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## THESIS

TROPO: A MICROCOMPUTER BASED TROPOSCATTER  
COMMUNICATIONS SYSTEM DESIGN PROGRAM

by

Edward Michael Siomacco

September 1985

Thesis Advisor: J. B. Knorr

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|---|----------------------------------|--|
| 1. REPORT NUMBER  | 2. GOVT ACCESSION NO.<br>AD 7160 | 3. RECIPIENT'S CATALOG NUMBER<br>877                                     |
| 4. TITLE (and Subtitle)<br>TROPO: A Microcomputer Based<br>Troposcatter Communications<br>System Design Program   |                                  | 5. TYPE OF REPORT & PERIOD COVERED<br>Master's Thesis;<br>September 1985 |
|   |                                  | 6. PERFORMING ORG. REPORT NUMBER   |
| 7. AUTHOR(s)<br>Edward Michael Siomacco   |                                  | 8. CONTRACT OR GRANT NUMBER(s)   |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Postgraduate School<br>Monterey, California 93943-5100   |                                  | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS           |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Naval Postgraduate School<br>Monterey, California 93943-5100   |                                  | 12. REPORT DATE<br>September 1985  |
|   |                                  | 13. NUMBER OF PAGES<br>161   |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)   |                                  | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED                     |
|   |                                  | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE                            |
| 16. DISTRIBUTION STATEMENT (of this Report)<br>Approved for public release; distribution is unlimited.  |                                  |  |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)  |                                  |  |
| 18. SUPPLEMENTARY NOTES   |                                  |  |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>Troposcatter; Over-the-Horizon Communications; Height Gain;<br>Tropospheric Ducting   |                                  |  |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>This thesis presents a microcomputer based, computer-aided design program for tactical military tropospheric scatter radio systems. The program has the capability of predicting the system performance and reliability for both analog (FM/FDM) and digital troposcatter radiolinks. Propagation gain generated by elevated tropospheric ducting is called height gain. A height gain computational model for specific elevated tropospheric ducts. |                                  |  |

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TROPO: A Microcomputer Based Troposcatter  
Communications System Design Program

by

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Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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## ABSTRACT

This thesis presents a microcomputer based, computer-aided design program for tactical military tropospheric scatter radio systems. The program has the capability of predicting the system performance and reliability for both analog (FM/FDM) and digital troposcatter radiolinks. Propagation gain generated by elevated tropospheric ducting is called height gain. A height gain computational model for specific elevated tropospheric ducts is derived from statistical radiosonde data. A terrain profile plot, real-time radiosonde data analysis, and the probability of error for digital radiolinks are provided as program options.

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## I. INTRODUCTION

### A. PURPOSE

The development of digital transmission techniques in military communications systems has generated a renewed interest in tropospheric scatter. Digital troposcatter radio systems have required changes in the present planning and engineering design methods. The military design engineer has the responsibility to predict system performance and reliability within limited planning time. Under certain tactical situations, the urgency to restore vital communications has forced the engineer to provide several alternative designs for a single communications link. These requirements have justified the need for an efficient, computer-aided design method to accomplish the task. The purpose of this thesis research is to develop a tropospheric scatter communications system design program. The objective is to design a microcomputer-based program which will predict the path reliability and system performance for troposcatter radiolinks. This program will introduce

several improvements over the manually generated, nomograph-based design methods. Specifically, the program will estimate the height gain at the average system antenna height for specific elevated tropospheric ducts. Other features include a terrain profile plot, radiosonde weather data analysis, and the calculation of the probability of error for binary and orthogonal digital signaling techniques.

#### B. BACKGROUND

Tropospheric scatter communications systems propagate microwave energy beyond line-of-sight (LOS) or "over the horizon" by taking advantage of the refraction and reflection phenomena in a section of the earth's atmosphere called the troposphere. Typical military troposcatter systems use transmitter power outputs from 1 to 10 kW, parabolic type antennas, and sensitive broadband FM receivers with front-end noise figures (NF) between 2.0 - 4.0 dB. These systems are most often employed in military applications because of the limited available channel capacity [Ref. 1:pp. 253-254]. Several system advantages are summarized as follows:

1. Fewer terminal and/or relay stations are required to cover the same transmission path as compared to tactical microwave line-of-sight radiolinks.

2. Reliable multichannel communications can be installed across long distances of hostile or inaccessible terrain.
3. Standard transmission ranges are suitable for the tactical military field environment for radiolinks from 30 to 200 miles.

A fundamental design parameter for troposcatter links is the allocation of allowable channel degradation to each link making up the total communications system. In analog scatter systems, the quality parameters are system availability and signal-to-noise ratio in the voice channel. However with the deployment of digital troposcatter radio systems the performance of the digitized voice channels under fading conditions is significantly different than the performance of analog voice systems under the same conditions. The primary measure of transmission quality for a digital system is its error performance. There are two main sources of transmission errors: (a) long-term error rate which will occur because of equipment degradation, channel interference, and long-term power fading; and (b) multipath fading [Ref. 2:pp. 4-5].

## C. RELATED WORK

### 1. Performance Models for Troposcatter Links

Monsen [Ref. 3] has derived performance models for analog FDM/FM and digital quadrature phase shift keying (QPSK) systems on troposcatter communications links. The analysis included the effects of signal level variations and multipath delay dispersion. His performance criterion was the outage probability rather than either average error rate or median signal-to-noise ratio (SNR) values. Outage probability performance in a digital system was derived for two different modems: the Decision-Feedback Equalizer (DFE) and a transmitter time-gating technique, the Distortion Adaptive Receiver (DAR). Analog system performance was determined for the percentage of the time that the voice channel SNR including thermal noise and multipath delay dispersion effects were below a specified threshold.

The performance test results for a Distortion Adaptive Receiver (DAR) was presented in a paper by Zawislak [Ref. 4]. The critical problem with digital troposcatter is intersymbol distortion produced by the multipath dispersion of the fading channel. To resolve this problem, the distortion adaptive receiver was



implemented. The DAR modem employed QPSK modulation with adaptive matched filter demodulation. A complete functional description was explained in the reference. The advantage to this approach was that it did not require equalization at the receiver to correct intersymbol interference and it provided near optimum performance using the adaptive matched filter receiver.

Typical bit error rate performance for the DAR on a troposcatter channel is shown in Figure 1-1 for different values of rms multipath delay dispersion. For low multipath spread, the fading on each diversity channel has a Rayleigh distribution and the performance is indicated by the "flat. fading" marked curve. Note that the performance improves rapidly with increasing multipath spread and, at a  $10^{-5}$  error rate a 10 dB improvement is achieved for multipath curve [B]. However, as the multipath spread increases (with increased path length), a irreducible error rate occurs as shown in curve [C] due to the transmitter time-gate limitation. To compensate for this problem, the DAR is modified by utilizing a dual frequency pulse waveform. This technique is also used in the modem employed by the AN/TRC-170 tactical digital troposcatter radio set.

# SINGLE PULSE DAR PERFORMANCE

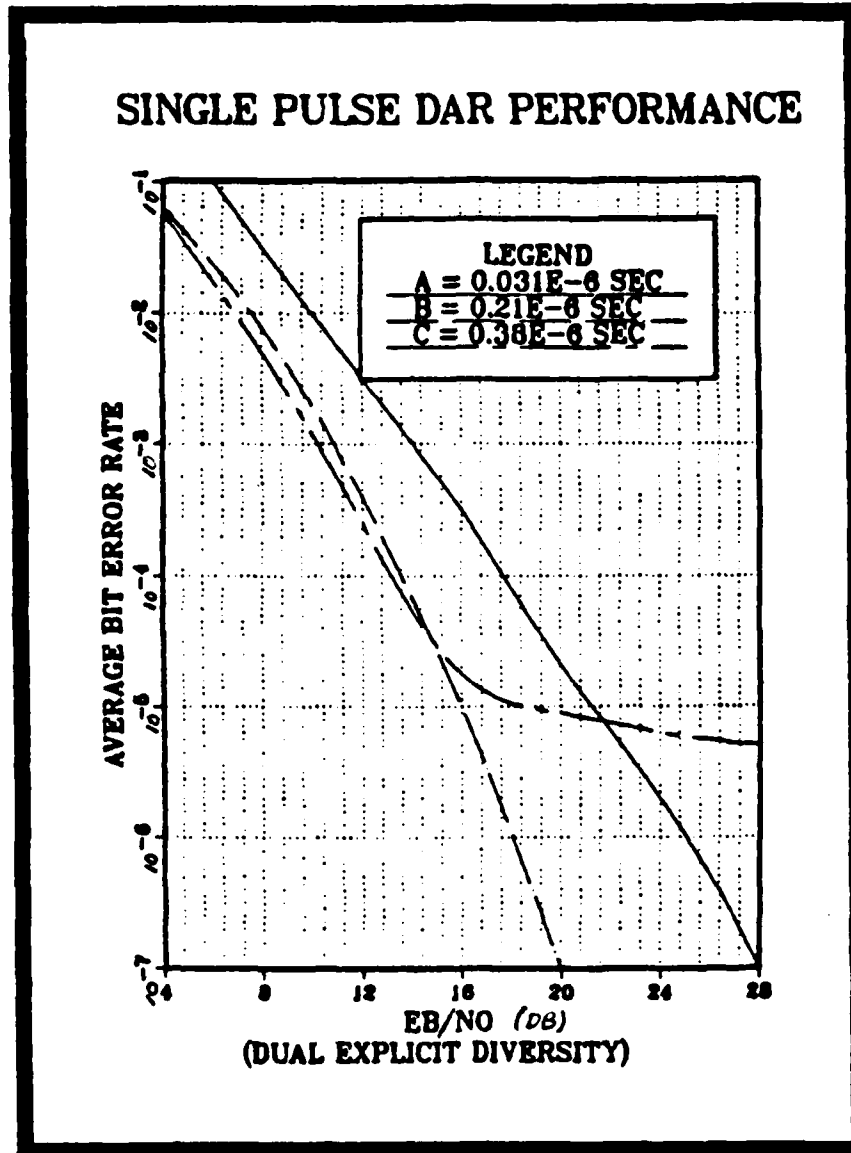


Figure 1-1 Distortion Adaptive Receiver Performance

(After Zawislán, Ref. 4:p. 3)

## 2. Tropospheric Elevated Duct Models

Several mathematical models have been developed to calculate the ducted signal field strength based on the refractivity profile and by modeling the tropospheric duct as a laterally homogeneous-layer atmospheric waveguide [Ref. 5:pp. 22]. A detailed mathematical analysis was presented by Marcus and Stuart [Ref. 6]. These authors have developed an effective modal solution computer program, called "DUCT", which requires a large processing capability of a main-frame computer [Ref. 7]. A version of this program, called "PDUCT", is available at the Naval Postgraduate School Computer Center [Ref. 8] and [Ref. 5:pp. 23-24].

Weston [Ref. 5:pp. 58-70] has proposed a statistical model, based on "PDUCT" predictions for selected ducts of interest. The height gain data, for these ducts, was used to derive model coefficients. These unique coefficients were stored according to their respective transmitter and receiver heights in a matrix form. Thus, given a receiver height and range from the transmitter for a selected duct/frequency data point, the coefficients for each receiver height are obtained and used to produce the corresponding height gain curve.

This approach required a significant number of main-frame computer "PDUCT" computations to establish height gain data for all the ducts of interest.

In December 1983, a microcomputer-based program, called "MINIDUCT" Version 1.1, based on Knorr's mathematical model was developed by Nagel, [Ref. 9], at the Naval Postgraduate School to calculate elevated ducted signal levels at various frequencies. This program used either historical radiosonde data or current elevated duct information [Ref. 10]. The radiosonde data represented the atmospheric temperature, pressure, and humidity at specific altitudes over a five year recording period. This model was valid for the case where the transmitter is at the optimum duct coupling height and the receiver is located either below, within or above the duct. The optimum coupling height is the altitude above the surface where the gradient of the modified refractive index becomes negative.

## II. TROPOSPHERIC PERFORMANCE CONSIDERATIONS

### A. SCATTER PROPAGATION

#### 1. General

At frequencies above 30 MHz three propagation mechanisms can carry energy beyond the horizon: (a) variations in the refractive index in the troposphere can scatter radio energy, (b) horizontally-stratified abrupt changes in the refractive index can cause reflection, and (c) atmospheric regions of negative modified refractive index gradients can introduce ducting. Refractive index and tropospheric ducting will be thoroughly discussed in the following section. The forward scattering of radio signals is the most dominant propagation mechanism at the frequencies of 0.3 to 10 GHz. [Ref. 11:p. 1]

#### 2. Received Scattered Field

The index of refraction depends on pressure, humidity, and temperature. Slight variations in these quantities, caused by atmospheric turbulence, will produce random fluctuations in the refractive index. When an electromagnetic wave propagates through this

inhomogeneous medium, energy will be scattered out from the original incident direction. The turbulent-scattering theory, [Ref. 12:p. 345], has shown to a first approximation that the index of refraction fluctuations can be replaced by a model of so-called "blobs", inhomogeneities of different dielectric constants randomly distributed. If these "blobs" are in the common volume formed by the transmitter and receiver antenna beams, the complex received field can be described by [Ref. 13:p. 146]:

$$Re^{j\theta} = \sum_{i=1}^m A_i e^{j\phi_i} \quad (2-1)$$

where  $m$  is the number of "blobs" in the scattering volume,  $A_j$  is the amplitude, and  $\phi_j$  is the phase of a wave scattered by a single "blob". Assume  $m$  to be very large and the blobs are spherical and uniformly distributed through the scattering volume. Then the phase difference of the waves scattered by the inhomogeneities at the top and bottom of the volume will be [Ref. 13:p. 147]:

$$\Delta\phi = \frac{4\pi h \sin\gamma}{\lambda} \quad (2-2)$$

where  $\gamma$  = transmitter, receiver antenna elevation angle

$h$  = mean thickness of the scatter volume (m)

$\lambda$  = transmitter wavelength (m)

The variables in Equation 2-2 are described in Figure 2-1.

By observing the volume geometry, it can be determined that more "blobs" exist in the central volume region than at the top or bottom. This indicates a non-uniform "blob" distribution.

Many phase variations will occur over many phase cycles of length  $2\pi$ . The antenna elevation angle will be less than 2 degrees for most systems and the ratio of scatter volume thickness to operating wavelength will be very large. These conditions make the scattered phases uniformly distributed from zero to  $2\pi$  [Ref. 13:p. 148].

The amplitude distribution will now be determined. The real and imaginary components of the complex received field, Equation 2-1, were resolved into two random variables  $X$  and  $Y$ . The number of blobs,  $m$ , is assumed to be large, so by the Central Limit Theorem, both  $X$  and  $Y$  will approach a normal "gaussian" distribution. Finally it was shown that these variables

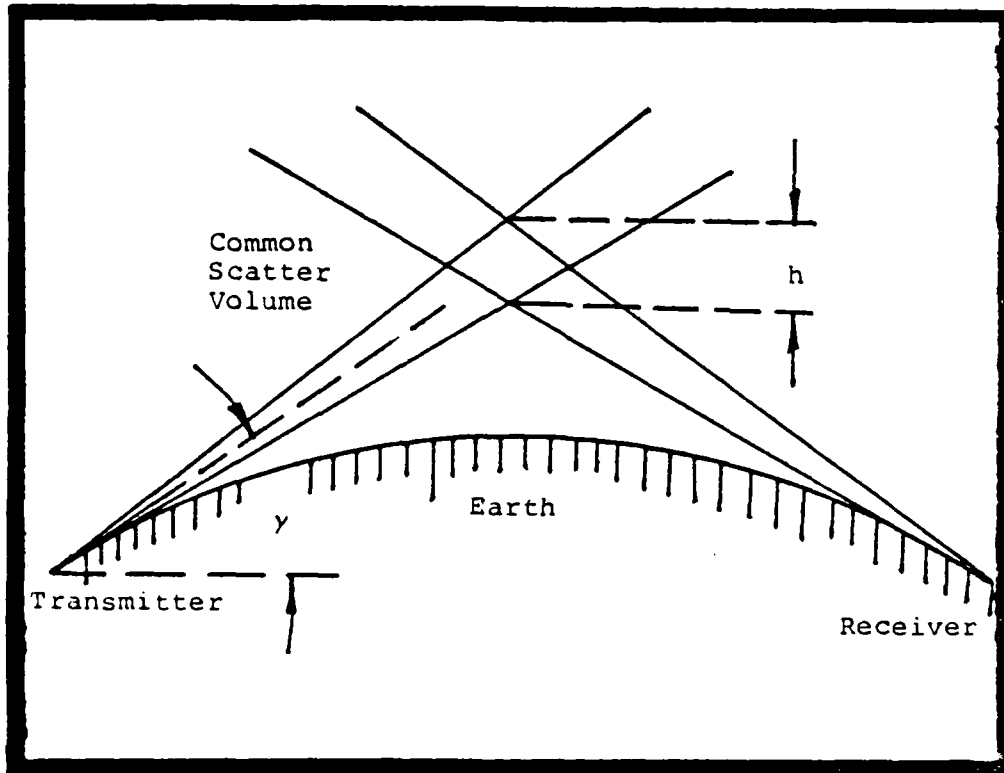


Figure 2-1 Scatter Volume Geometry

(After Beckmann, Ref. 11:p. 147)



are also uncorrelated and independent. Then their two-dimensional normal distribution can be transformed into the Rayleigh distribution.

Turbulence, mixing, and wind continuously change the positions and structure of the inhomogeneities making the random terms of Equation 2-1 functions of time. The reality of nature is the inhomogeneities do not vary isotropically because the index of refraction changes more rapidly with altitude than with distance. There can also be a stratification or layering of inhomogeneities near a particular height (or heights) that changes the assumed spherical shape of the so-called "blobs". Under these conditions the uniform phase distribution may change to an unknown distribution.

#### B. TROPOSPHERIC DUCTING.

The index of refraction,  $n$ , of air is defined as the ratio of the velocity in a vacuum of electromagnetic (EM) radiation to the velocity in the medium. A convenient parameter is refractivity,  $N$ , defined as [Ref. 11:p.14]:

$$N = ( n - 1 ) \times 10^6 \quad (2-3)$$

Another parameter called modified refractivity,  $M$ , is defined as [Ref. 10:p.9]:

$$M = N + 0.157 h \quad (2-4)$$

where  $h$  is the altitude in meters above the surface. The modified refractivity accounts for the curvature of the earth so the presence of ducting can be easily determined by observing the  $M$ -gradient on the  $M$  versus height plot.

Refraction of incident radio waves across a discontinuity of refractivity is described by the principles of Snell's Law. It is important to remember that the wave "bends" towards the higher value of refractivity, and the more dense a material the higher its  $n$ . Since the density of the atmosphere decreases with height, we expect that a wave will bend back downward from a geometric straight path. Whenever the refractive index decreases sharply with height, radiowaves can be trapped and experience low-loss propagation for long distances. This condition is known as tropospheric ducting [Ref. 11:p. 29].

The following conditions must be satisfied for a duct to occur: (1) the modified refractive index gradient shall be equal to or more negative than 0 M-units/km, and

(2) this gradient should continue over a height of many wavelengths. The important duct parameters are the duct thickness,  $D$ , the intensity,  $M$ , and the optimum coupling height,  $H_{opt}$ . A piecewise linear approximation to the modified refractivity (tri-linear) profile for several types of ducts are shown in Figure 2-2. There are three types of ducts: (1) surface or ground-based ducts, also called evaporation ducts when formed over water, Figure 2-2a; (2) surface-based ducts from elevated refractive layers, Figure 2-2b; and (3) elevated ducts from elevated refractive layers, Figure(s) 2-2c and d. Note that all positive  $M$ -gradients are assumed at 118  $M$ -units/km which corresponds to a standard atmosphere. Once the slopes are identified, the important duct parameters are quickly determined [Ref. 9:pp. 9-12].

Tropospheric ducts more often occur as ground-based ducts because of both evaporation and advection. Evaporation of water vapor from the surface of the sea may create a zone of high humidity (i.e. high refractive index) below a region of drier air. Advection, defined as the movement of one air type over another, may cause hot dry air (from the land) to be blown over cold wet air, producing a region of low refractive index above a region of high refractive index. Such a duct may also

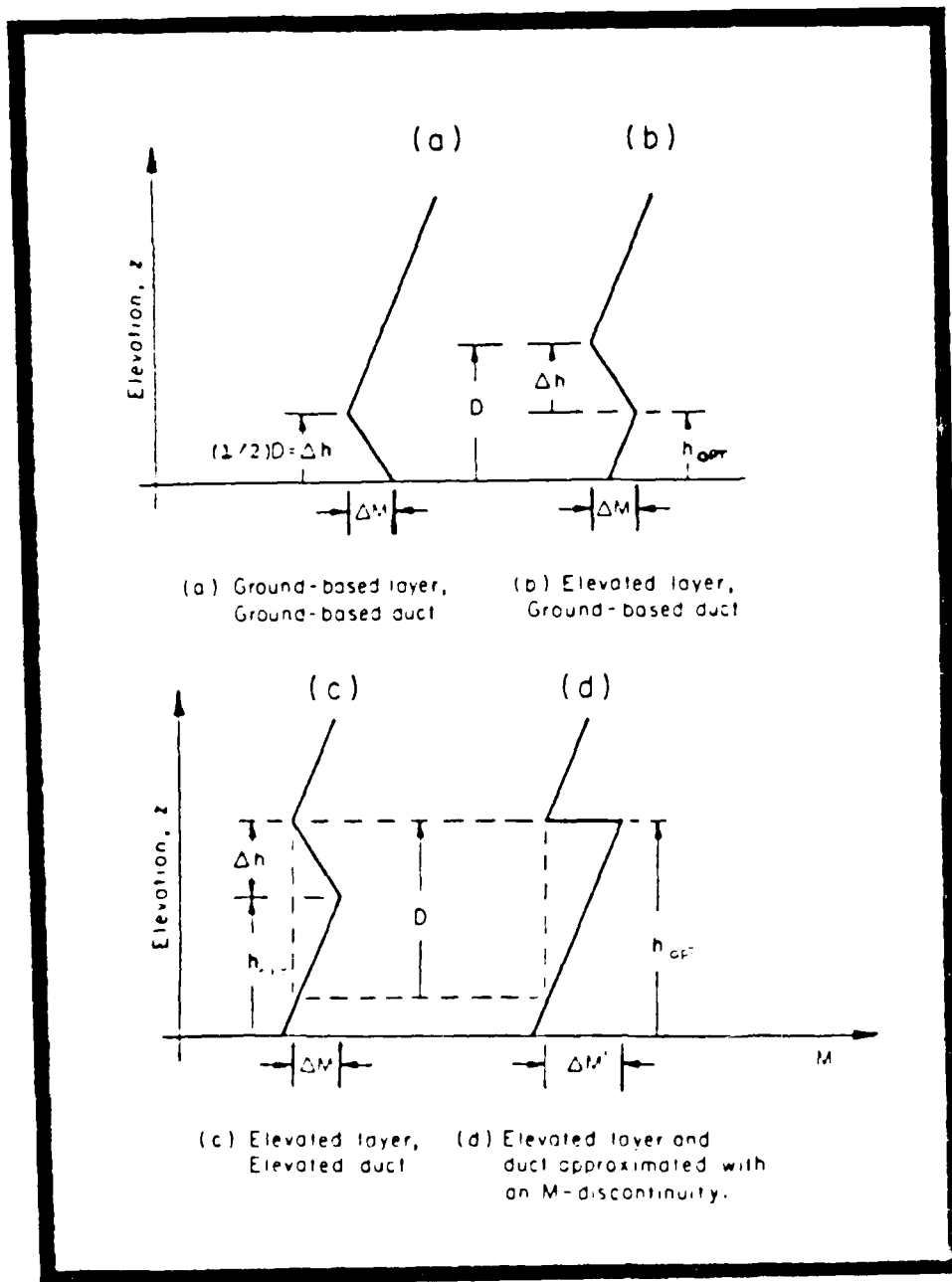


Figure 2-2 Tropospheric Duct Descriptions  
 (After Marcus, Ref. 7:p. 2-5)

form when warm dry air is blown over cold ground. Radiation cooling can produce temperature gradients which cause ground-based ducts. Air next to the ground becomes cooler and the duct becomes thicker as the night continues.

