to select desired options and ensure continuity of the ARTIST operation.

EDITMENU contains a built-in timer. After 15 minutes of unattended operation, the timer will cause an exit to ARTISTSV data processing.

When the ARTIST is idling in the ART mode, the user may employ ARTIST as a note pad to communicate with another user at a remote site. This feature is possible as ARTISTSV continues to check and to display the keyboard input until 'EDITMENU' is entered. EDITMENU can also be employed from a remote site.

### 2.5.4 Diagnostics Programs

A number of programs have been developed to test the ARTIST input, output and communication port functions. These are menu driven programs that assist the user to complete the function.

The available programs include:

- TESTASTA - test remote port (PT2K).
- TESTASTB - test AWN port at the main site and the printer port at the remote site (PT3K).
- TESTGENO - test screen display.
- TESTPRN - test printer port.
- TESTPROC - test processor output to ARTIST.
- TESTTECO - test 37 pin serial I/O port (JKM).
- TESTTEC1 - test modem port (PT1K).
- TESTTAPE - test tape drive read/write.

A report "ARTIST Diagnostic Tests" is in preparation.

## 3.0 FUTURE CAPABILITIES

### 3.1 Recognition of Multiple Sporadic E Traces

Multiple sporadic E (Es) traces have posed a problem for the DISS version of ARTIST. In ARTISTD, the second and third order multiple traces are detected and tagged. Experience reveals fourth and higher order Es traces occur frequently at mid-latitude in local summer daytime. In ARTISTD, these higher order Es traces are often confused with and scaled erroneously as an F layer trace. Even 2xEs (second hop sporadic E) and 3xEs are often left undetected in ARTISTD because of improper determination of foEs (see Section 2.2.1).

The future Scientific Version of ARTIST will allow for the occurrence of sixth order Es traces. Once the height of the primary Es trace is determined a template will be prepared and overlaid on the ionogram. Multiple Es echoes will be tagged to order six and eliminated. The algorithms have been laid out and the coding is currently being developed.

### 3.2 Other Needed Scaling and Operational Improvements

#### 3.2.1 Scaling

ARTISTD occasionally identifies the 2xF trace as 1xF trace. A better 2xF identification technique is under development. Under disturbed conditions, ARTISTD occasionally determines completely erroneous F-traces. Better boundary conditions will be introduced to eliminate or at least reduce occurrence of this mistake.

### 3.2.2 h'(f) Smoothing

The autoscaled h'(f) traces contained in the IONHEIGHT message are used for frequency management in OTH radar operations. The ARTISTD algorithm does not perform adequate data smoothing to allow direct use of the h'(f) traces. To improve the quality of the h'(f) data, digital filters will be developed to sort out erroneous trace points.

### 3.2.3 Tape Recording

During routine operation of the Digisonde 256, the tape drive is connected to the ARTIST unit and the DISS software supports tape recording of those ionograms that have a standard ARTIST compatible format (100 kHz frequency steps, 5 km height increment and O/X identification). This causes a dilemma for the DORIS development program, where oblique ionograms must be recorded with different frequency and height steps. The tape recording software will be rewritten to accommodate the recording of ionograms with arbitrary formats. This is also important for the use of AWS DISS stations for scientific purposes, when a higher frequency resolution than the presently allowed 100 kHz is required, as for example at Wallops Island in support of ionospheric modification experiments.

## 3.3 Incorporate an ARTIST Version Number

The current ARTISTSV program consists of approximately 50 modules. Each module contains three to ten routines. To provide for tighter software configuration management and to assist in software maintenance, each subroutine and module will be given a version number. The version number will combine the ARTISTD

Configuration Item Number (CIN) of the routine and the date last changed. The version number will be coded into the routine. This means it will be part of the ARTISTSV execution file. The version format is defined as follows:

| | | |
|---|---|---|
| Subroutine | - xxxMMDDYY | (xxx = CIN number of routine) |
| Module | - zzzMMDDYY | (zzz = module name) |
| ARTIST Program | - VSMMYY | |

The ARTISTSV program version number will be printed in the ARTIST header output of each ionogram. A utility program SEARCHVS will be developed to list all associated version numbers in the ARTISTSV program. The list will be in alphabetical order by subroutine and module name. If there is uncertainty in the ARTIST version, the SEARCHVS program can be run to list the module and subroutine version numbers needed to audit the situation.