When morning solar heating warms the air next to the ground, a region of rapid decrease of refractive index with height produces an elevated duct. However these ducts quickly disappear because continued ground heating increases convection mixing and destroys the stable elevated layer. Elevated ducts may form for several days by a subsidence inversion. Hot air rises at the center of a high pressure region and spreads out horizontally, cooling as it slowly descends. This produces a boundary with the slightly colder air near the surface. The increasing temperature with height at the boundary forms the subsidence (temperature) inversion. Changes in temperature and/or humidity may cause related changes in the refractive index within the boundary interval [Ref. 11:pp. 33-35].

Figures 2-3a thru d illustrate propagating rays within ground-based ducts. Rays leaving the transmitter at elevation angles close to the horizontal will parallel the earth's surface, while other departing rays will

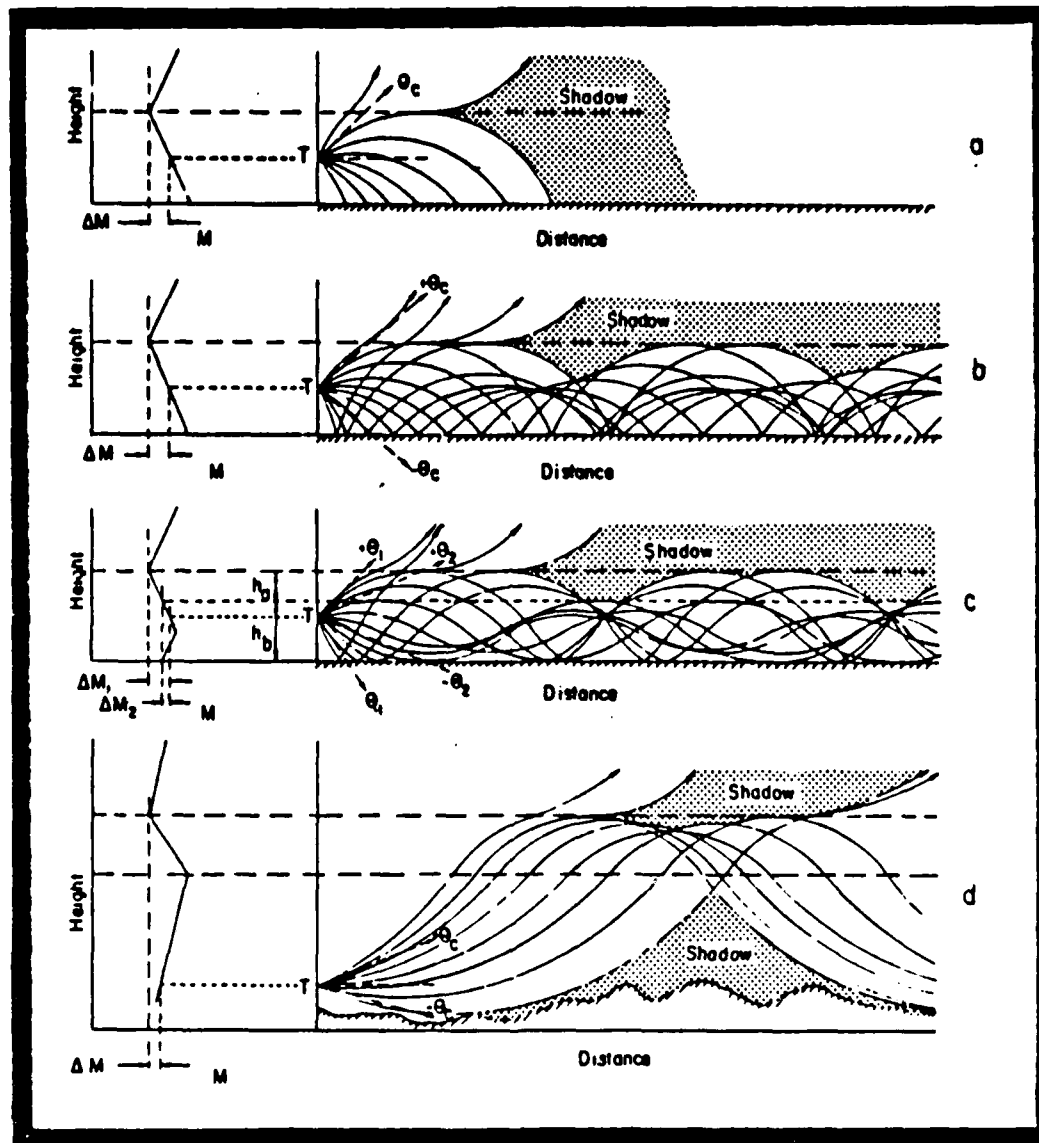


Figure 2-3 Propagation Effects of Ducts  
 (After Hall, Ref. 9:p. 31)

either travel upward or downward. If the M-gradient is negative and assumed uniform within the duct, rays beginning at elevation angles below the critical angle, defined as [Ref. 11:p. 31]:

$$\theta_c = \sqrt{(2 \Delta M \times 10^{-6})} \quad (2-5)$$

will strike the surface, and those above the critical angle will leave the duct. If ground reflection is neglected, Figure 2-3a, a shadow region depicts minimum propagated energy. In the case where surface reflectivity is high, Figure 2-3b, the rays launched within the critical angle range will travel beyond the radio horizon. Figure 2-3c describes the situation when the M-gradient is not constant within the duct. If a transmitter is positioned in the height region  $h$ , then rays within the  $\pm \theta_1 = \pm \sqrt{(2 \Delta M_1 \times 10^{-6})}$  range <sup>a</sup> will remain in the duct with bounces as depicted in Figure 2-3b. Similarly rays transmitted within the  $\pm \theta_2 = \pm \sqrt{(2 \Delta M_2 \times 10^{-6})}$  range are trapped within the height range  $h$ . Finally a surface-based duct from an elevated layer <sup>b</sup> over rough terrain is illustrated in Figure 2-3d. In this case the refractive "bending" takes place at the top of the duct [Ref. 11:pp. 30-32].

For elevated ducts formed by advection or subsidence, the position of the transmitter and receiver relative to the optimum coupling height,  $H_{opt}$ , will influence the propagation effects. The means in which energy enters or leaves an elevated duct can be described by the duct acting as a "leaky" waveguide. Energy is "leaked" or coupled into the duct from the transmitter, and "leaks" out as the energy propagates along the duct [Ref. 11:p. 36].

Because of the non-permanent characteristic of elevated ducts, their effects are seldom an influence to troposcatter links, especially if they form above the common scatter volume. But the presence of tropospheric ducts can degrade the overall performance of troposcatter systems by changing the predicted transmission loss. The term that will change the total path loss is the duct's height gain, which is derived in Chapter IV.

#### C. MULTIPATH CONSIDERATIONS

The multipath fading model for a tropospheric scatter channel produces received signal fading. The received signal consists of the sum of a large number of time-variant, complex vectors having amplitudes and phases. The fading is caused by randomly time-variant



phases variations. At times the received signal vectors add destructively to decrease the mean received signal amplitude. While at other times, the vectors add constructively, so the received signal is large. Thus the amplitude variations, or signal fading, are due to the multipath characteristics of the tropospheric channel. The channel can be modeled as a zero mean, complex-valued gaussian process, with the envelope of the instantaneous signal level being Rayleigh-distributed. This Rayleigh fading channel describes the short-term fading. When there are fixed constant regions of refractivity or stratified refractive layers in the vicinity of the common scatter volume the channel cannot be modeled as having a zero mean. In this case, the Rayleigh distribution does not apply and the channel approaches a Rice distribution [Ref. 14:pp. 456-458]. All performance predictions in this study will assume Rayleigh "short-term" fading as the channel model.

Channel performance will be degraded during periods of severe multipath fading. With digital systems, the voice user is unaware of any increase in background noise until the PCM (Pulse Code Modulation) outage threshold is broken. Once this threshold is passed the complete multichannel circuit will be unusable due to noise. The

characteristics of fade outages for a typical digital troposcatter circuit can experience three (3) primary categories of fade outage. The first category occurs when the voice user is subjected to a single fade outage of duration less than 200 milliseconds. This outage will be hardly noticed. The second category of outage will have an outage duration ranging from 1/5 second to 5 seconds. The user will detect this distortion but will continue to communicate following the outage. When a recurrence of short duration outages take place (e.g. 2 to 4 outages per minute) annoyance rather than total disruption will occur. The third category are fade outages that exceed a subjective level of user patience. The Defense Communications Agency (DCA) [Ref. 15] has specified five (5) ranges of fade outage conditions, refer to Table I. DCA has defined the fade outage in terms of a diversity signal-to-noise ratio threshold corresponding to a  $10^{-4}$  bit error probability.

Techniques used to counter multipath propagation are frequency diversity, space diversity, amplitude equalization, and channel equalization. If a modulated signal is simultaneously transmitted over the same troposcatter radiolink on two or more frequencies, the correlation between the individual received signals will

TABLE I  
 VOICE PERFORMANCE CHARACTERISTICS  
 FOR  
 DCS TROPOSCATTER LINKS

| Outage Range | Criteria                   | Outage Probability   |
|--------------|----------------------------|----------------------|
| I            | See Note                   | See Note<br>-4       |
| II           | 0.2 sec. < Outage < 5 sec. | $7.5 \times 10^{-5}$ |
| III          | 5 sec. < Outage < 1 min.   | $7.5 \times 10^{-3}$ |
| IV           | 2 < Outages/min. < 5       | $2.5 \times 10^{-4}$ |
| V            | 5 < Outages/min.           | $1.0 \times 10^{-4}$ |

NOTE:

| Range | Voice Performance Description                                       |
|-------|---|
| I     | Outages with adequate fade margin.                                  |
| II    | Outages with adequate fade margin and high frequency of occurrence. |
| III   | Call disruption possible.   |
| IV    | Marginal fade margin.   |
| V     | Unavailability of circuit.  |

be small. This method of signal diversity is called frequency diversity. The important advantage of frequency diversity is that it requires a single antenna at each site. But the need for additional frequencies can increase the probability of co-channel interference among other operating transmitters.

Uncorrelated short-term fading can also be achieved by separating the receiving antennas in space. This is known as space diversity. Horizontal and vertical polarization can be used to distinguish between two space-separated signals. However horizontal and vertical polarization do not provide a satisfactory degree of noncorrelation of signal fading for efficient diversity.

The multiplicity of signals provided by these diversity methods must be combined. The diversity-combining techniques are classified into: (1) selection or switching; (2) combining a desirable weighted combination of received available signals; and (3) a combination of selection and combining.

In the selection techniques the diversity channels are scanned until one is found whose level exceeds a selected threshold. This may not necessarily select the best available signal. In the combining techniques, all

diversity channels are simultaneously monitored and equally weighted. This is called equal-gain combining. In maximal-ratio combining, the weighting factor of each channel is automatically adjusted to yeild the maximum signal-to-noise ratio for the total of all the diversity channels [Ref. 12:pp. 453-454].

Amplitude equalizers are designed to properly equalize the propagation channel for minimum phase fading. Channel equalizers balance the channel for amplitude and mutlipath delay distrotion. They are typically adaptive transversal equalizers that consist of tapped delay lines (TDL) with tap-weight multipliers (i.e., amplifiers or attenuators); and control circuitry that adaptively vary the tap-weights in response to temporal channel variations [Ref. 16:p. 11-12].

### III. TROPOSCATTER SYSTEM DESIGN PROGRAM

#### A. GENERAL PROGRAM ALGORITHM

The main program, named "TROPO", is presented as Appendix B. Figure 3-1 illustrates the program flow and the primary computational program modules. The program development and mathematical approach for the Radiosonde Data Analysis and Height Gain modules are described in Chapter IV. The remaining modules are formulated in this chapter. A program tutorial and compilation instructions are contained within the program.

#### B. PREDICTION OF PATH LOSS

##### 1. General

The basic median transmission loss will be the sum of several additive losses, expressed in decibels, [Ref. 17]:

$$L_T = L_s + L_d + L_c + L_a + L_w - G_t - G_r + HG \quad (3-1)$$

where  $L_s$  = free-space propagation/scatter loss (dB)  
 $L_d$  = knife-edge diffraction loss (dB)

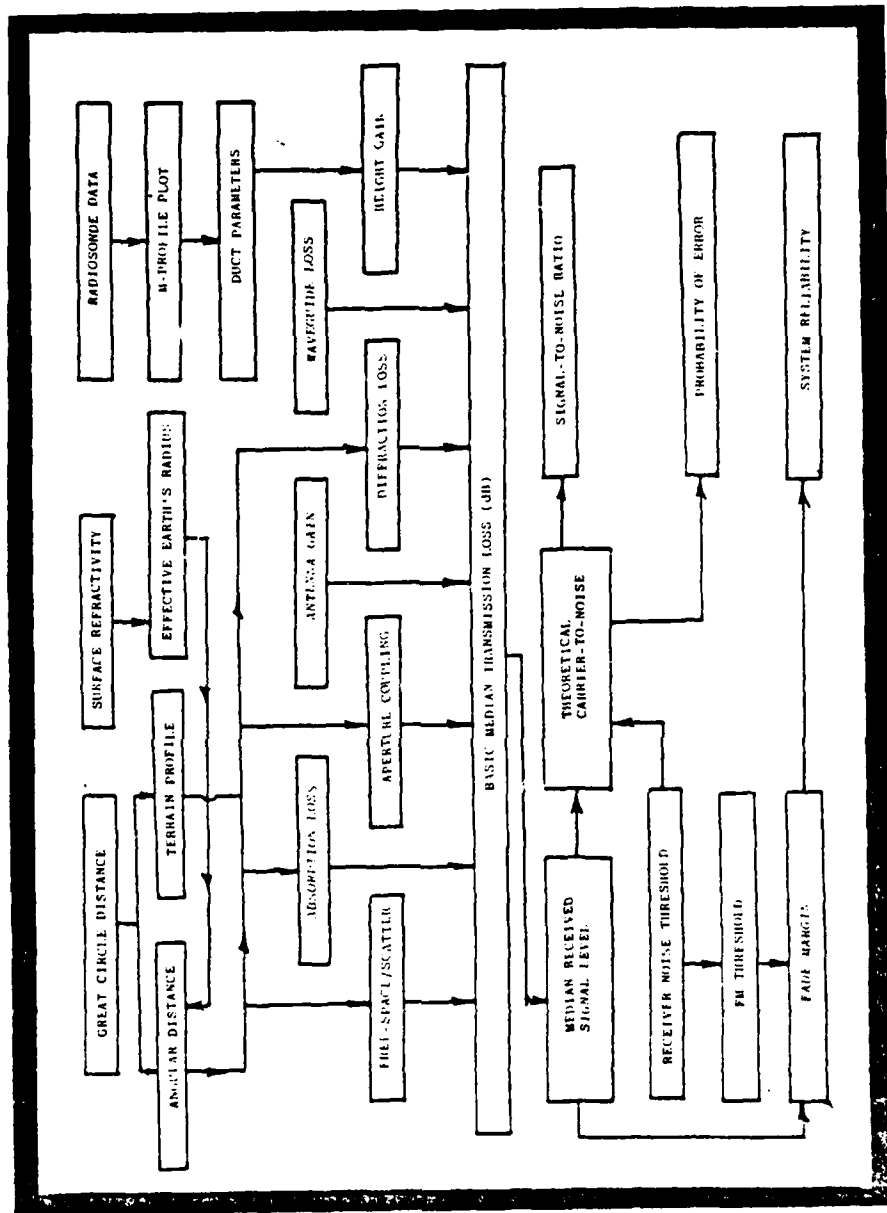


Figure 3-1 Program "TROFO" Module Block Diagram

$L_c$  = medium-to-aperture coupling loss (dB)  
 $L_a$  = atmospheric absorption loss (dB)  
 $L_w$  = waveguide/connector loss (dB)  
 $G_t$  = transmit antenna gain (dB)  
 $G_r$  = receive antenna gain (dB)  
 $HG$  = height gain (dB)

## 2. Surface Refractivity

An adjustment to the average surface refractivity  $N_o$ , refer to Figure 3-2, is made for the elevation at each terminal site. The adjusted surface refractivity,  $N_s$ , is [Ref. 18:p. 2-12]:

$$N_s = N_o \exp(-0.03222h_s) \quad (3-2)$$

where  $N_o$  = minimum monthly average refractivity  
 $h_s$  = average antenna height (kft)

If the surface refractivity at each site is significantly different, an option to calculate the respective  $N_s$  for each site can be selected and an average path surface refractivity can be calculated. The average antenna height is calculated by averaging the transmit and receive antenna heights.



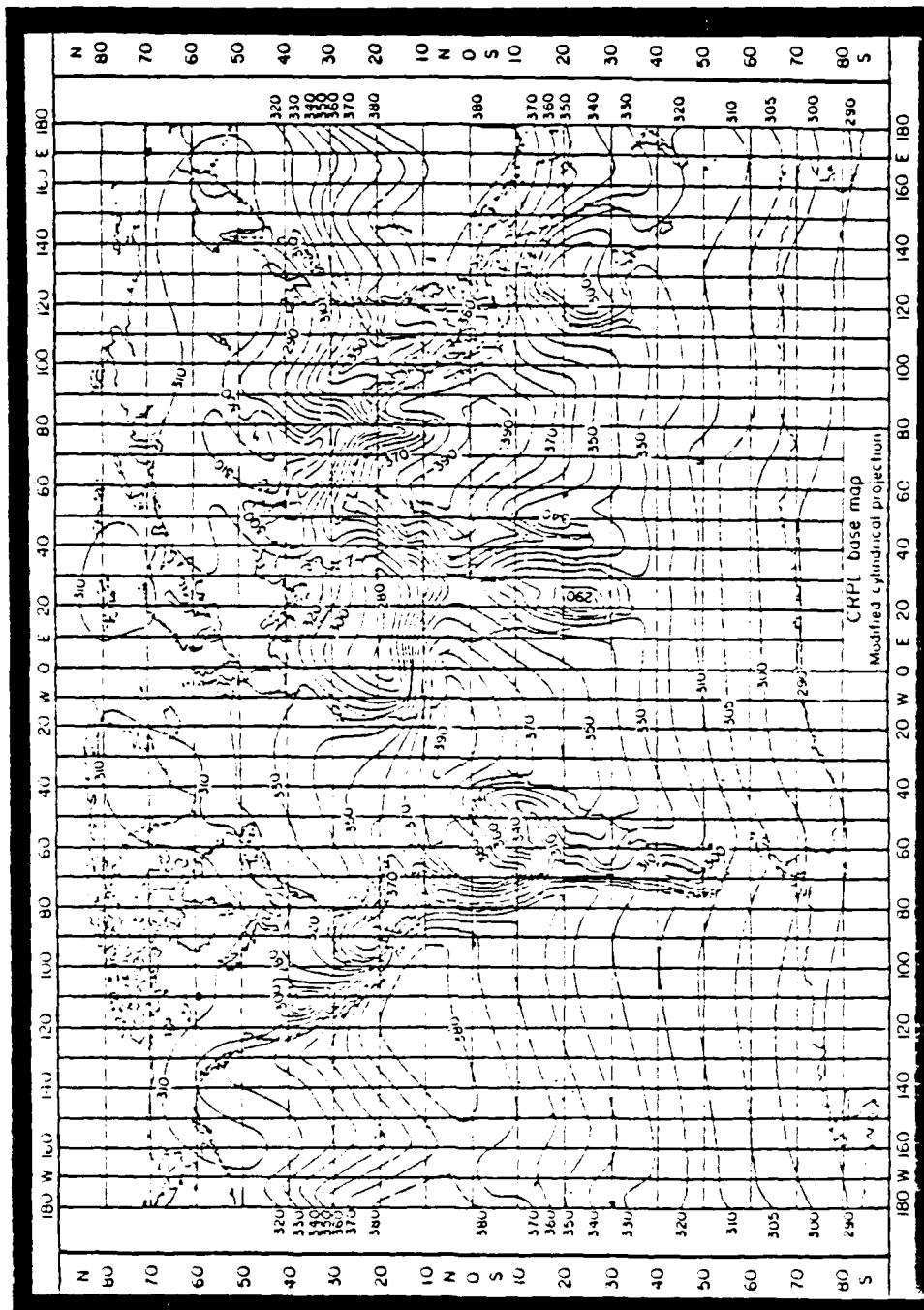


Figure 3-2 Monthly Surface Refractivity (Sea Level)

(After Panter, Ref. 12:p. 375)

### 3. Effective Earth's Radius

Changes in the surface refractivity will effect the radio-ray path curvature as the wave propagates over the earth. To accurately represent the ray-path an effective earth's radius is calculated as [Ref. 12:p. 374]:

$$a = a_o \left[ 1 - 0.04665 \exp(0.005577N_s) \right]^{-1} \quad (3-3)$$

where  $a_o$  = actual earth's radius (6370 km)

### 4. Terrain Profile Plot

Several methods are available to plot a troposcatter system terrain profile. The most fundamental method is to plot the successive path terrain elevations along the great circle path. Special 4/3 earth plotting graph paper is required for this method. Alternatively, computer graphics techniques which obtain terrain information from topographical databases, can rapidly plot the profile.

The program provides a dot-matrix printer plot. The terrain profile is linearly plotted by modifying the terrain elevations, in meters, to include the effect of

the average curvature of the radio-ray path and the earth's surface. Elevations,  $h_i$ , of the terrain are manually obtained from topographical maps and tabulated versus distances,  $x_i$ , from a selected reference terminal. The terrain data points are keyboard entered into the program. The modified elevations are computed as [Ref. 12:p.380]:

$$y_i = h_i - \frac{x_i^2}{2a} \quad (3-4)$$

where  $a$  = effective earth's radius (Equation 3-3)

Figure 3-3 illustrates a typical linear terrain plot.

#### 5. Calculation of the Angular Distance

The terrain profile can now determine various path geometries. The three (3) path configurations considered are:

- a. Smooth Earth Horizons at Both Terminals
- b. Obstacle Horizons at Each Terminal
- c. Smooth Earth and Obstacle Horizons

The terrain geometries are depicted in Figure(s) 3-4a, 3-4b, and 3-4c. The respective terminal take-off angles are calculated for the predicted path type as [Ref. 12:pp. 385-337]:

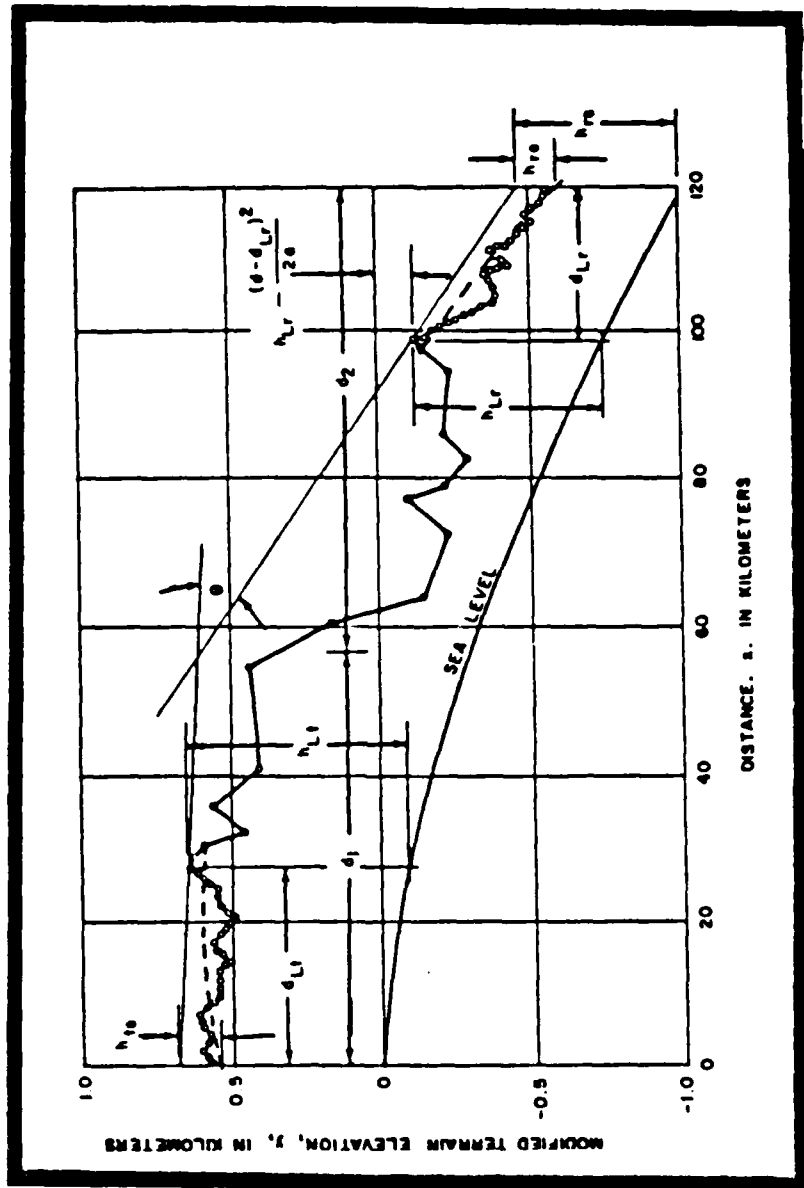


Figure 3-3 Linear Terrain Profile Plot Example  
 (After Panter, Ref. 12:p. 382)

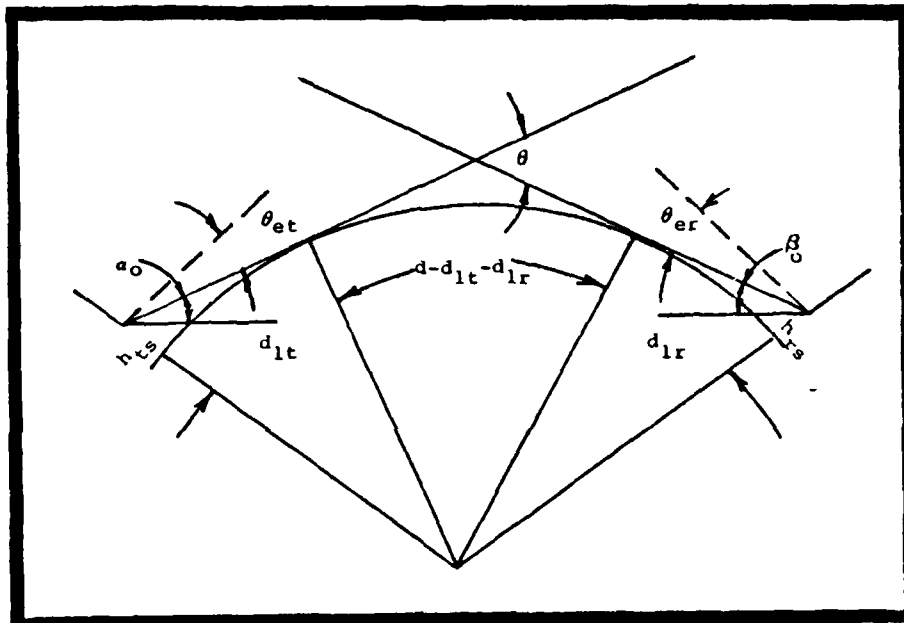


Figure 3-4a Smooth Earth Path  
 (After Panter, Ref. 12:p. 385)

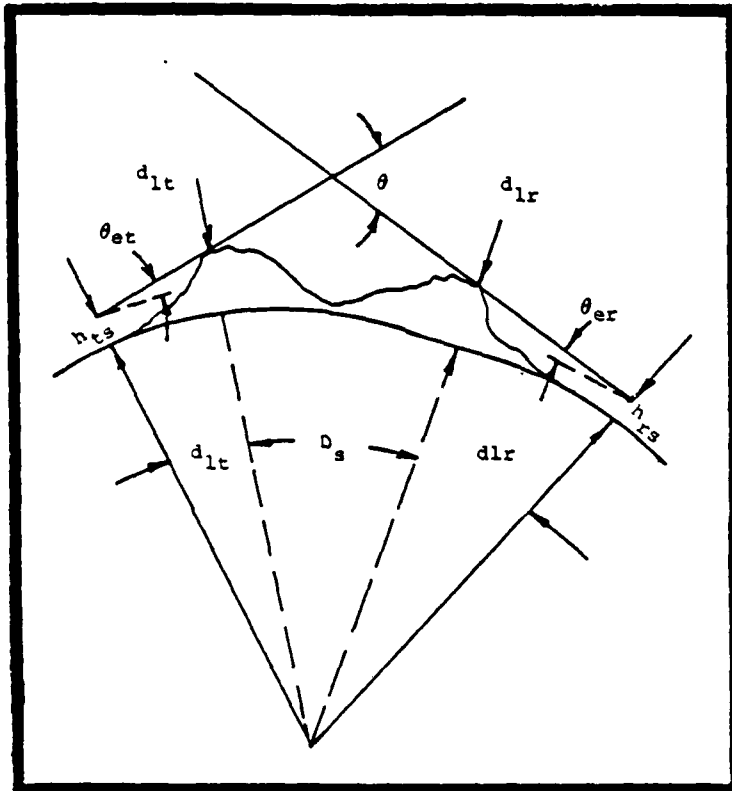


Figure 3-4b Near Obstacle Path  
 (After Panter, Ref. 12:p. 386)

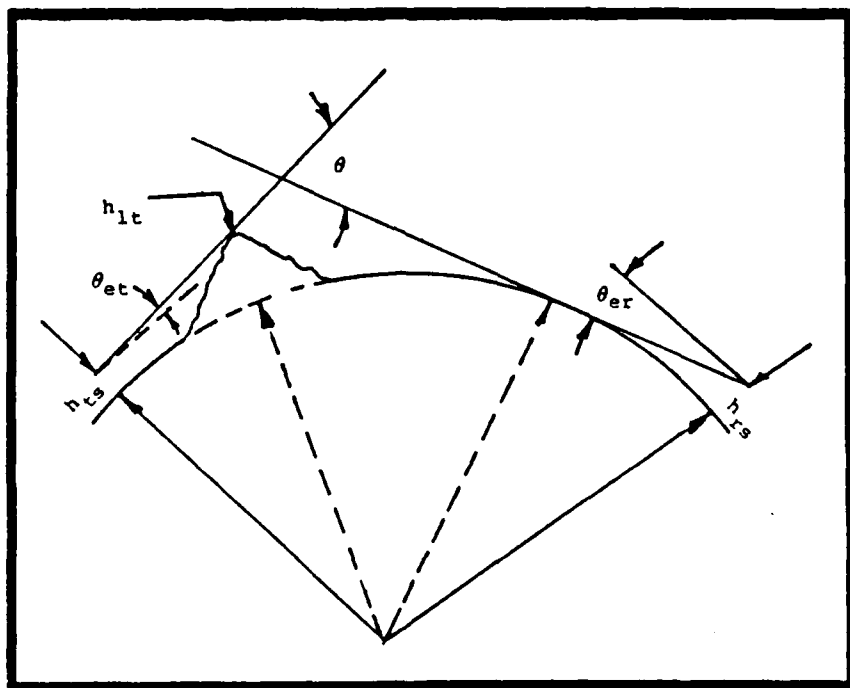


Figure 3-4c Near Obstacle/Smooth Earth Path  
 (After Panter, Ref. 12:p. 385)

a. Type I Radio Horizon/Radio Horizon

$$\theta_{et} = - \frac{\sqrt{2ah_{ts}}}{a} \quad (3-5a)$$

$$\theta_{er} = - \frac{\sqrt{2ah_{rs}}}{a} \quad (3-5b)$$

where  $h_{ts}$ ,  $h_{rs}$  = transmitter, receiver terminal elevation

b. Type II Obstacle Horizon/Obstacle Horizon

$$\theta_{et} = \frac{h_{lt} - h_{ts}}{d_{lt}} - \frac{d_{lt}}{2a} \quad (3-5c)$$

$$\theta_{er} = \frac{h_{lr} - h_{rs}}{d_{lr}} - \frac{d_{lr}}{2a} \quad (3-5d)$$

where  $h_{lt}$ ,  $d_{lt}$  = transmitter obstacle elevation, distance  
 $h_{lr}$ ,  $d_{lr}$  = receiver obstacle elevation, distance

c. Type III Obstacle Horizon/Radio Horizon

$$\theta_{et} = \text{(Same as Equation 3-5c)}$$

$$\theta_{er} = \text{(Same as Equation 3-5b)}$$

The path type combination may be reversed to satisfy a Radio Horizon/Obstacle Horizon configuration. Referring to Figure 3-5, the angles  $\alpha_{oo}$  and  $\beta_{oo}$  are calculated as:



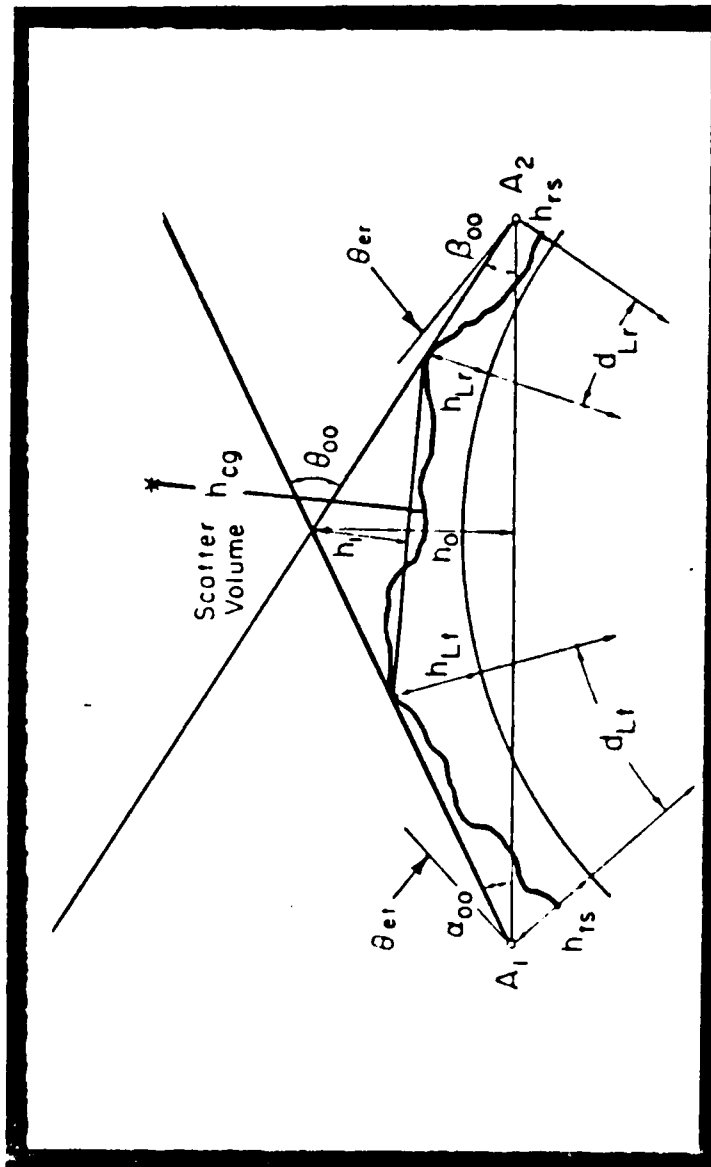


Figure 3-5 Typical Path Geometry  
 (After Ref. 18:p.8-6)

$$\alpha_{oo} = \frac{d}{2a} + \frac{h_{ts} - h_{rs}}{d} + \theta_{et} \quad (3-5e)$$

$$\beta_{oo} = \frac{d}{2a} + \frac{h_{rs} - h_{ts}}{d} + \theta_{er} \quad (3-5f)$$

These angles are modified by correction factors,  $\Delta\alpha_o$  and  $\Delta\beta_o$  to allow for the effects of a non-linear refractivity gradient [Ref. 12:p. 383]. The correction factors can be obtained from Appendix A, Figure A-7, however for most transhorizon, "over the horizon", paths these factors are negligible.

The angular distance (often called scatter angle) is:

$$\theta = \alpha_{oo} + \Delta\alpha_o + \beta_{oo} + \Delta\beta_o \quad (3-5g)$$

The ratio  $\alpha_{oo}$  and  $\beta_{oo}$  defines the path symmetry factor [Ref. 18:p. 4-7]:

$$S = \frac{\alpha_{oo}}{\beta_{oo}} \quad (3-5h)$$

The following equation will calculate the height of the intersection point of the transmit and receive antenna beams. This result will estimate the bottom of the common scatter volume (Refer to Figure 3-6) as

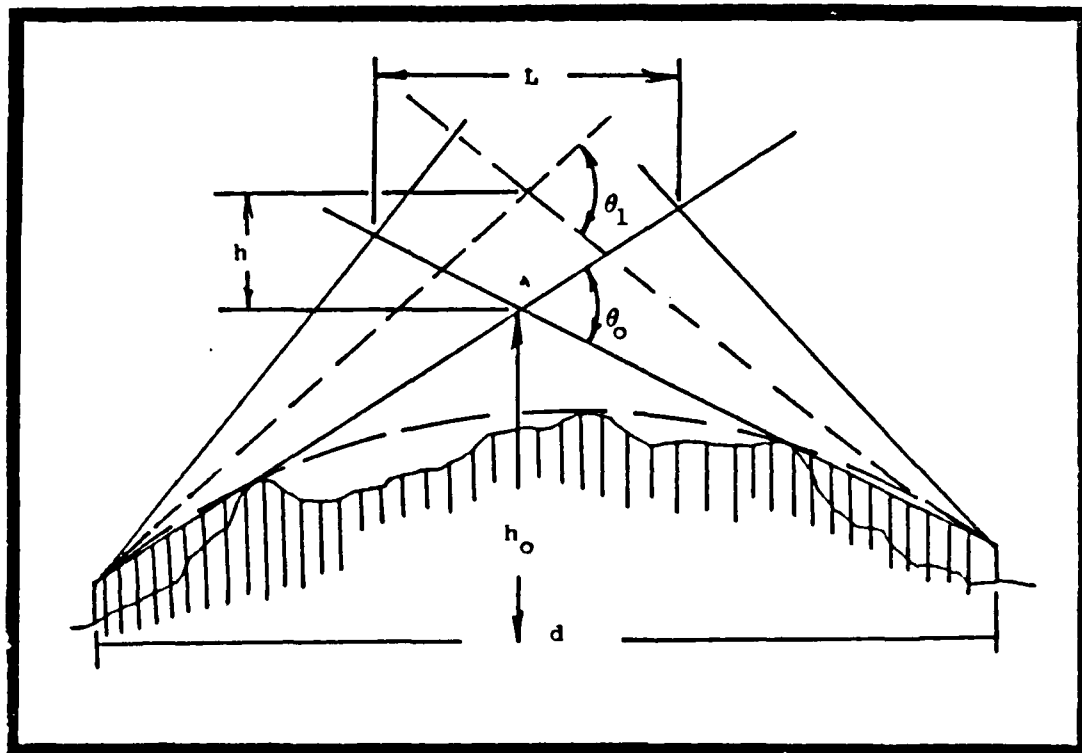


Figure 3-6 Common Scatter Volume Dimension  
(After Du Castel, Ref. 19:p. 145)

[Ref. 18:p. 8-8]:

$$h_o = \frac{s d \theta}{(1 + s)^2} \quad (3-5i)$$

where S = symmetry factor

Du Castel, [Ref. 19:p 146], approximates the dimensions of a typical common scatter volume. The volume height is:

$$H = 2h_o \frac{\theta_1 - \theta_o}{\theta_o} \doteq 0.3h_o \quad (3-5j)$$

where  $\theta_1 = 1.15\theta_o$

$\theta_o$  = scatter angle

The maximum longitudinal dimension, L, is:

$$L = \frac{d H}{2 h_o} \doteq 0.15d \quad (3-5k)$$

where d = great circle path distance (m)

The center of gravity of the scatter volume is approximated as:

$$H_{cg} \doteq h_o + 2/3H \quad (3-5l)$$

## 6. Diffraction Loss

Propagation paths having a common obstacle horizon, such as a mountain ridge, can be referred to as an obstacle gain path. It is assumed that the obstacle will introduce additional path attenuation. However, the angular distance may be reduced because of the changed path geometry from the obstacle. The possible reduction in the scatter loss may be offset by the increased loss due to diffraction over the obstacle. In some situations the common obstacle may be visible to both terminals, and the path loss might be less than the smooth earth path loss. The International Radio Consultative Committee (C.C.I.R.) has developed the following formula for diffraction loss relative to free-space [Ref. 20:p. 170]:

$$L_d = 20 \log_{10} \left[ \sqrt{2\pi} \sqrt{\frac{2(d_a + d_b) \tan \theta_{et} \tan \theta_{er}}{\lambda}} \right] \quad (3-6a)$$

where  $d_a$  = transmitter to obstacle distance (m)

$d_b$  = receiver to obstacle distance (m)

When the take-off angles are less than 10 degrees and

$d_a$  is greater than  $2d_b$  then Equation 3-6a can be approximated by:

$$L_d \doteq 20 \log_{10} \left[ 2\pi\theta \sqrt{\frac{d_a}{\lambda}} \right] \quad (3-6b)$$

### 7. Worst-Hour Loss

Seasonal annual-to-worst month path loss variations can be determined from a knowledge of the annual changes in surface refractivity of the atmosphere over the path. The C.C.I.R. recommends a loss variation of 0.2 dB (U.S.) and 0.5 dB (Europe) per unit change of refractive index.

The worst-hour median loss can be derived by assuming a log-normal distribution during the month. It was shown by Panter, [Ref. 12:p. 401], that on a log-normal distribution, the 99.9 percent point can be approximated by the value  $3.1\sigma$  in decibels below the median, where  $\sigma$  is the standard deviation of the log-normal distribution. The worst-hour median loss can be determined as:

$$\begin{aligned} \text{Worst-Hour Median Loss} &= \text{Median Annual Path Loss} \\ &+ \text{Difference of Annual-to-Worst-Month Median Loss} \\ &+ 3.1 \sigma_{wm} \end{aligned}$$

where  $\sigma_{wm}$  = standard deviation of the worst-month

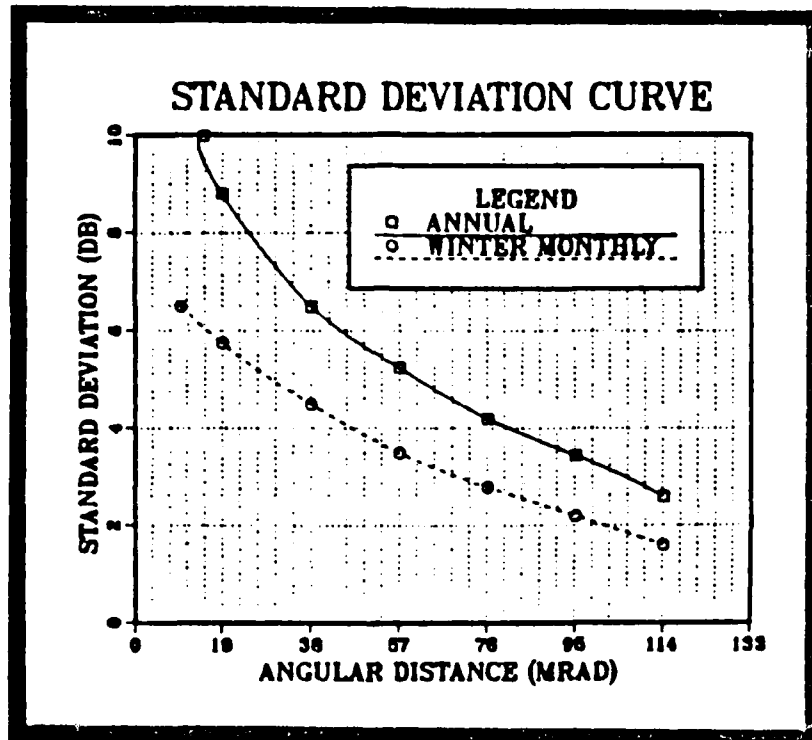


Figure 3-7 Annual and Winter Monthly Standard Deviation  
 (After Panter, Ref. 12:p. 359)

distribution obtained from Figure 3-7.

#### 8. Aperture-to-Medium Coupling Loss

The parabolic reflector microwave antenna gain equation, [Ref. 12:p. 103], can be expressed in decibels as:

$$G = 20\log_{10} f + 20\log_{10} D - 52.6 \text{ dB} \quad (3-7)$$

where  $D$  = aperture diameter (feet)

An illumination factor of 0.54 was assumed to derive Equation 3-7. It would appear that Equation 3-7 depicts an ever increasing power gain as the antenna aperture area increases. However the power received by an antenna does not increase linearly with an increase in antenna diameter,  $D$ . This effect is called aperture-to-medium coupling loss or loss in antenna gain [Ref. 12:p. 362].

Aperture coupling loss in troposcatter systems is caused by a non-planar wavefront due to atmospheric irregularities, and a geometric effect due to the decrease in the scattering properties with height inside the scatter volume. An incoming wavefront consists of many plane waves, each arriving at a different angle from the scatter volume. If the arrival angle range variation



is much smaller than the antenna beamwidth the wavefront will appear nearly plane. If the common volume is much wider than the receiving antenna's beamwidth a wider angle range will result, and the wavefront will appear non-planar.

Basically, coupling loss can be explained as limited antenna pickup, as compared to the effective scatter volume dimensions and the antenna 3 dB beamwidth. Figure 3-8 compares aperture coupling loss results between several authors. A unique constant curve is presented by the C.C.I.R. [Ref. 21:p. 145]. This curve is independent of the scatter angle and is written as:

$$L_c = 0.07 \exp \left[ 0.055 (G_T + G_R) \right] \quad (3-8)$$

where  $G_T, G_R$  = transmit, receive antenna gain (dB)

This empirical formula gives a high coupling loss and will not be used in the program. The proposed empirical curve appears as the average of several different formulas and will be used as a conservative estimate for the aperture coupling loss.