## 3.4 New Profile Program

We are currently working on a new version of the true height algorithm with improvements over both the ARTISTSV or ARTISTD versions. This new version will include more geophysical modeling and error checks to ensure continuous running. The morning and evening transition periods are modeled to produce smoothing changing profiles on time scales based on the ionization and recombination processes. The program will now be able to use frequency step sizes other than 0.1 MHz. The start height extrapolation routine will have McNamara's [1979] model start height as a default when data does not allow proper extrapolation. Error codes will be added to stop the inversion when terminal errors are forthcoming, a message will be printed which pinpoints the problem in the data and control returned to the calling program. The new program will also include Titheridge's [1985] model valley between the E and F layers.

## 3.5 Printer Control

ARTIST stores the printer output in a large buffer. This allows for a peripheral driver or a communication utility program to intermittently poll the buffer for new or yet-to-be completed printer outputs. ARTIST supports three communication ports such as the Automated Weather Network, remote, and telephone dial-up ports.

The remote terminal can be connected directly to the ARTIST remote port or can be connected via a modem through a telephone line. When the remote terminal is connected directly, ARTIST will send printer output out to the remote terminal and also to the remote printer. This means that the same ionogram can be printed by the ARTIST local printer, the remote, and the telephone port printer if all ports are active. For a station where ARTIST is constantly monitored by a remote terminal, the local printout is usually not needed.

At times it may be desirable to print selected ARTIST outputs rather than the standard output (Figure 2.1). This is especially true during special experiments. We propose to develop a method to control on/off of the aforementioned printers. First, we will modify ARTISTSV to add output control sequences to turn on/off the printers. Next, the print options will be modified to allow users to selectively print specific minute ionograms (a maximum of 60 minute entries will be provided), print selected ARTIST outputs, and to print raw ionograms similar to those obtained through the processor.

### 3.6 Direct Communication Mode

This mode will allow ARTIST programs to directly access and modify information stored in the Processor's INPUT CPU without an echo display appearing in the DGS window unless it is requested explicity. This new mode will have several advantages:

1. Direct mode commands will be transmitted to the Processor at 2400 baud rate. Also, all information will be available to programs independent of the Processor mode. Presently, the Processor accepts user keyboard entered commands through the DGS window at approximately a 75 baud rate. The user can modify only the information that is displayed in the DGS window. For example, at present the user can change the time setting only when the processor is in the TIME mode or in the sounding schedule in the DISPLAY mode.

2. The direct communication mode uses check sum for error detection. This means that if a new command is entered but the Processor receives a bad check sum, the new command will be aborted and the user must resubmit the command. This feature will prevent the inadvertent execution of a hardware faulted command.

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# APPENDIX A

## CCIR foE Prediction

# CCIR foE Prediction

$$foE = \left[\left(1 + 0.0094\left\{\Phi_{12} - 66\right\}\right)\cos^{m}\chi_{noon}\left(A + B\cos\lambda\right)D\right]^{0.25}$$

Where: $\Phi_{12}$ is the 12-monthly smoothed solar flux expressed as follows:

$$\Phi_{12} = 63.7 + 0.728\ R_{12} + 0.00089\ R_{12}^{2}$$

$R_{12}$ = 12-month mean sunspot number

$\chi_{noon}$ = solar zenith angle at local noon

and $\lambda$ = geographic latitude (positive for northern hemisphere)

for $|\lambda| < 32°$; $m = 1.93 + 1.92 \cos\lambda$; $A = 23$ and $B = 116$

for $|\lambda| \geq 32°$; $m = 0.11 - 0.49 \cos\lambda$; $A = 92$ and $B = 35$

D is the time-of-day factor and is given as follows:

Case (a): For $\chi'$ $^{-}$ 73°

$D = \cos P\chi'$

Where $\chi'$ is related to the solar zenith angle $\chi$.

For $|\lambda|$ $^{-}$ 23°, $\chi' = \chi$.

For $|\lambda| > 23°$, $\chi'(t) = \chi(t - 3\ \text{minutes})$

For $|\lambda|$ $^{-}$ 12°, $p = 1.31$

For $|\lambda| > 12°$, $p = 1.20$

<u>Case (b)</u>: For $73^\circ < \chi' < 90^\circ$

$$D = \cos P(\chi' - \delta\chi')$$

Where $\delta\chi' = (6.27 \times 10^{-13})\ (\chi' - 50^\circ)^8$ expressed in degrees and $\chi'$ in degrees and p given as in case (a).

<u>Case (c)</u>: For $\chi' \, \tilde{} \, 90^\circ$

$$D = (0.077P \exp[-1.68\ (t_1 - t)]$$ from midnight to sunrise

and

$$D = (0.077)P \exp[-1.01\ (t - t_2)]$$ from sunset to midnight

Where t is the local time in hours

$t_1$ is the local time of sunrise ($\chi' = 90^\circ$) in hours and

$t_2$ is the local time of sunset ($\chi' = 90^\circ$) in hours and

p has the same value as in Case (a).