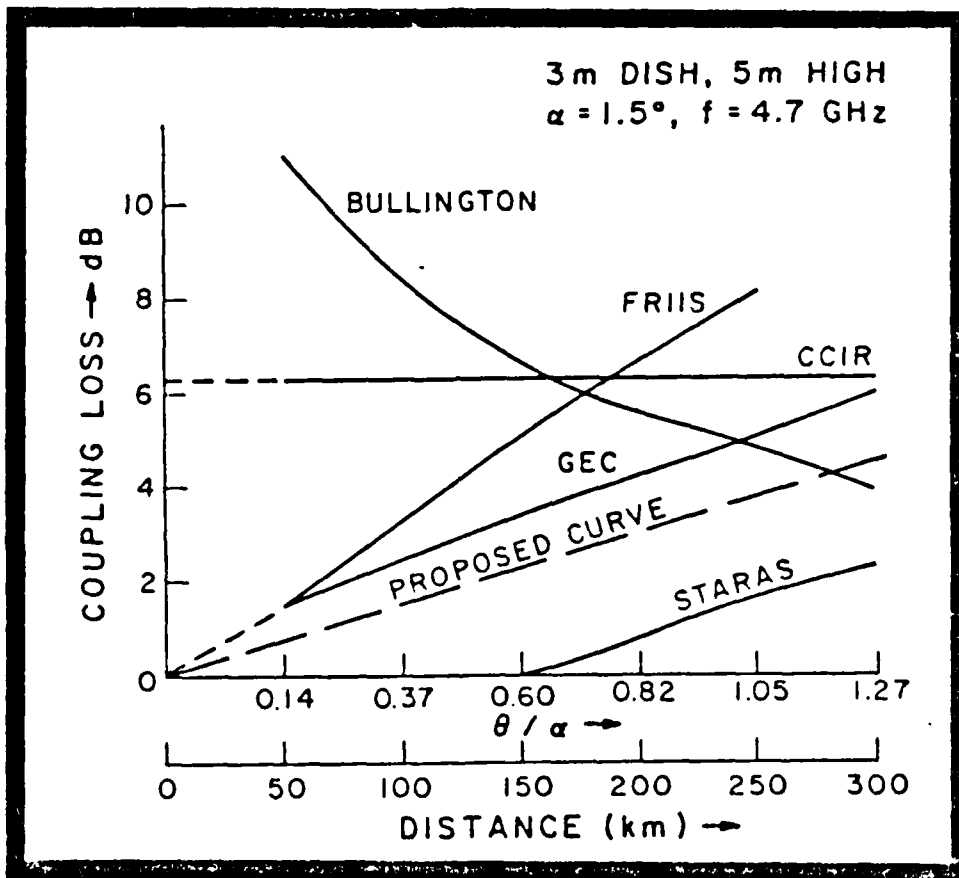


Figure 3-8 Aperture-to-Medium Coupling Loss  
 (After Levin, Ref. 21)

#### 9. Combined Free-Space/Scatter Loss

Yeh, [Ref. 22], has derived the following formula to calculate the combined free-space and scatter loss, in decibels:

$$L_s = 30 \log_{10} f + 20 \log_{10} d + 10\theta + 0.2(N_s - 310) + 57 \quad (3-9)$$

where  $f$  = operating frequency (MHz)

$d$  = great circle path distance (miles)

$\theta$  = scatter angle (degrees)

$N_s$  = surface refractivity

#### 10. Waveguide/Connector Loss

The waveguide attenuation factor was derived for standard rigid waveguide. At an operating frequency of 4.5 GHz the waveguide loss will be approximately 1.25 dB per 100 feet [Ref. 18:p. 7-14]. Each waveguide connection will introduce an additional 0.06 dB per joint [Ref. 1:p. 210].

#### 11. Absorption Loss

Rainfall, snowfall, and fog produce atmospheric absorption loss which depends on the amount of moisture and on the frequency. Figure 3-9 was used to

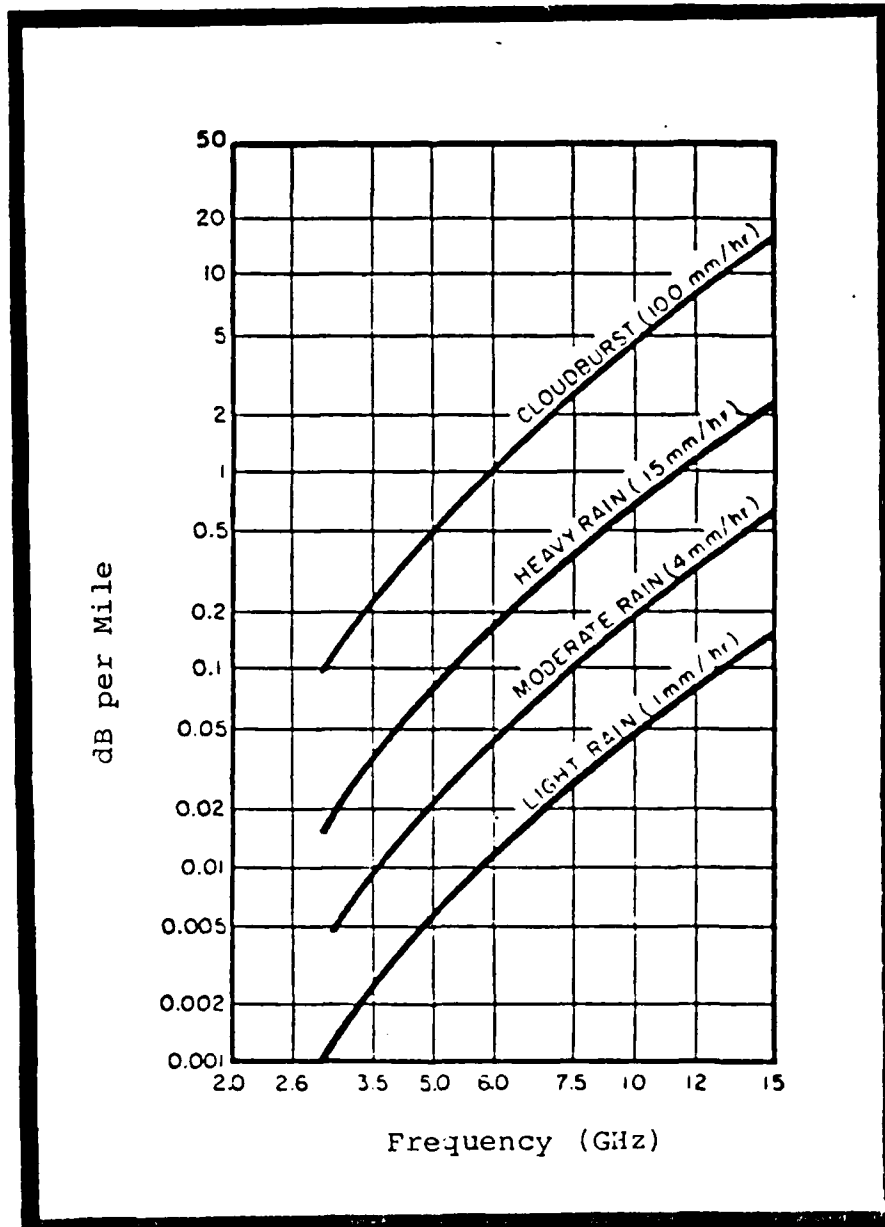


Figure 3-9 Estimated Atmospheric Absorption  
 (After Ref. 18:p. 2-43)

estimate the rainfall attenuation on a particular transmission path at four (4) rainfall rates [Ref. 18:p.2-43].

### C. DESIGN PARAMETERS

#### 1. Carrier-to-Noise Ratio

The performance of troposcatter communications circuits are determined by the minimum acceptable ratio of hourly median carrier signal to thermal noise for a type of modulated signal. This ratio, expressed in decibels, is called the carrier-to-noise ratio (CNR). The following equation is used to determine the received carrier power level:

$$P_r(\text{dBW}) = P_t(\text{dBW}) - L_T(\text{dB}) \quad (3-10)$$

where  $P_t$  = transmitter power output (dBW)

$L_T$  = total median transmission loss (Equation 3-1)

The receiver noise threshold level is written as:

$$P_n(\text{dBW}) = -204(\text{dBW}) + \text{NF}(\text{dB}) + 10 \log_{10} B_{IF} \quad (3-11)$$

where  $-204 \text{ dBW}$  = thermal noise constant

NF = receiver noise figure (dB)

B = receiver IF bandwidth (Hz)

IF

Finally the carrier-to-noise ratio, [Ref. 10:p. 411],

is:

$$\text{CNR(dB)} = P_r(\text{dBW}) - P_n(\text{dBW}) \quad (3-12)$$

where CNR = carrier-to-noise ratio (dB)

$P_r$  = received power level (dBW)

$P_n$  = receiver thermal noise level (dBW)

## 2. Digital Radio Link Parameters

In digital systems the modem performance is usually plotted versus average bit energy,  $E_b$ , to the receiver noise spectral density,  $N_o$ . The probability of error (often called bit error rate) will be determined from the  $E_b/N_o$  ratio. The transformation of the calculated carrier-to-noise ratio (CNR) to  $E_b/N_o$  is written as [Ref. 23:p. 158]:

$$E_b/N_o = \text{CNR(dB)} + 10 \log_{10} B_w - 10 \log_{10} R \quad (3-13)$$

where  $B_w$  = transmission noise bandwidth (Hz)

R = transmission data rate (bit/sec)

### 3. Propability of Bit Error Calculations

Current military multichannel communications use Pulse Code Modulation/Time Division Multiplexing (PCM/TDM) techniques to transmit digital information over both frequency modulated (FM) and phase modulated (PM) troposcatter carrier systems. The quality of the multiplexed circuits is determined by the number of bit errors that occur because of the channel fading and multipath dispersion. The probability of bit errors can be predicted for different PCM carrier modulation methods. Multiphase signaling and M-ary orthogonal signaling over a Rayleigh fading channel are derived by J. G. Proakis [Ref. 14:pp. 490-499].

The bit error rate (BER) for QPSK (four-phase phase shift keying) and DPSK (differential phase shift keying) is expressed as:

$$P_b = \frac{1}{2} \left[ 1 - \sqrt{\frac{\mu}{2 - \mu^2}} \sum_{k=0}^{L-1} \binom{2k}{k} \left( \frac{1 - \mu^2}{4 - 2\mu^2} \right)^k \right] \quad (3-14)$$

where  $\mu$  = correlation coefficient

$$\mu = \sqrt{\frac{\overline{\gamma_c}}{1 + \overline{\gamma_c}}} \quad (\text{for coherent PSK})$$

$$\mu = \frac{\overline{\gamma}_c}{1 + \overline{\gamma}_c} \quad (\text{for DPSK})$$

where  $\gamma_c$  = average received  $E_b/N_0$  per channel

$\gamma_b$  = average received  $E_b/N_0$  per bit

$$\gamma_b = \frac{L \overline{\gamma}_c}{j}$$

where  $L$  = order of diversity

$j = 1$  (for BPSK signaling)

$j = 2$  (for QPSK signaling)

Bit error probabilities are depicted in Figure 3-10 for two-phase and four-phase DPSK signaling with  $L = 1, 2$  and  $4$ .

Orthogonal signaling may be viewed as  $M$ -ary FSK (Frequency Shift Keying). The expression for the probability of symbol error ( $P_M$ ), derived by Proakis, assuming no diversity ( $L = 1$ ) is:

$$P_M = \sum_{m=1}^{M-1} \frac{(-1)^{m+1} \binom{M-1}{m}}{1 + m + m \overline{\gamma}_c} \quad (3-15)$$

where  $M = 2$  (for BPSK signaling)

$M = 4$  (for QPSK signaling)

The equivalent bit error rate (BER) can be computed using:

$$P_b = \left( \frac{2^{k-1}}{2^k - 1} \right) P_M \quad (3-16)$$



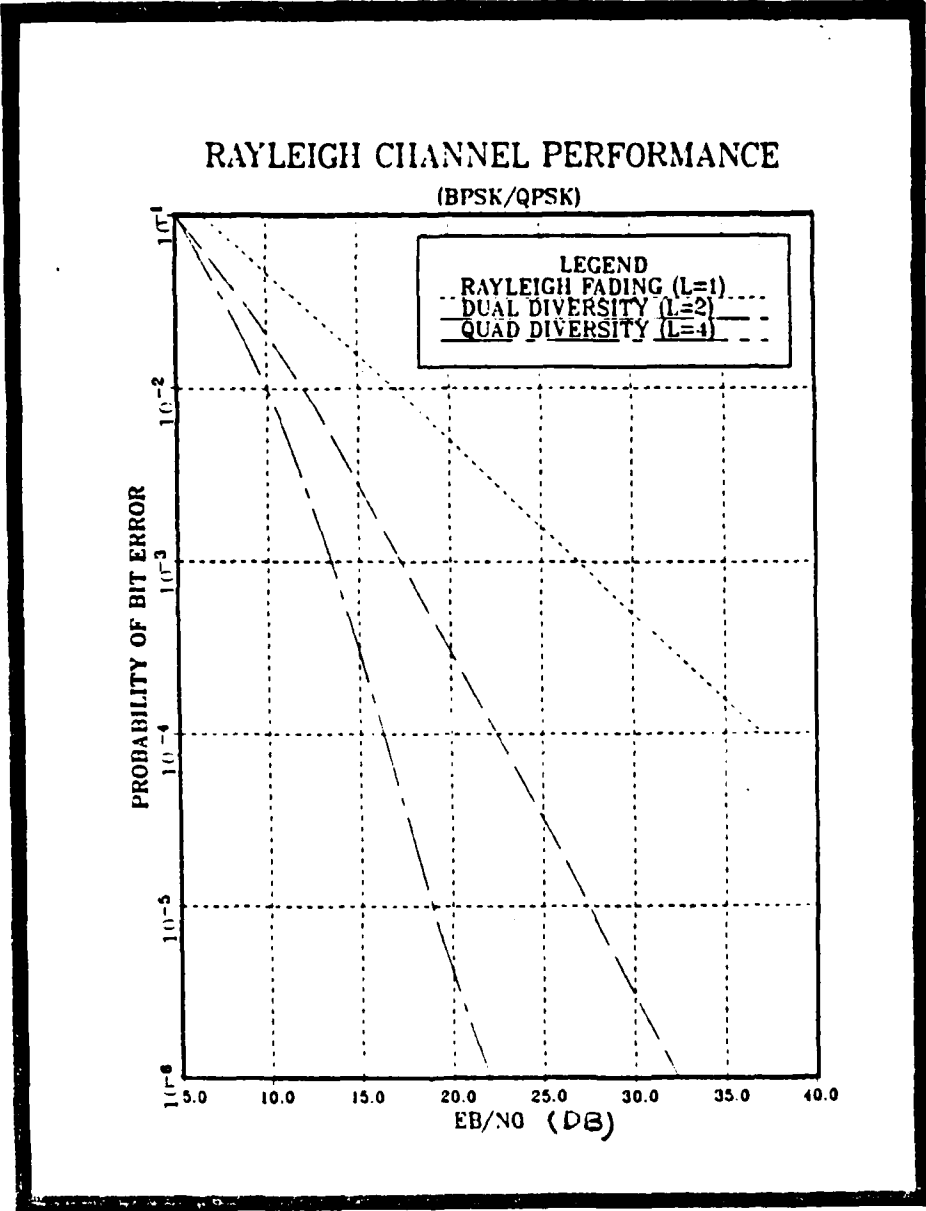


Figure 3-10 Probability of Error (BPSK/QPSK)  
 (After Proakis, Ref. 14:p. 492)

where  $k = \log M$

The graphs of  $P$  versus  $E/N$  for  $M = 2, 4$  and  $L = 1, 2, 4$  are shown in Figure 3-11.

The Distortion Adaptive Receiver [DAR] is currently being used in the military troposcatter digital radio set, AN/TRC-170. Experimental modem performance results are illustrated in the BER versus  $E/N$  curves, Figure(s) 3-12 and 3-13. The results are determined for three (3) different multipath delay values.

Sunde, [Ref. 24:pp. 144-214] has derived a general expression for the maximum differential transmission delay. This equation is valid when the transmitting and receiving antenna beamwidths are different:

$$\delta = \frac{d}{2} \left[ \left( \frac{\theta}{2} + \theta_{et} \right) \left( \frac{\theta}{2} + \theta_{er} \right) - \frac{\theta^2}{4} \right] \quad (3-17a)$$

where  $d$  = path distance (meters)

$\theta$  = scatter angle (mrad)

$\theta_{et}$  = transmitter take-off angle (mrad)

$\theta_{er}$  = receiver take-off angle (mrad)

The time dispersion (multipath spread) relative to the

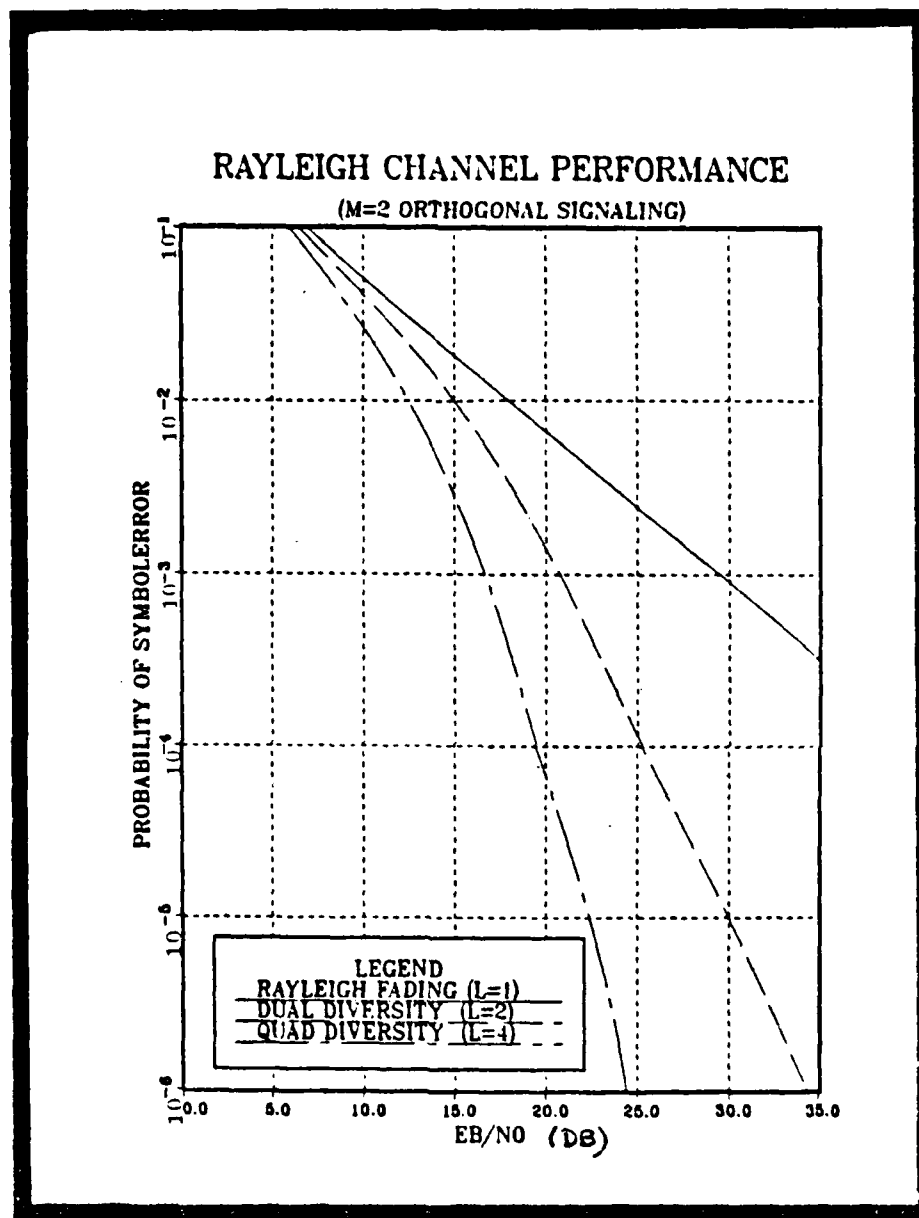


Figure 3-11 Probability of Error (M-ary FSK)

(After Proakis, Ref. 14:p. 499)

### PERFORMANCE OF DUAL PULSE DAR

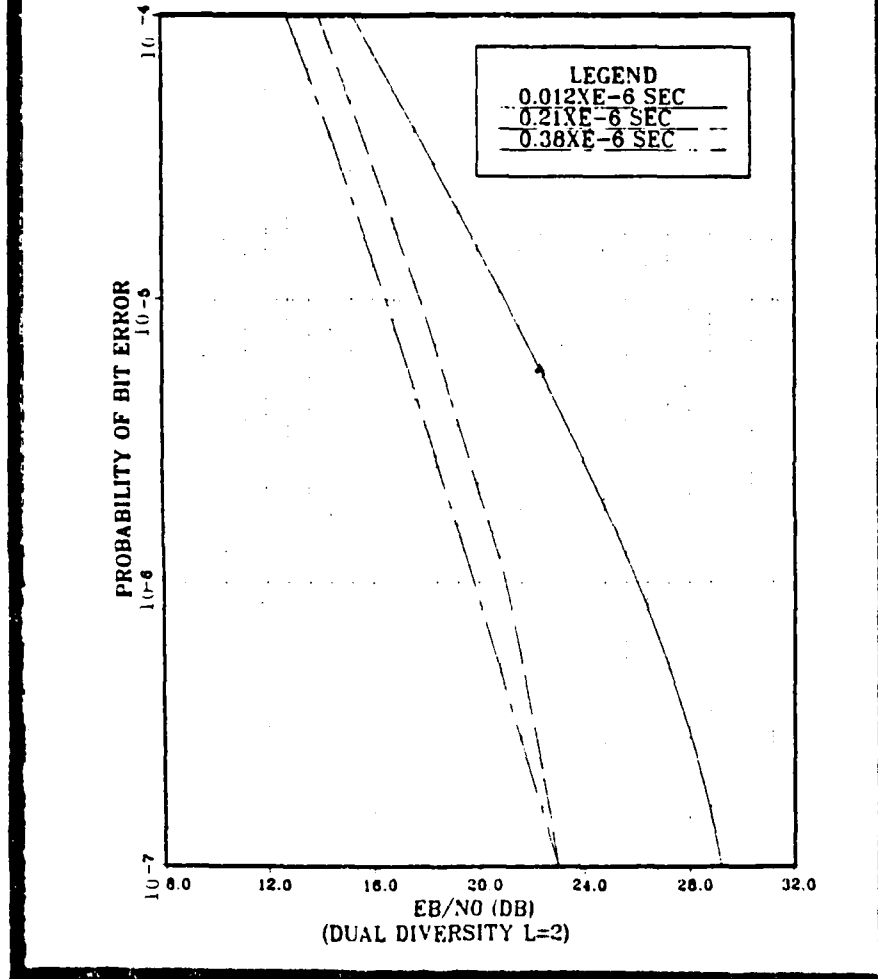


Figure 3-12 DAR Performance - Dual Diversity

(After Zawislán, Ref. 4:p. 4)

### PERFORMANCE OF DUAL PULSE DAR

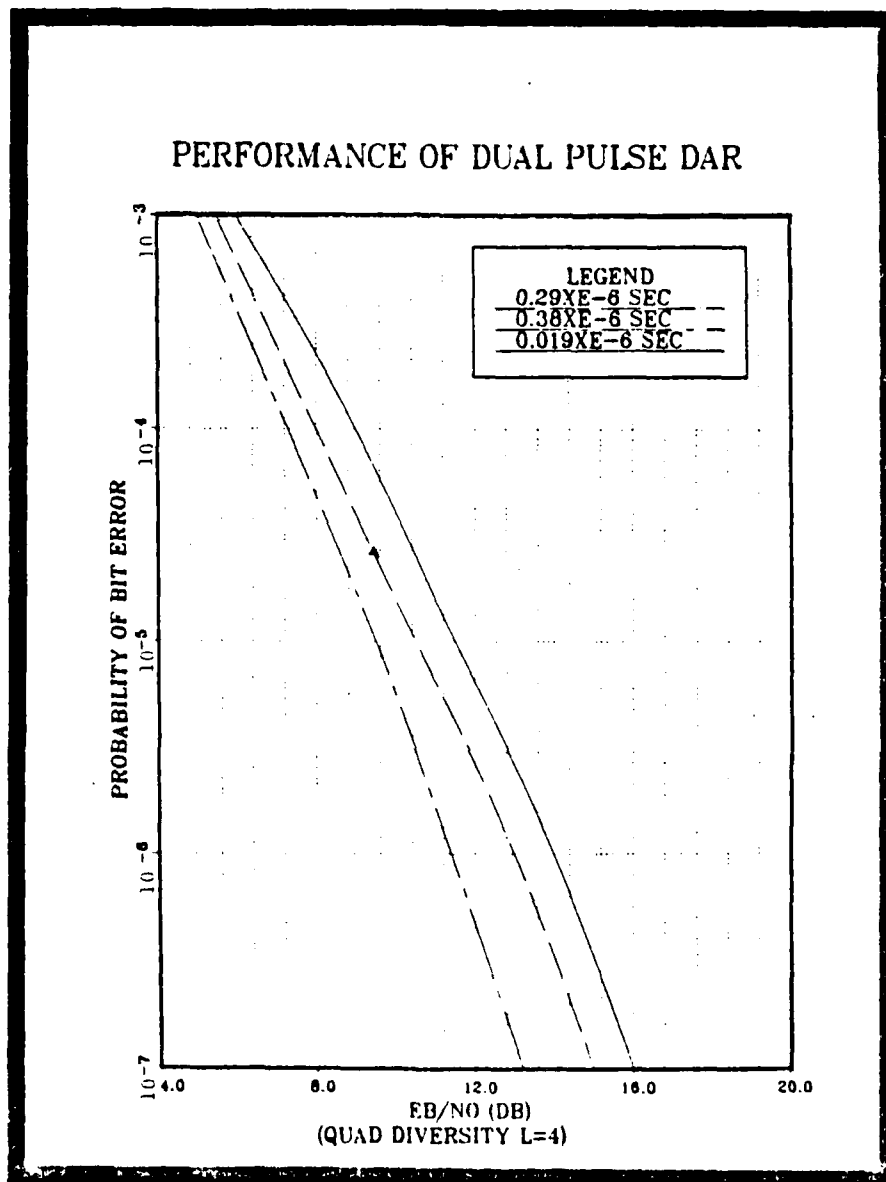


Figure 3-13 DAR Performance - Quad Diversity  
(After Zawislan, Ref. 4:p. 4)

average time delay for unequal antenna beamwidths is:

$$\Delta = \frac{\delta}{2c} = \frac{\delta}{2(3 \times 10^8 \text{ m/s})} \quad (3-17b)$$

where  $c = 3 \times 10^8$  m/sec

In the case of equal transmitting and receiving antenna beamwidths, Equation 3-17b is simplified to:

$$\Delta = \frac{3d\theta^2}{16c} \quad (3-17c)$$

For a particular order of diversity, the probability of error can be computed for the AN/TRC-170 troposcatter radiolink by evaluating a least-squares polynomial equation derived from experimental data curves.

#### 4. Fade Margin and System Reliability

The system fade margin, in decibels, is the difference between the "practical threshold" level and the median received signal level. The propagation reliability values for the worst fading condition, Rayleigh fading, can be compared with their required fade margins in Table II [Ref 1:p. 225]. The "practical threshold", or minimum acceptable received signal level, cannot be below the FM improvement threshold

TABLE II

RAYLEIGH FADING PROPAGATION RELIABILITY

| Single Hop<br>Propagation Reliability<br>(%) | Fade Margin<br>(dB) |
|--|---------------------|
| 90.0   | 8                   |
| 99.0   | 18                  |
| 99.9   | 28                  |
| 99.95  | 33                  |
| 99.99  | 38                  |
| 99.999                                       | 48                  |

[Ref. 25:p. 71]. The fade margin can be evaluated by:

$$\text{Fade (dB)} = P_r(\text{dBm}) - N_p(\text{dBm}) \quad (3-18)$$

where  $N$  = "practical noise threshold"

$$N_p = P_r(\text{dBm}) + \text{FM improvement}$$

$$P_r = -174 \text{ dBm} + 10 \log \frac{B}{10 \text{ IF}} + \text{NF}$$

W. T. Barnett and A. Vigants of Bell Telephone Laboratories, [Ref 25:pp. 59-60], have developed an empirical method to determine the nondiversity annual path availability. Barnett's procedure begins by defining  $U_{ndp}$  as the nondiversity annual outage probability and  $r$  as the fade occurrence factor:

$$r = \frac{\text{actual fade probability}}{\text{Rayleigh fade probability}}$$

If  $F$  is the fade margin in decibels:

$$r = \frac{\text{actual fade probability}}{10^{-F/10}}$$

For the worst month:

$$r_m = a \times 10^{-5} \left( \frac{f}{4} \right) d^3 \quad (3-19)$$

where  $d$  = path length (statue miles)



- f = frequency (GHz)
- F = fade margin (dB)
- a = 4 (for smooth earth, over water, flat desert)
- a = 1 (for average terrain with some roughness)
- a = 0.25 (for mountainous terrain)

Considering the annual fade occurrence:

$$r_{yr} = br_m \quad (3-20)$$

- where
- b = 0.5 (for hot, humid coastal areas)
  - b = 0.25 (for normal, temperate or subarctic)
  - b = 0.125 (for very dry climate)

Finally the nondiversity annual path outage is:

$$U_{ndp} = r_{yr} 10^{-F/10} \quad (3-21)$$

The annual nondiversity availability percentage is:

$$A = 100(1 - U_{ndp}) \text{ (percent)} \quad (3-22)$$

The percentage of availability is improved with the use of frequency and space diversity. Figure 3-14 is used to graphically determine the approximate

availability improvement for various percentages of frequency separation (F.S.). Figure(s) 3-15 (Dual Diversity) and 3-16 (Quad Diversity) provide a graphical method to determine the percent of path availability (percent of level exceeded) for different diversity combining techniques.

#### 5. Diversity Requirements

The antenna spacing, in meters, required for effective space diversity has been experimentally derived for frequencies greater than 1 GHz, in the horizontal as [Ref. 11:pp. 145-146]:

$$\Delta_h = 0.36(D^2 + 1600)^{1/2} \quad (\text{meters}) \quad (3-23a)$$

and in the vertical as:

$$\Delta_v = 0.36(D^2 + 225)^{1/2} \quad (\text{meters}) \quad (3-23b)$$

where  $D$  = parabolic antenna diameter (m)

A satisfactory frequency separation, in MHz, for frequency diversity has been derived as:

$$\Delta_f = (1.44f/d)(D^2 + 225)^{1/2} \quad (\text{MHz}) \quad (3-23c)$$

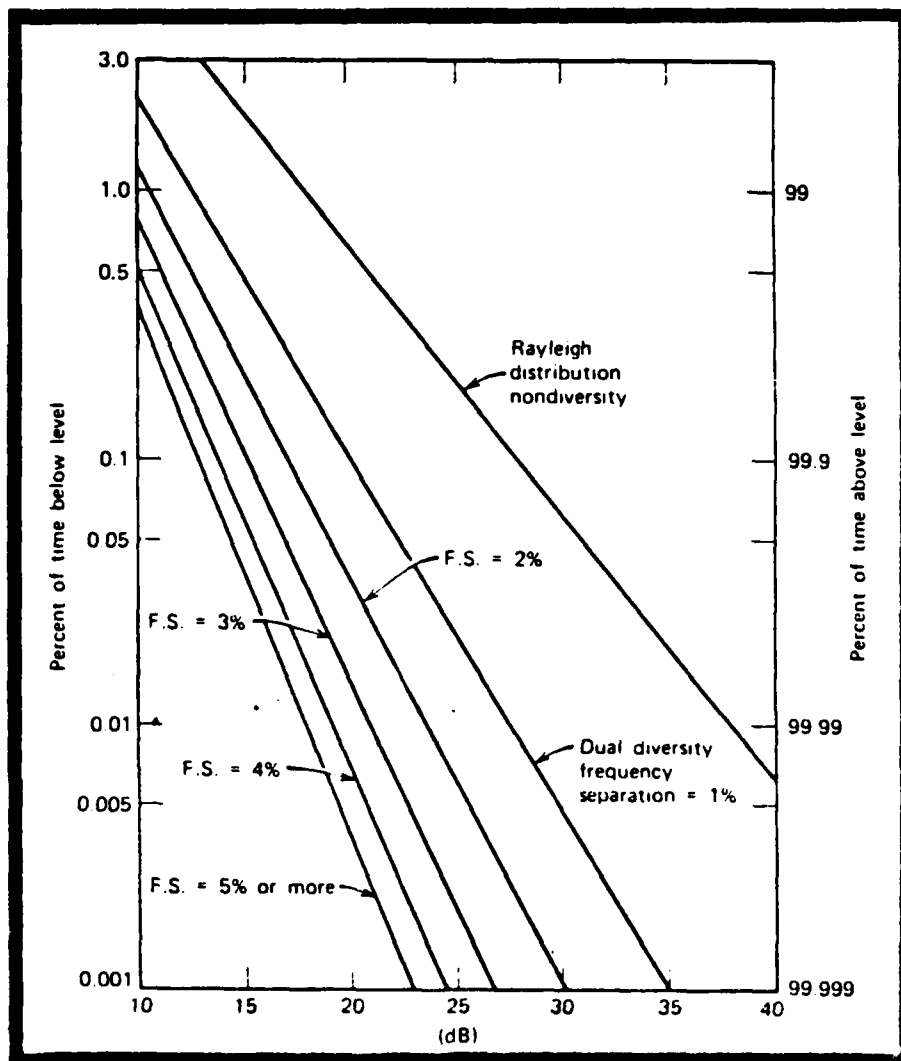


Figure 3-14 Approximate Interference Fading  
 Distribution versus Order of Diversity  
 and Frequency Separation  
 (After Ref. 18:p. 2-46)

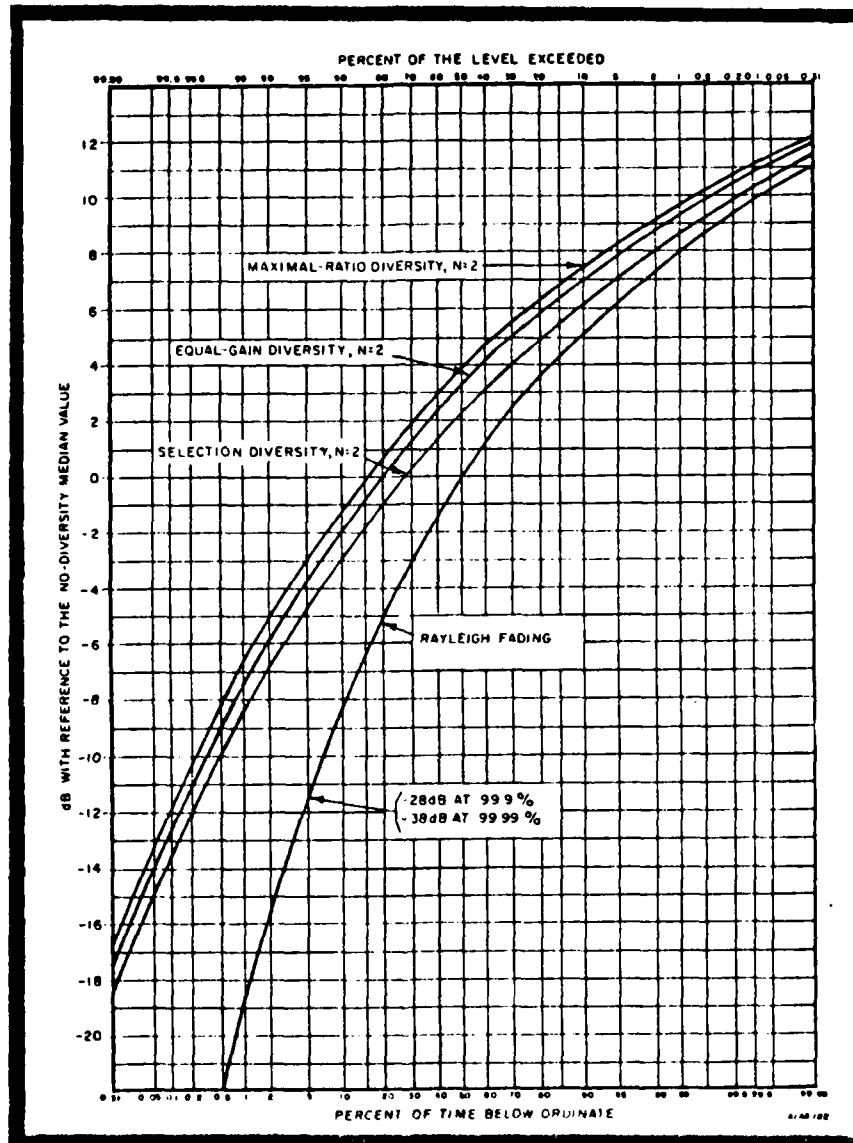


Figure 3-15 Short-Term Fading (Dual Diversity)  
 (After Ref. 18:p. 4-11)

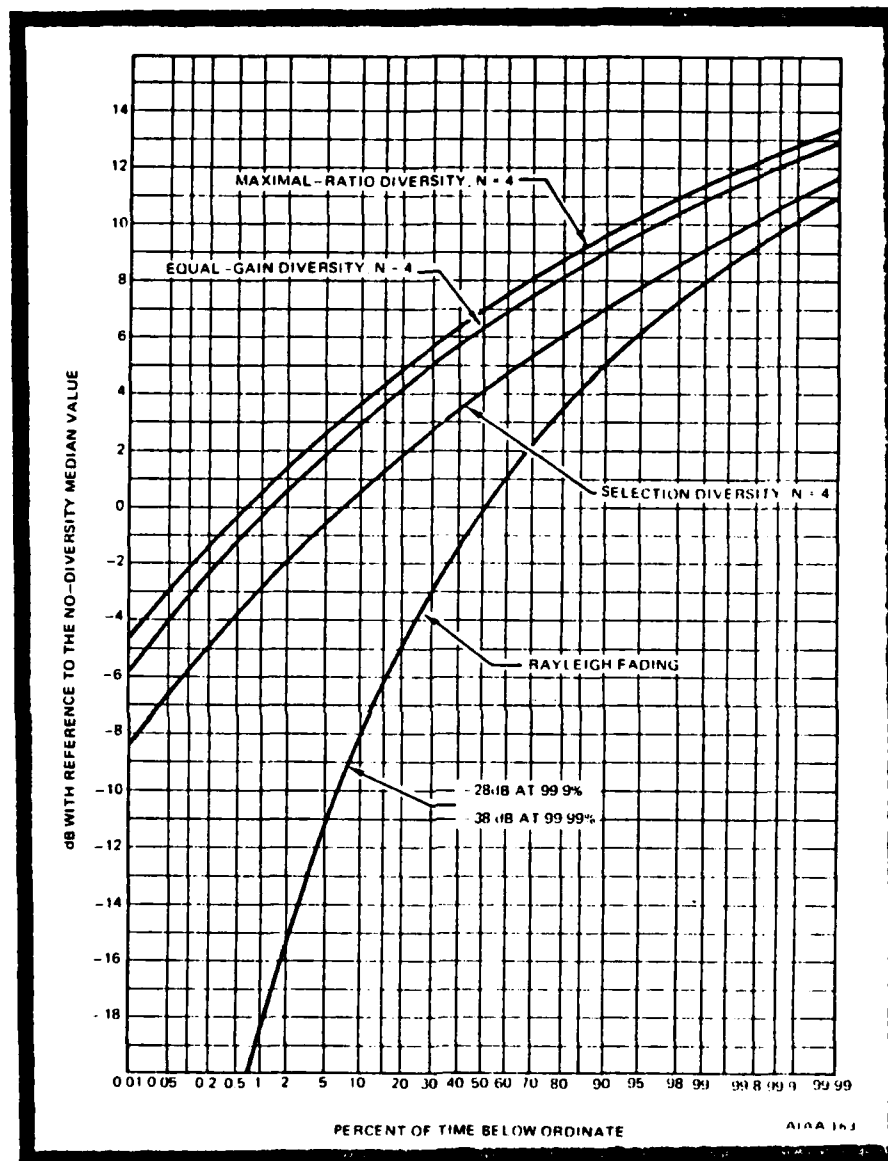


Figure 3-16 Short-Term Fading (Quad Diversity)

(After Ref. 18:p. 4-13)

where  $f$  = transmitter frequency (MHz)

$\theta$  = scatter angle (mrad)

$d$  = path length (km)

#### 6. Analog Radio Link Parameters

The analog radiolink considered will be a FM transmitter using frequency division multiplexing (FDM).

##### a. Receiver IF Bandwidth

For FM modulation techniques, the receiver IF bandwidth is computed as [Ref. 18:p. 8-16]:

$$BW_{IF} = 2(\Delta F_p + F_m) \quad (3-24)$$

where  $F$  = peak frequency deviation (Hz)

$F_p$  = maximum modulating frequency (Hz)

The peak frequency deviation is the product of the frequency modulation index and the bandwidth of the modulating signal. The maximum modulating frequency is computed as the sum of the minimum modulating frequency, the voice channel bandwidth, and the frequency spacing between multiplexed supergroups. The calculated IF bandwidth can now be used to compute the receiver noise

threshold, Equation 3-11. The carrier-to-noise ratio is determined by Equation 3-12.

b. Expected Channel Noise

According to DCA System Performance Specifications [Ref. 18:p. 3-11], the channel noise standard for a troposcatter link is:

$$N(\text{pWp0}) = \frac{L}{2000} (16,000) \quad (3-25a)$$

and

$$N(\text{dBa0}) = 10 \log_{10} (\text{pWp}) - 6 \text{ dB} \quad (3-25b)$$

where  $L$  = path length (nautical miles)

$\text{pWp}$  = picowatts psophometrically weighted measured at, or referred to, a zero transmission level point.

The term  $\text{dBa}$  refers to decibels of noise power above a reference noise power, with an adjustment factor to compensate for equipment weighting. The referenced noise power that  $\text{dBa}$  is referred to is  $-85 \text{ dBm}$ . To obtain  $\text{dBa0}$ , it is required to calculate the number of  $\text{dB}$  above this reference power the signal is. For flat voice channels, the corrected reference level is  $-82 \text{ dBm}$  and the expression for  $\text{dBa0}$  is:

$$\text{dBa0} = 82 - \text{SNR} \quad (3-26)$$

The signal-to-noise ratio, SNR, must be calculated to compute Equation 3-26. The channel SNR may be calculated after the carrier-to-noise ratio (CNR) has been determined by Equation 3-11. The relationship between channel SNR and system CNR in a FM/FDM system is [Ref. 1:p. 272]:

$$\text{SNR} = \text{CNR} + D_{im} + \text{FM}_{im} - L_f + P_{im} \quad (3-27)$$

where

- $\text{FM}_{im}$  = FM improvement factor (assumed 20 dB)
- $D_{im}$  = diversity improvement factor (Fig. 3-17)
- $P_{im}$  = preemphasis improvement factor (Fig. 3-18)
- $L_f = -10 + 10 \log_{10} N$  (dB)

where  $N$  = number of voice channels



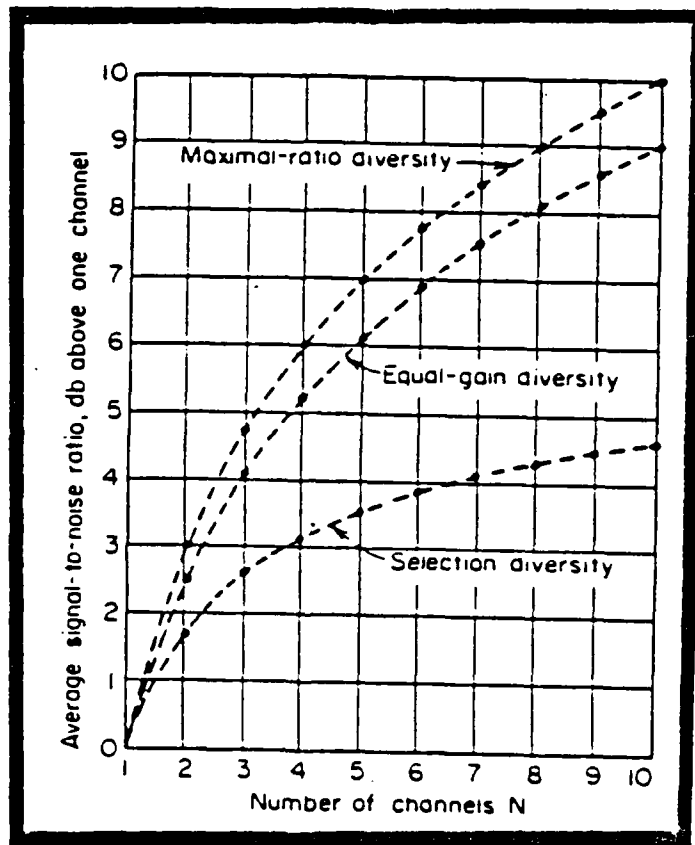


Figure 3-17 SNR Improvement from Diversity Techniques

(After Freemann, Ref. 1:p. 207)

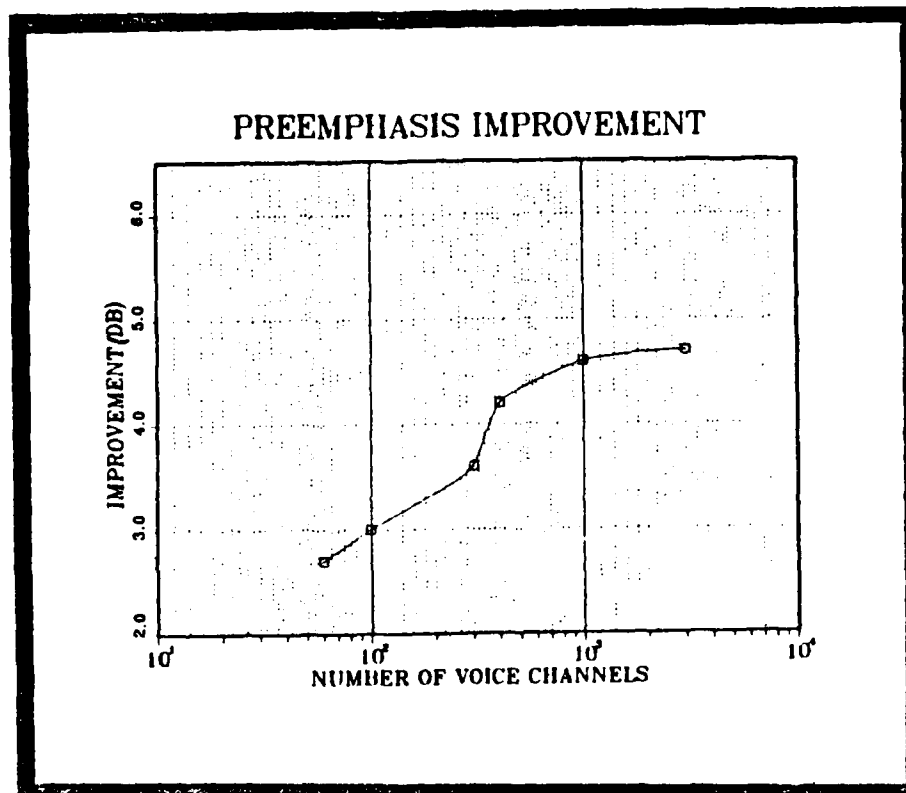


Figure 3-18 Preemphasis Improvement for FDM Channels  
(After Freemann, Ref. 1:p.224)

#### IV. HEIGHT GAIN COMPUTATION

##### A. GENERAL

One of the purposes of this research was to develop a tactically practical method of calculating the height gain caused by the presence of an elevated tropospheric duct. The calculation must provide a result that was within 10 dB of the FDUCT computer program prediction. Several related works were investigated for a possible approach to the problem. Military troposcatter systems have introduced several constraints to the height gain problem. These constraints include:

1. The transmitter and receiver terminals are both located outside and below the elevated duct.
2. The operating frequency range was between 4.5 GHz to 5.0 GHz.
3. The geographical area of system deployment was limited to Western Europe (i.e. West Germany).

A statistical analysis of elevated duct histograms was obtained from several radiosonde recording stations located throughout West Germany [Ref. 26]. This information is condensed in Table III. Elevated ducts that had a percentage of occurrence greater than twenty

percent (20%) over the 5 year recording period were prime candidates for further study. Eight (8) elevated ducts were selected as typical for the area. Their optimum coupling heights ranged from 951 to 1452 meters above the surface. The elevated duct intensities were all less than 6 M-units with 4 M-units being the dominant value.

TABLE III  
ELEVATED DUCT HISTORICAL INFORMATION

| Station Location (LAT/LONG)            | Mean Optimum Coupling Height (Meters) | Mean Duct Intensity (M-Units) | Mean Duct Thickness (Meters) |
|--|---------------------------------------|-------------------------------|------------------------------|
| Stuttgart, FRG<br>(48-49N/09-11E)      | 1452                                  | 4                             | 115                          |
| Essen, FRG<br>(51-23N/06-58E)          | 1412                                  | 3                             | 106                          |
| Hannover, FRG<br>(52-28N/09-41E)       | 1376                                  | 4                             | 109                          |
| Rheine, FRG<br>(52-16N/07-25E)         | 1257                                  | 3                             | 113                          |
| Idar-Oberstein, FRG<br>(49-41N/07-19E) | 1151                                  | 3                             | 88                           |
| Emden, FRG<br>(53-22N/07-13E)          | 1071                                  | 4                             | 124                          |
| Goch, FRG<br>(51-40N/06-10E)           | 1044                                  | 6                             | 172                          |
| Greifswald, FRG<br>(54-05N/13-22E)     | 951                                   | 4                             | 119                          |

(After Ortenburger, Ref. 26, Vol. 12)

Height gain values, in decibels, were computed by the PDUCT program for each of the eight selected ducts. The following common input parameters were entered into the PDUCT program for each duct. [Ref. 7]:

1. The transmitter site elevation was fixed as the reference at 5 meters above the surface.
2. The receiver site elevation was increased from 5 to 280 meters in 25 meter increments.
3. The path distance was increased from 75 to 325 kilometers in 50 meter increments.
4. The antenna polarization was set for both horizontal and vertical polarization.
5. The frequency of interest was increased from 4500 MHz to 5000 MHz in 100 MHz increments. The frequency was changed every PDUCT program run for each selected duct of interest.
6. The relative permittivity (15), conductivity (0.01 mho/m), and maximum mode attenuation (1.0 dB/km) were selected for the path characteristics.

#### B. MATHEMATICAL FORMULATION

The PDUCT height gain results for each duct were investigated, and the following observations were discovered. The height gain values increased exponentially as the receiver elevation approached the bottom of the elevated duct. The other significant observation was that for any fixed receiver elevation, the height gain increased linearly with increased path

distance.

Two empirical methods were considered in developing the height gain prediction model. One method was to directly store the individual height gain results for each of the elevated ducts and then to interpolate a height gain result from a database. This would have required an extensive height gain database. The chosen approach was to approximate height gain curves from the PDUCT results using a least-squares curve fitting program. A second order polynomial equation was derived for each frequency of interest at the initial 75 kilometer path length for each selected duct height.

The height gain program module consisted of eight (8) optimum coupling height decision regions which corresponded to the selected elevated ducts. Each duct height region contained a height gain polynomial equation for each frequency of interest. For a particular operating frequency and optimum coupling height, a baseline height gain was estimated and multiplied by an incremental range correction factor. This range factor was the average differential difference in height gain between the successive 50 kilometer path increments. Figure 4-1 outlines how the height gain estimate was computed.

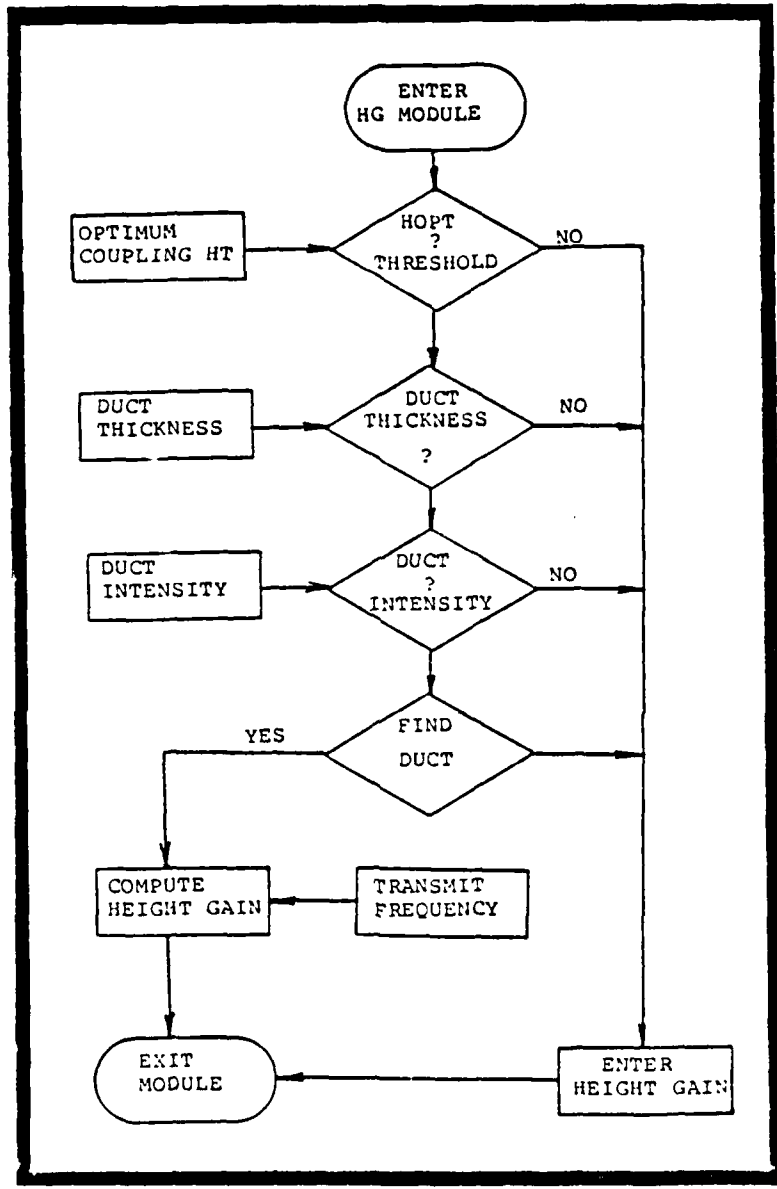


Figure 4-1 Height Gain Estimation Flowchart

### C. RADIOSONDE DATA ANALYSIS

Elevated ducts are described by their optimum coupling height, duct intensity, and duct thickness. This information can be determined indirectly from real-time radiosonde data taken along the system's path length. The atmospheric pressure, vapor pressure, temperature and relative humidity readings are used to calculate the refractive index,  $N$ , for various altitudes using the expression, [Ref. 27:p.4]:

$$N_s = \frac{77.6}{273 + T} P + \frac{48.1 H P_w}{273 + T} \quad (4-1)$$

where  $P$  = atmospheric pressure (millibars)

$T$  = temperature (celsius)

$P_w$  = saturated vapor pressure (millibars)

$H$  = relative humidity (%)

The radiosonde information can be entered into the program. The refractive index values are calculated for available altitude readings and then converted to modified refractive index values. At this point a M-profile plot can be obtained along with a radiosonde data listing. If an elevated duct does exist, the optimum coupling height, intensity, and thickness can be



determined directly from the M-profile. These duct descriptors must satisfy the respective limits established by the height gain prediction model. If the detected elevated duct exceeds the limits of the model, the height gain prediction will become inaccurate. The program user will be alerted of this condition. At this point the design engineer must decide to obtain the height gain from an alternative computation or neglect ducting effects.

## V. RESULTS

### A. GENERAL

For validation purposes, the TROPD Program was used to determine the design predictions for a typical tropospheric scatter communications system. Table IV outlines the proposed system specifications and assumptions. Both the terrain and radiosonde data have been assumed to accommodate the program's capabilities. The program results are illustrated in Figure(s) 5-1 through 5-4. The Radiosonde Environmental Data Listing (Figure 5-3) identifies the occurrence of a tropospheric duct by detecting a "trapped" radio ray path condition. Other refractive bending conditions identified are super-refractive (bending toward the earth's surface), normal (standard bending), and sub-refractive (upward bending). The M-Profile Plot, Figure 5-4, graphically verifies the program's computed duct parameters.

### B. HEIGHT GAIN COMPARISON

Height gain prediction model results were compared with the PDUCT program computed values for identical elevated duct parameters. Height gain curves were

TABLE IV  
PROPOSED EXAMPLE SYSTEM SPECIFICATIONS

| Site:      | Transmitter | Receiver    |
|------------|-------------|-------------|
| Latitude:  | 36 38' 23"N | 37 09' 12"N |
| Longitude: | 06 22' 02"W | 05 35' 16"W |
| Elevation: | 13 meters   | 94 meters   |

Terrain Data Available: Near Obstacle Path Mode

Radio Terminal: Military (AN/TRC-170V3)

Diversity: Dual

Frequency: 4560.0 MHz

Antenna Diameter: 15 Ft. Parabolic

Waveguide Length: 25 Ft. per Antenna

Digital Trunk Data Rate: 2.048 Mb/s

Transmission Bandwidth: 3.5 MHz

Radiosonde Data Available: Surface Duct Detected

plotted for two test cases: (1) a fixed optimum coupling height and range with a varying frequency, and (2) a fixed optimum coupling height and frequency with a varying range. Figure(s) 5-5a thru 5-5c has shown that a prediction error of approximately 5 dB is possible. The error increases as the frequency approaches the adjacent frequency increment. In this case height gain values validated at 4700 MHz have been averaged into those computed for 4600 MHz to produce a shift of the prediction curve. Figure(s) 5-6a thru 5-6c illustrate the results of only changing the path distance. In this case the greatest error detected was within 3 dB of PDUCT, which supports the linearity between height gain and range.

-----  
TROPOSCATTER SYSTEM DESIGN SPECIFICATIONS  
-----

| SITE       | TRANSMITTER | RECEIVER |
|------------|-------------|----------|
| LATITUDE:  | 36.60 N     | 37.15 N  |
| LONGITUDE: | 6.37 W      | 5.58 W   |
| ELEVATION: | 13.00 M     | 94.00 M  |

TERRAIN PROFILE TYPE: NEAR OBSTACLE PATH MODE

|                             |            |
|-----------------------------|------------|
| TRANSMITTER TAKE-OFF ANGLE: | 4.73 MRAD  |
| RECEIVER TAKE-OFF ANGLE:    | 4.97 MRAD  |
| SCATTER (ANGULAR DISTANCE): | 20.94 MRAD |

|                             |              |
|-----------------------------|--------------|
| TRANSMITTER TAKE-OFF ANGLE: | .27 DEGREES  |
| RECEIVER TAKE-OFF ANGLE:    | .28 DEGREES  |
| SCATTER (ANGULAR DISTANCE): | 1.20 DEGREES |

TRANSMIT FREQUENCY: 4560.00 MHZ

MINIMUM RECOMMENDED FREQUENCY SEPARATION FOR QUAD DIVERSITY: 52.77 MHZ

|                                    |                    |
|------------------------------------|--------------------|
| AZIMUTH AT TRANSMITTER (TO RECVR): | 48.70(DEGREES N.)  |
| AZIMUTH AT RECEIVER (TO TRANS):    | 229.17(DEGREES N.) |

GREAT CIRCLE PATH: 57.91 STATUTE MILES / 93.20 KILOMETERS

MINIMUM RECOMMENDED ANTENNA VERTICAL SEPARATION FOR SPACE DIVERSITY: 18.5 FEET

ESTIMATED SCATTER VOLUME BASE ALTITUDE: 417.09 METERS

Figure 5-1 Example System Design Specifications

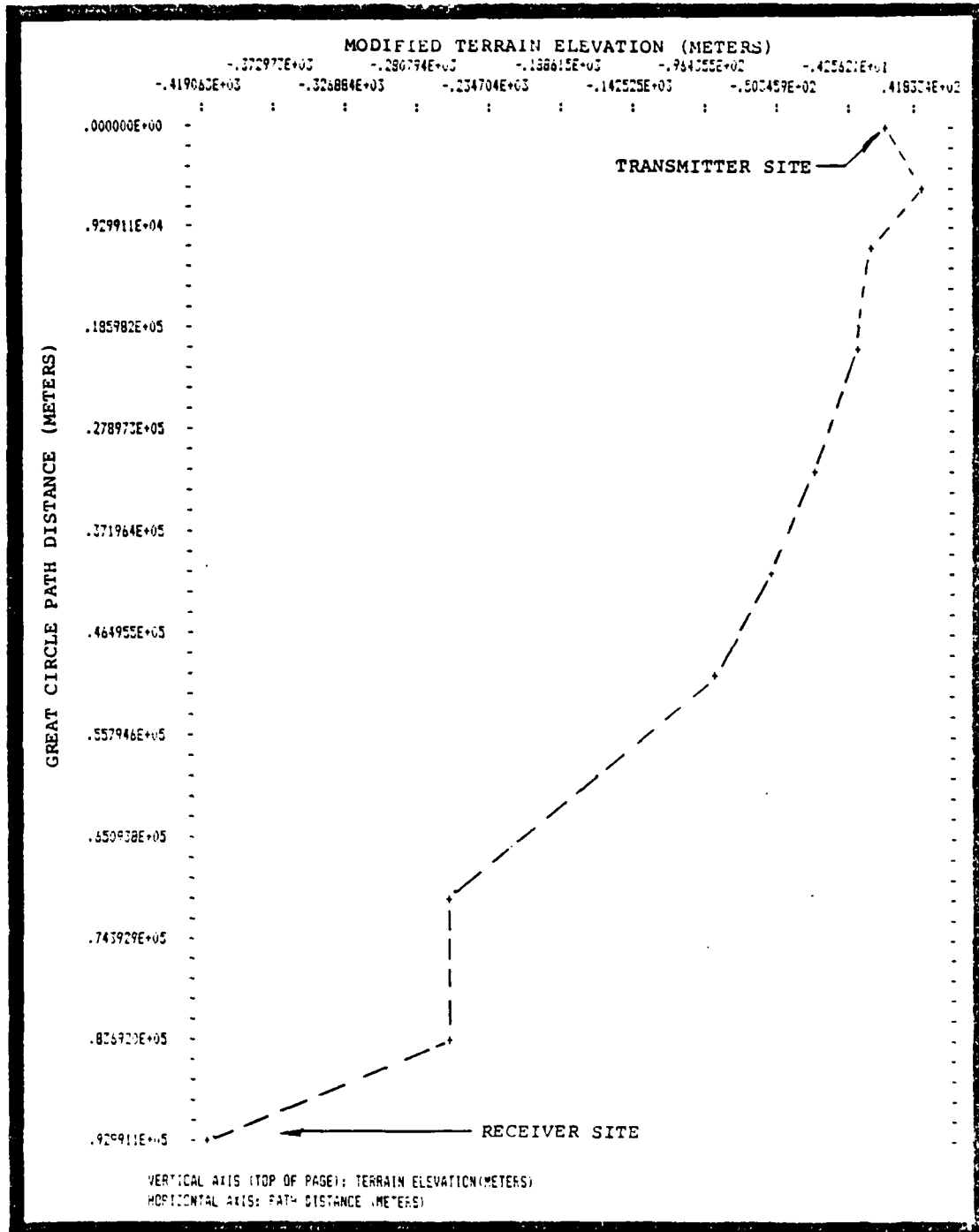


Figure 5-2 Example System Terrain Profile Plot

\*\*\* ENVIRONMENTAL DATA LIST \*\*\*

| LEVEL | PRESS (MB) | TEMP (C) | VAPOR PRESS (MB) | ALT (FEET) | N UNITS | N/KFT  | M UNITS | CONDITION |
|-------|------------|----------|------------------|------------|---------|--------|---------|-----------|
| 1     | 1008.0     | 15.1     | 15.2             | 60.0       | 339.7   | -26.4  | 342.6   | SUPER     |
| 2     | 1000.0     | 14.2     | 14.1             | 281.6      | 333.8   | 15.7   | 347.3   | SUB       |
| 3     | 993.0      | 13.9     | 15.1             | 476.6      | 336.9   | -11.3  | 359.7   | NORMAL    |
| 4     | 982.0      | 13.3     | 14.8             | 785.3      | 333.4   | -176.3 | 371.1   | TRAP      |
| 5     | 972.0      | 20.4     | 6.0              | 1071.3     | 282.9   | 26.6   | 334.4   | SUB       |
| 6     | 962.0      | 21.5     | 8.7              | 1364.9     | 290.8   | -28.9  | 356.3   | SUPER     |
| 7     | 949.0      | 21.5     | 6.9              | 1751.3     | 279.6   | .0     | 363.7   | NORMAL    |

TROPOSPHERIC DUCT DETECTED, TYPE: SURFACE  
 OPTIMUM COUPLING HEIGHT..... .239 KM  
 DUCT THICKNESS..... .326 KM  
 DUCT INTENSITY (M-UNITS)..... 36

Figure 5-3 Radiosonde Environmental Data Listing

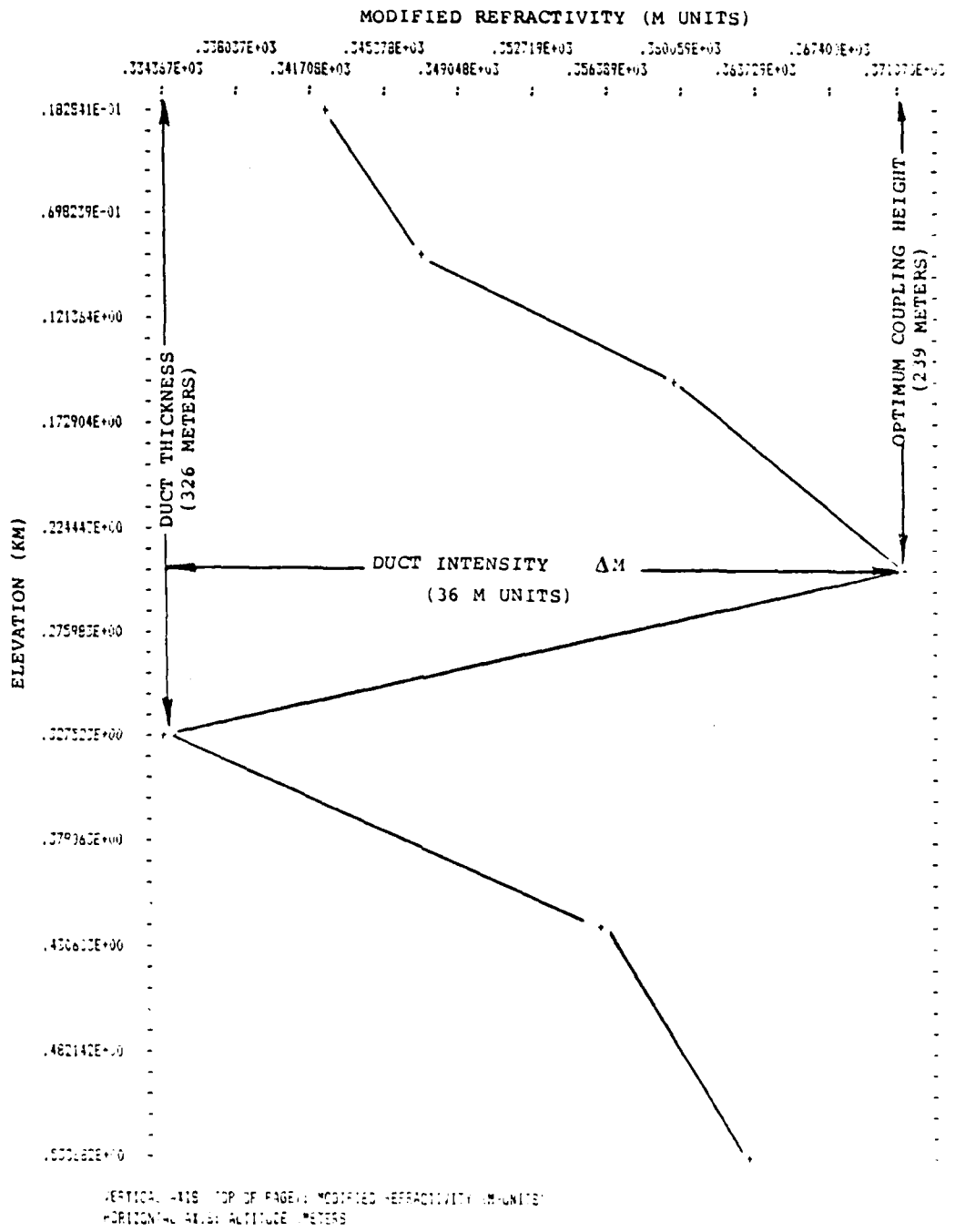


Figure 5-4 M-Profile Plot (Surface Duct)



-----  
BASIC MEDIAN TRANSMISSION LOSS FACTORS  
-----

SYSTEM LOSS FACTORS

|  |          |
|--|----------|
| FREE-SPACE/SCATTER LOSS .....          | 209.4 DB |
| WAVEGUIDE LOSS .....                   | 7.4 DB   |
| CONNECTOR LOSS .....                   | .4 DB    |
| APERTURE-TO-MEDIAN COUPLING LOSS ..... | 1.5 DB   |
| DIFFRACTION LOSS (IF APPLICABLE) ..... | NA DB    |
| RAINFALL ABSORPTION LOSS .....         | .3 DB    |

SYSTEM GAIN FACTORS

|                                   |           |
|-----------------------------------|-----------|
| ANTENNA SYSTEM GAIN .....         | 88.2 DB   |
| HEIGHT GAIN (IF APPLICABLE) ..... | -4.5 DB   |
| TOTAL SYSTEM GAIN .....           | 83.7 DB   |
| NET PATH LOSS .....               | 135.3 DB  |
| TRANSMITTER POWER .....           | 60.0 DBM  |
| MEDIAN RECEIVED SIGNAL .....      | -75.3 DBM |
| RECEIVED NOISE THRESHOLD .....    | -91.5 DBM |
| FM IMPROVEMENT THRESHOLD .....    | -81.5 DB  |
| THEORETICAL RF CNR .....          | 16.3 DB   |
| SYSTEM FADE MARGIN .....          | 6.3 DB    |

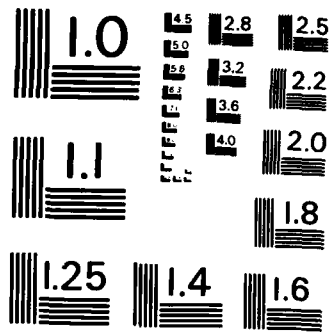
Figure S-5 System Performance Results

-----  
SYSTEM PERFORMANCE  
-----

|  |               |
|--|---------------|
| SYSTEM PATH RELIABILITY .....          | 87.01 PERCENT |
| EB/NO (BIT ENERGY/NOISE DENSITY) ..... | 21.63 DB      |
| PROBABILITY OF BIT ERROR .....         | .1363E-02     |

Figure 5-5 System Performance Results (Continued)





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS - 1963 - A

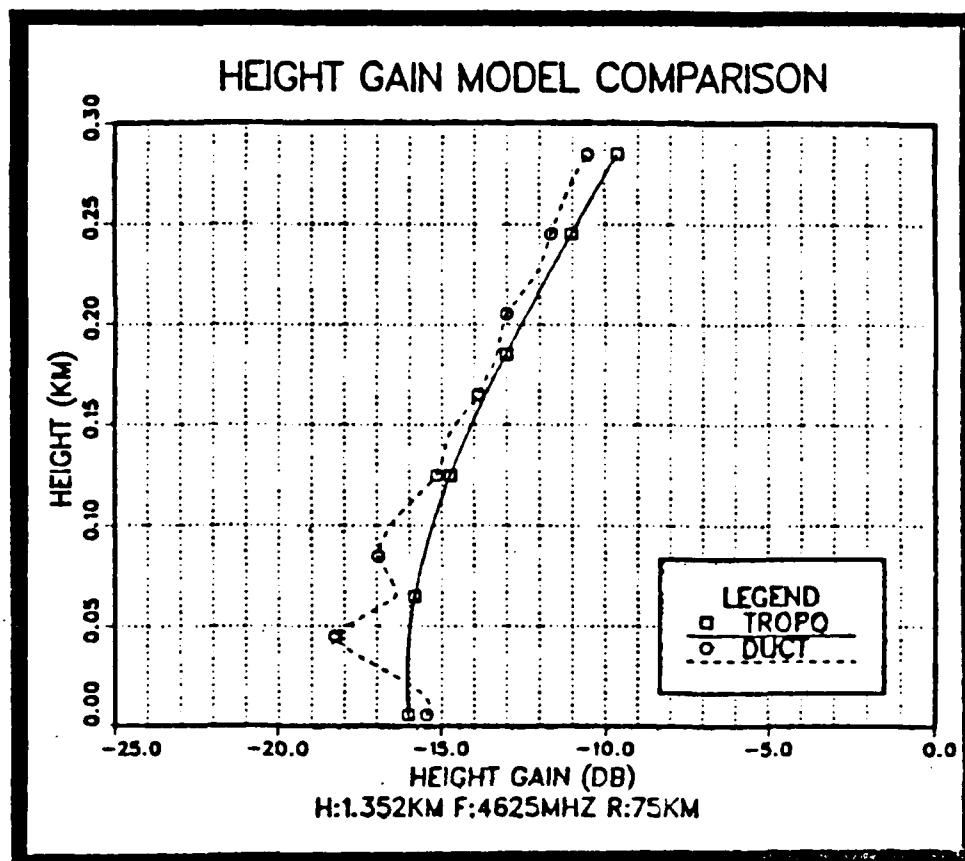


Figure 5-6a Height Gain Model Comparison

(Frequency: 4625.0 MHz)

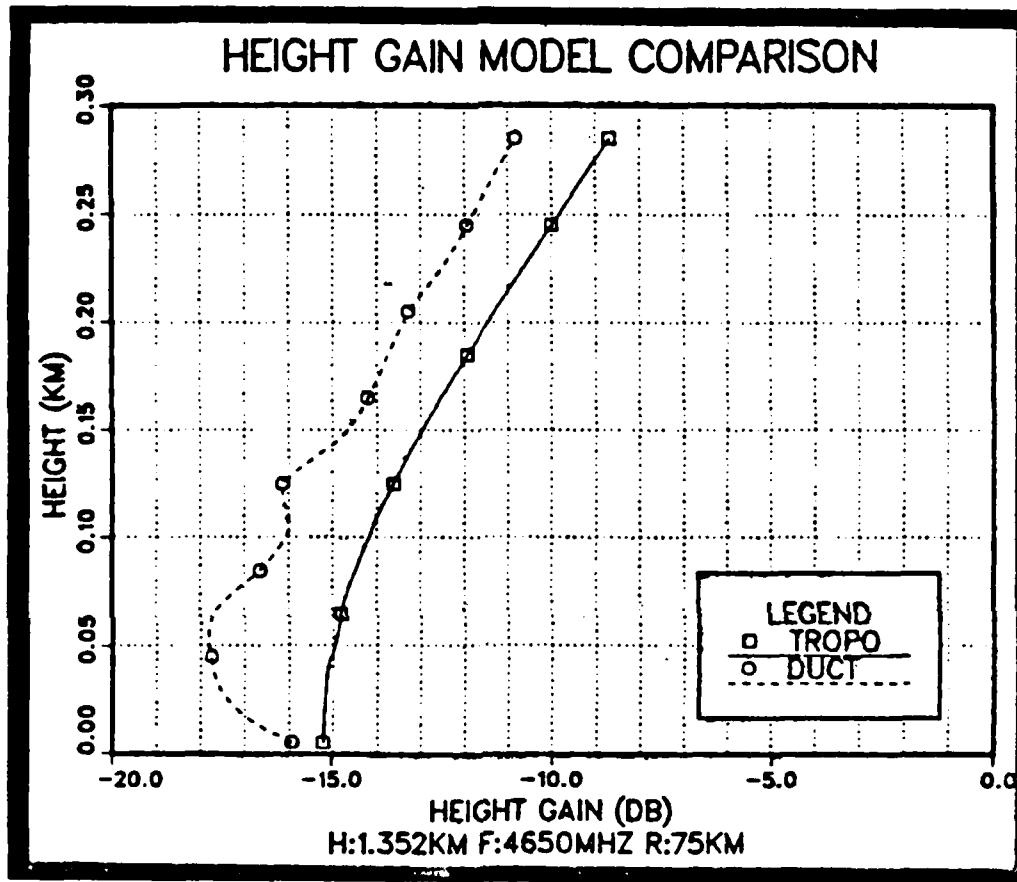


Figure 5-6b Height Gain Model Comparison  
(Frequency: 4650.0 MHz)

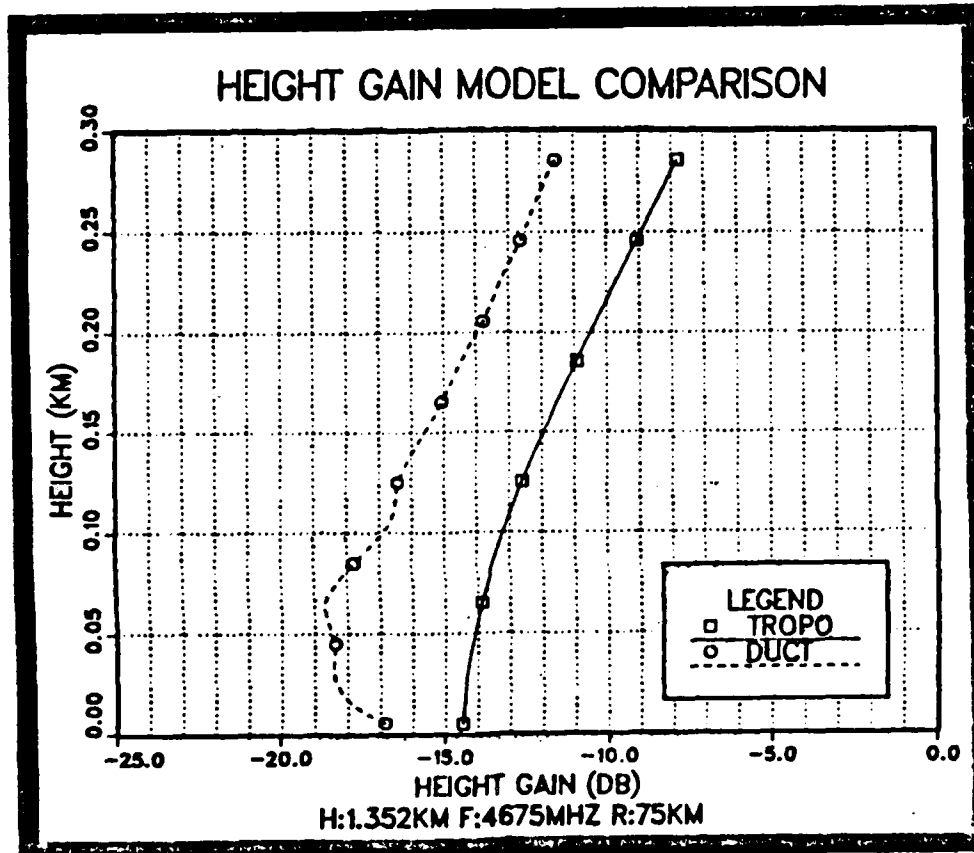


Figure 5-6c Height Gain Model Comparison  
 (Frequency: 4675.0 MHz)

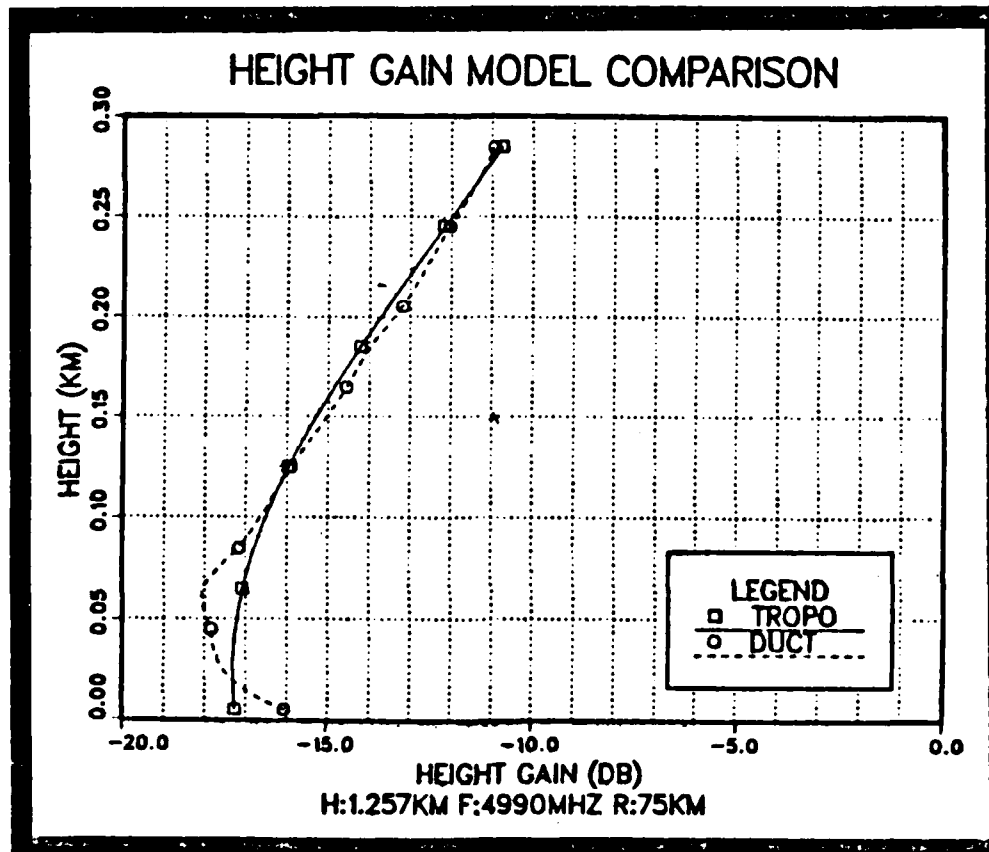


Figure 5-7a Height Gain Model Comparison  
(Range: 75 Kilometers)



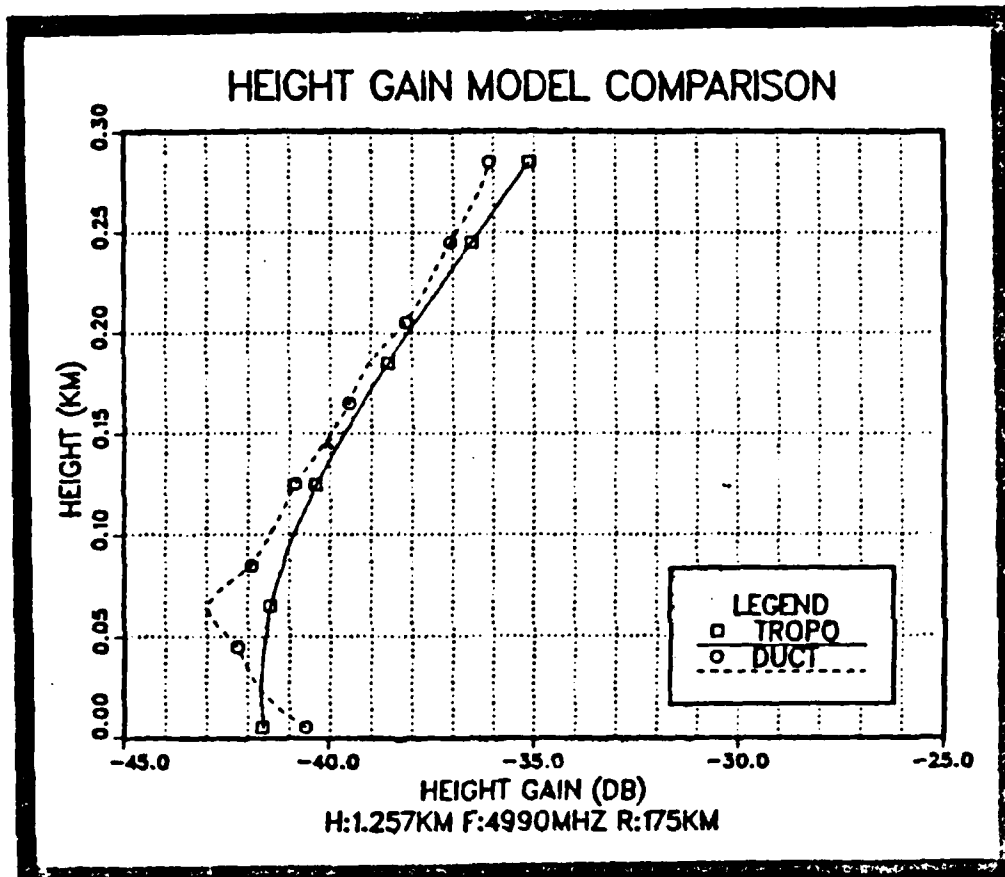


Figure 5-7b Height Gain Model Comparison  
(Range: 175 Kilometers)

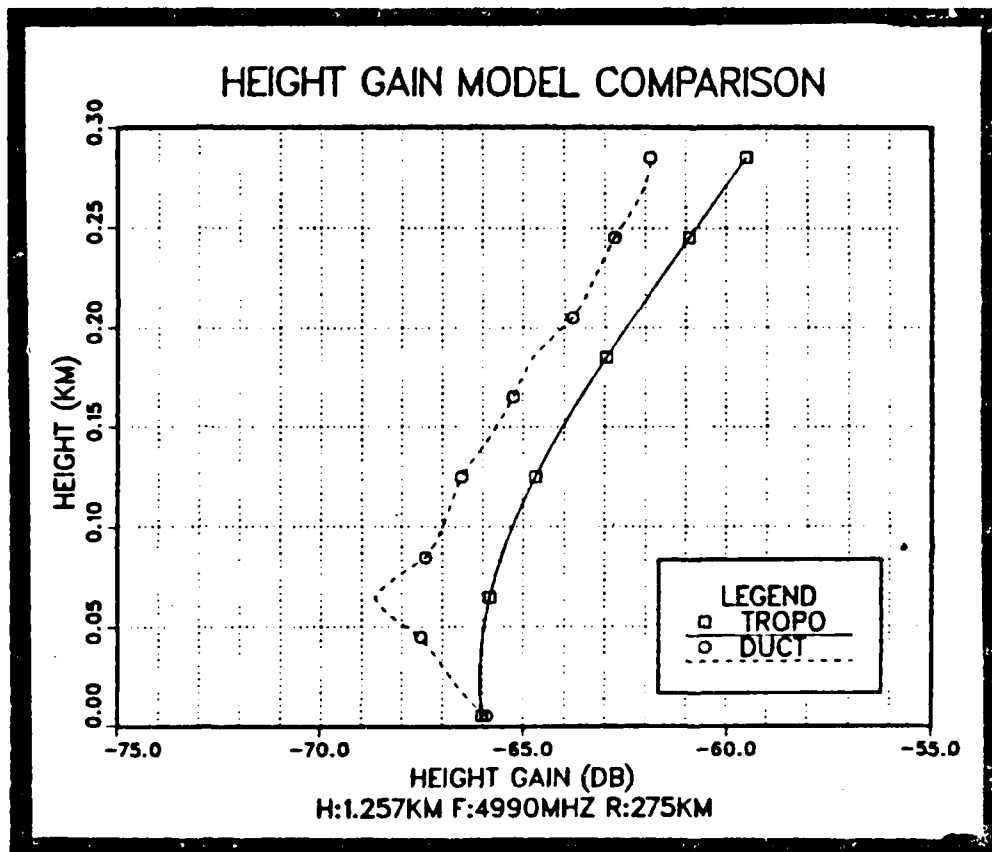


Figure 5-7c Height Gain Model Comparison

(Range: 275 Kilometers)

## VI. SUMMARY

### A. CONCLUSIONS

An interactive, computer-aided design program for military tropospheric scatter communications systems was developed. The program provides the communications engineer with an efficient and accurate system performance algorithm that can be used in a tactical environment on a microcomputer. The following thesis objectives were accomplished:

1. Both analog and digital troposcatter radio terminals are included as design options.
2. The influence of elevated tropospheric ducting on systems installed throughout West Germany was considered. A height gain estimation model was derived using numerical results obtained from the FDUCT main-frame computer program.
3. System performance predictions can be calculated for the newly deployed digital troposcatter radio, AN/TRC-170.
4. Real-time radiosonde information can be analyzed to determine the presence of both surface and elevated tropospheric ducts.

The accuracy of the height gain model was bounded by the range of selected duct parameters. However height gain results of elevated ducts which satisfied the limits of the model were within 5 dB of the FDUCT computer

model. The model did not compute the height gain for surface-based ducts.

#### B. RECOMMENDATIONS

Additional research is required and should focus on the following areas.

1. The validation of the computer-derived system performance results can be conducted during standard operational testing. Real-time radiosonde data should be obtained from available tactical weather facilities and tropospheric ducting phenomena determined. Received signal strength data can be recorded and statistically analyzed.
2. The height gain model should be expanded to include unlimited duct parameters, e.g. surface-based ducts and elevated surface ducts.
3. The effects of tropospheric ducting can be studied further within the laboratory. Radiated energy, produced by laser light, can be transmitted through a fluid medium containing light-scattering particles. A common scatter volume can be formed by mirror-like apertures at the laser sources. The refractivity index of the medium could be controlled to simulate ducting conditions. The received energy could be detected and experimental results studied.

## APPENDIX A

The following prediction formulas were developed by the National Bureau of Standards (NBS) for calculating the long-term median basic transmission loss,  $L_{bsr}$ , [Ref. 12:p. 389] and [Ref. 18:pp. 8-8 thru 8-14].

### 1. Long-term Median Basic Transmission Loss

$$L_{bsr} = 30 \log_{10} f - 20 \log_{10} D + F(\theta d) - F_o + H_o \quad (A-1)$$

where  $f$  = frequency (MHz)

$d$  = mean sea level arc distance (km)

$F(\theta d)$  = attenuation function (dB)

$F_o$  = scattering-efficiency term (dB)

$H_o$  = frequency-gain function (dB)

### 2. Attenuation Function

For a particular symmetry factor,  $S$ , and approximate surface refractivity,  $N_s$ , the following figures are used to determine the attenuation factor,  $F(\theta d)$ :

For a surface refractivity:

$N_s = 250$  ..... Refer to Figure A-1

- N<sub>s</sub> = 301 ..... Refer to Figure A-2
- N<sub>s</sub> = 350 ..... Refer to Figure A-3
- N<sub>s</sub> = 401 ..... Refer to Figure A-4

3. Scattering-Efficiency Term

The following equation can be used:

$$F_o = 1.086 \left( \frac{\eta_s}{h_o} \right) (h_o - h_1 - h_{1t} - h_{1r}) \quad (A-2)$$

where h<sub>o</sub> = height of transmitter/receiver antenna beam intersection (km)

h<sub>1</sub> = height from obstacle elevation baseline to the antenna beam intersection (km)

h<sub>1t</sub> = transmitter obstacle elevation (m)

h<sub>1r</sub> = receiver obstacle elevation (m)

4. Frequency-Gain Function

The frequency-gain function is expressed by as:

$$H_o = \frac{H_o(r_1) + H_o(r_2)}{2} + H_o \quad (\text{dB}) \quad (A-3)$$

and r<sub>1</sub> = 41.92 θ f h<sub>te</sub>  
 r<sub>2</sub> = 41.92 θ f h<sub>re</sub>

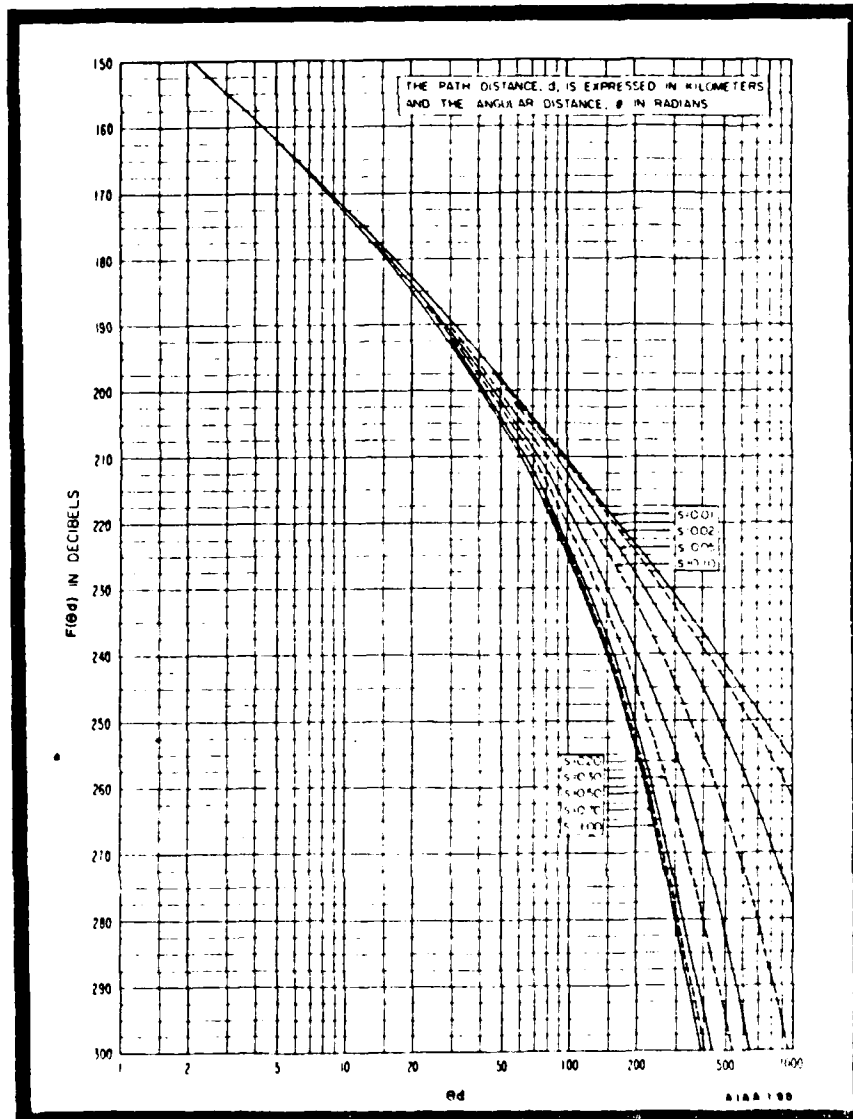


Figure A-1 Function  $F(\theta d)$  for  $N = 250$   
 (After Ref. 18:p. 8-9)

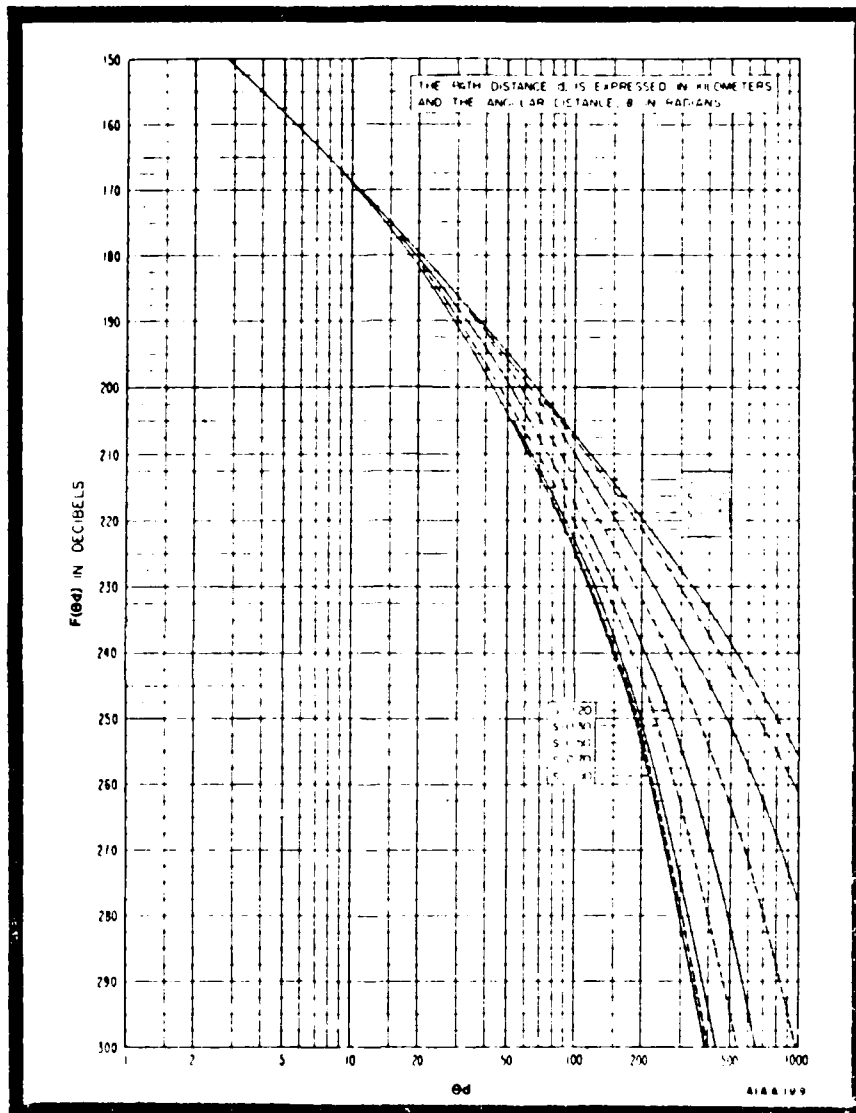


Figure A-2 Function  $F(\theta d)$  for  $N = 301$   
 $s$   
 (After Ref. 18:p. 8-10)



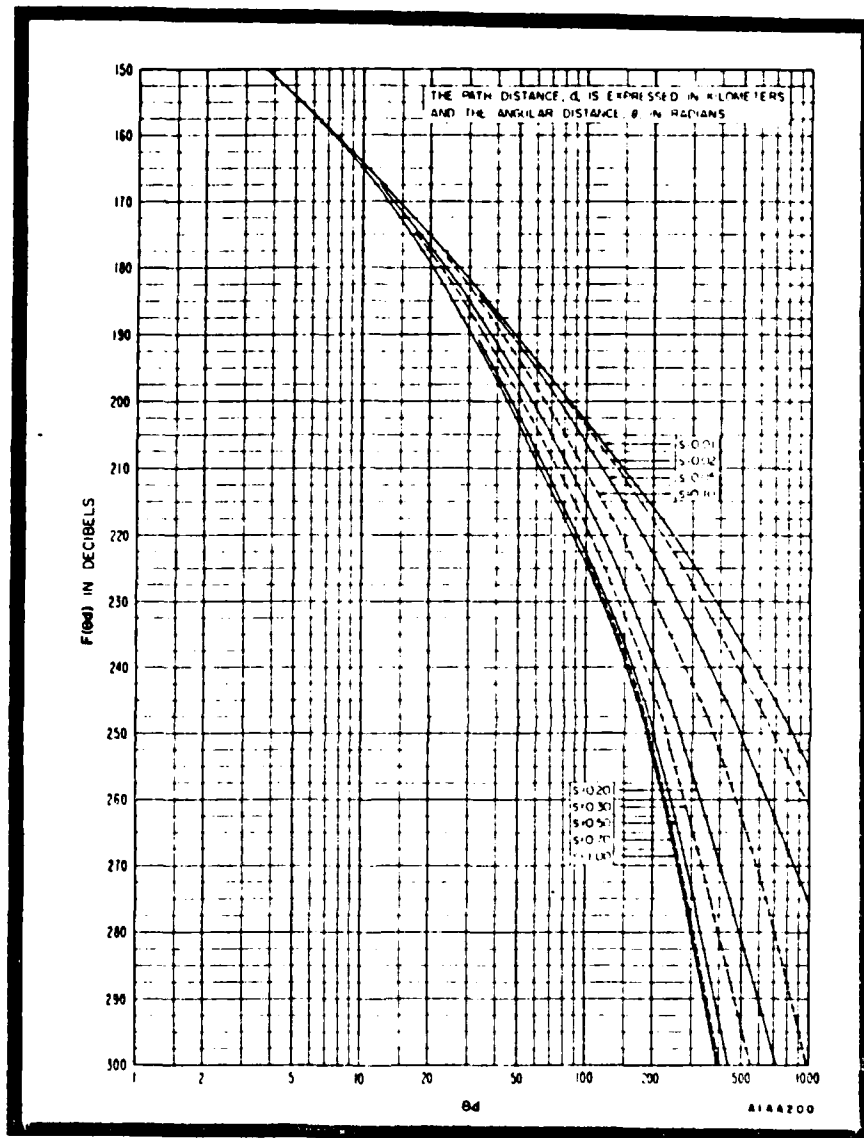


Figure A-3 Function  $F(\theta d)$  for  $N = 350$   
 $s$   
 (After Ref. 18:p. 8-11)

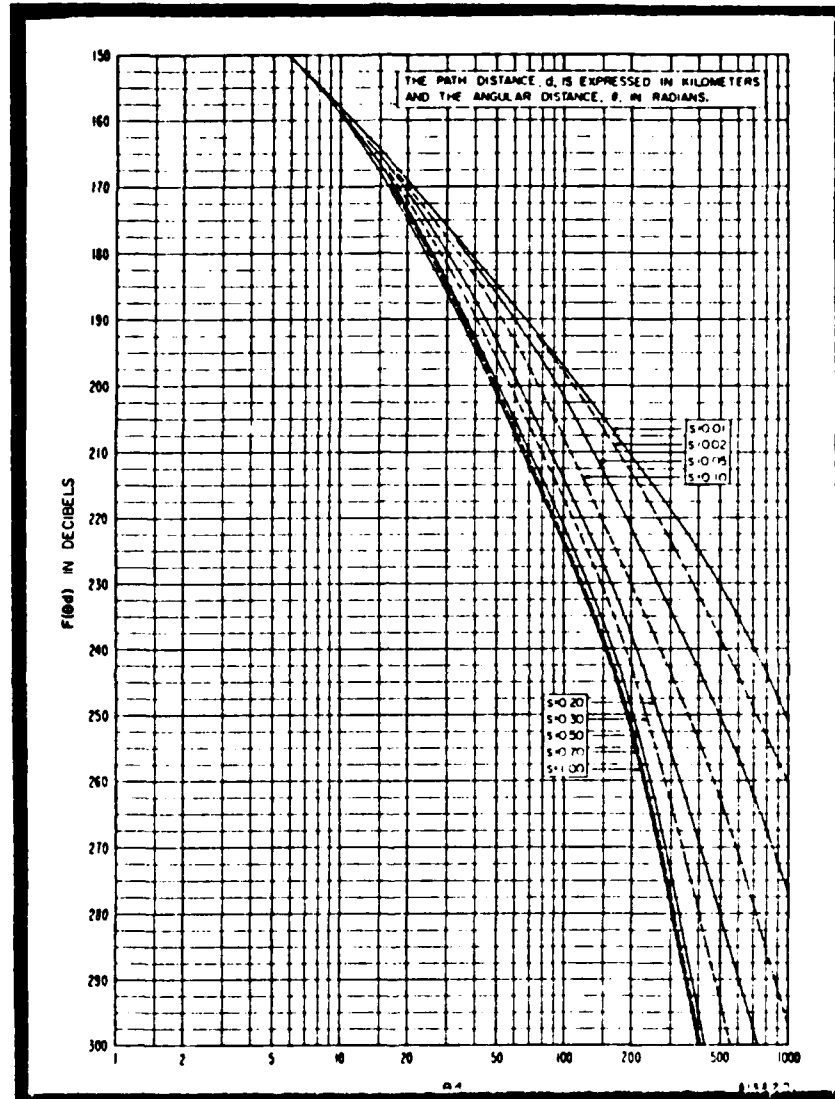


Figure A-4 Function  $F(\theta d)$  for  $N = 401$   
 (After Ref. 18:p. 8-12)

and  $H_o = 6[0.6 \log_{10} \eta_s] \log_{10} S \log_{10} q$

where  $\theta$  = scatter angle (angular distance) (mrad)

$f$  = frequency (MHz)

$h_{te}$  = transmitter elevation (km)

$h_{re}$  = receiver elevation (km)

$S_o = a_o / \beta_o$  (symmetry factor)

$q = r_2 / (s_1 r_1)$

$H_o(r_1)$  and  $H_o(r_2)$  are graphically derived using

Figure A-6, with  $\eta_s$  obtained from Figure A-5

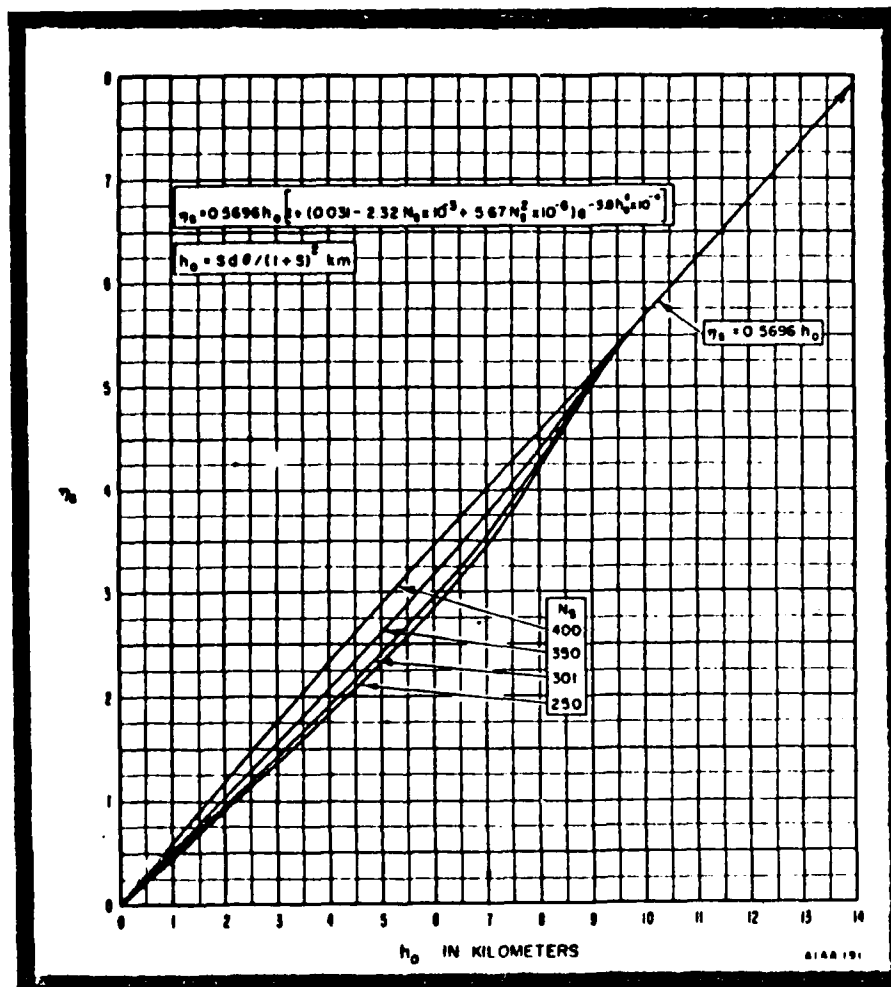


Figure A-5 Parameter N [h ] Used to  
 Compute  $h_0$   
 (After Ref. 18:p.6-32)

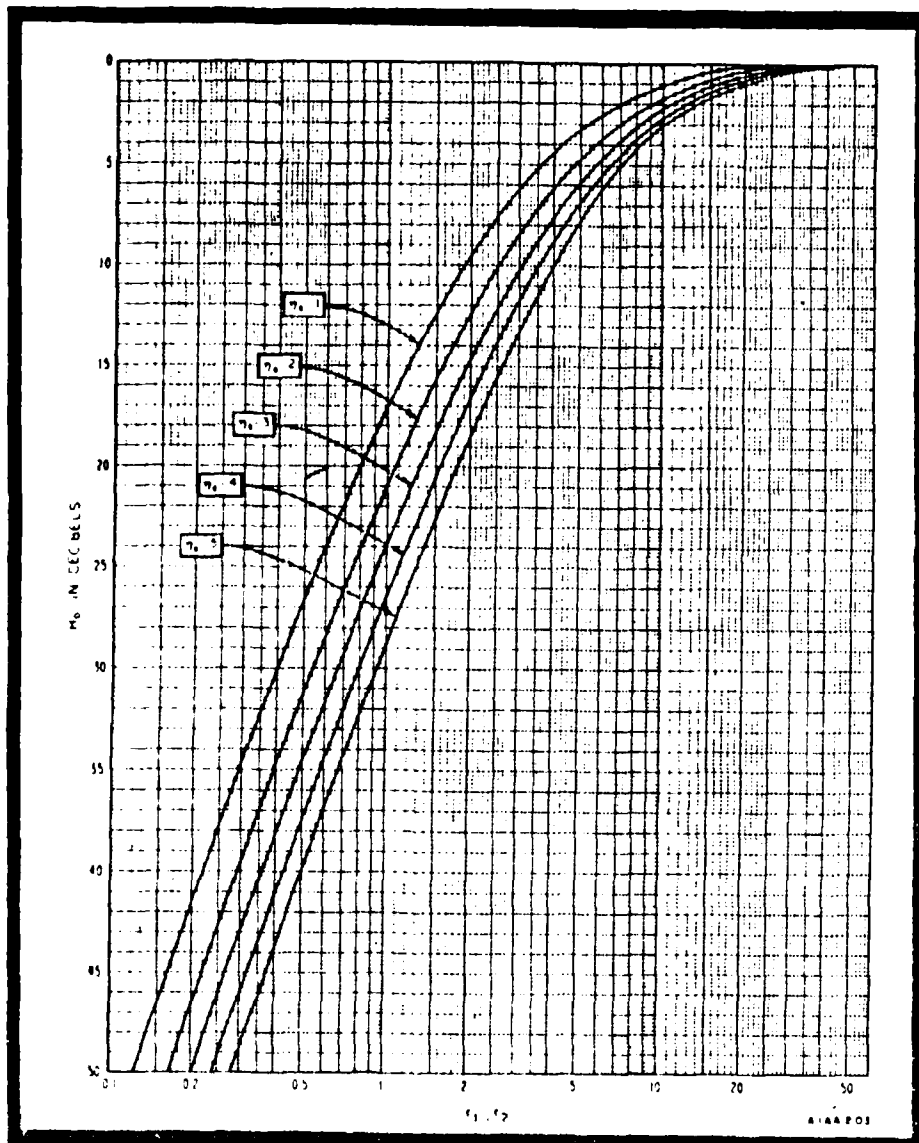


Figure A-6 Frequency Gain Function

(After Ref. 18:p. B-13)

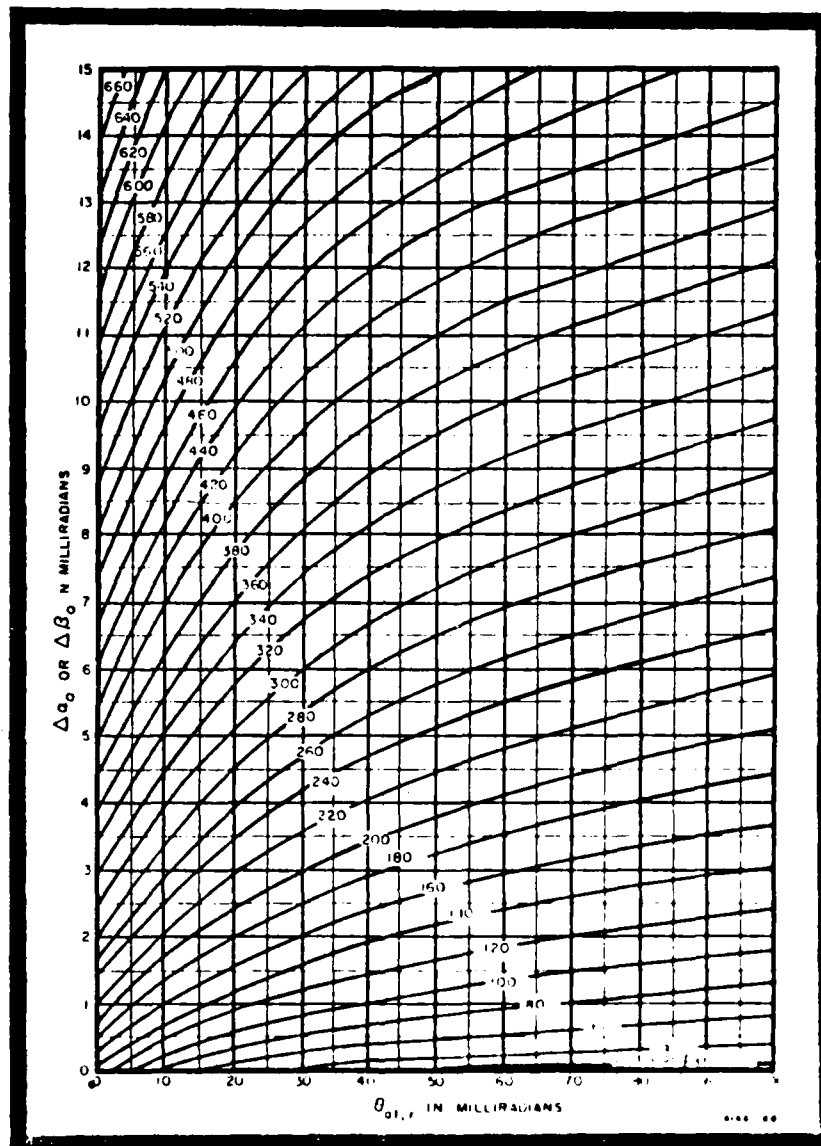


Figure A-7 Correction Terms for  $N = 301$   
 (After Ref. 18:p. 6-28)

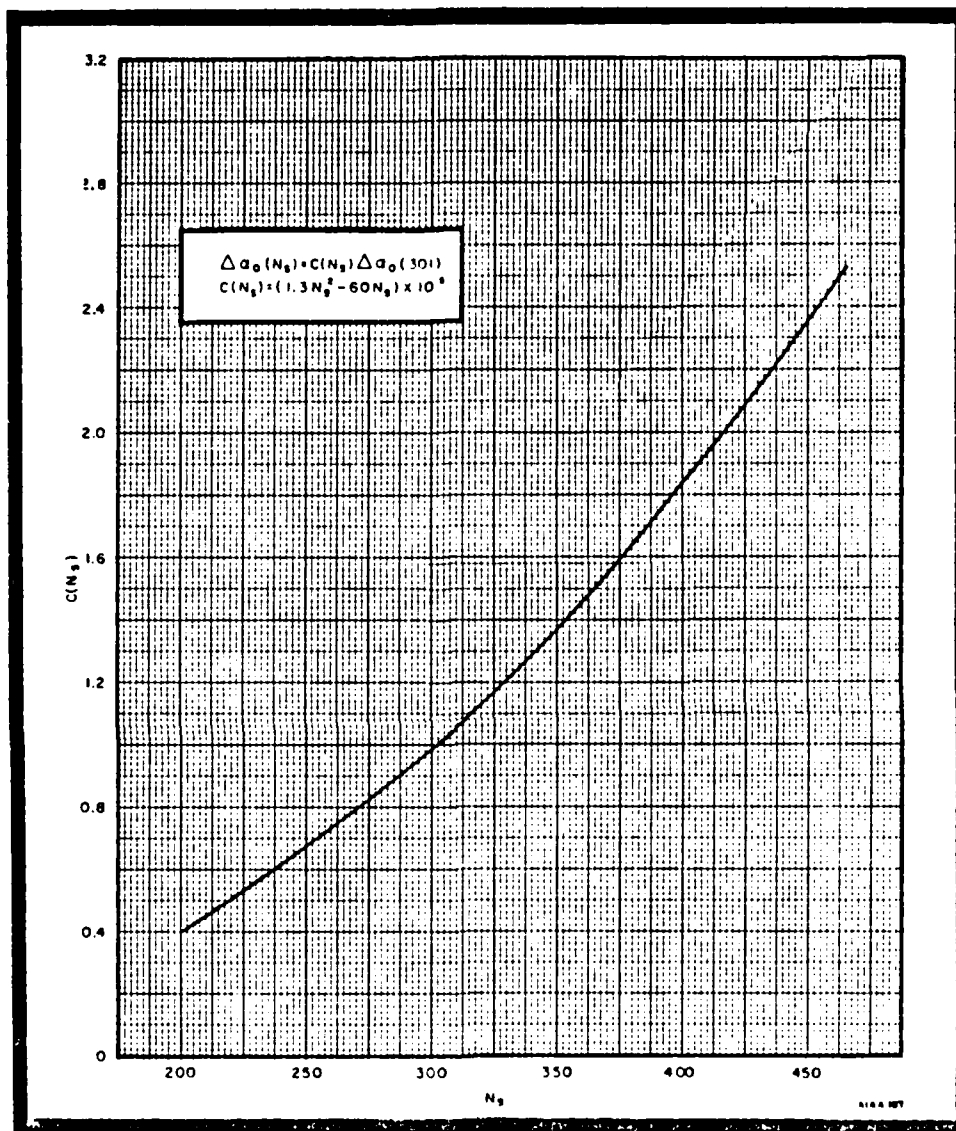


Figure A-8 Adjustment Factor for Figure A-7  
 (After Ref. 18:p. 6-29)





```

DIMENSION DIST(10), ELEV(10), MELEV(10), DIST1(40), MELEV1(40),
*MELEV1(40), DIST2(40), HELEV2(40), DIST3(40), PRES(40), TENP(40),
**WVP(40), ALI(40), KM(40), RN(40), NGRAD(40), COND(40), DRN(40),
*DALI(40), MALI(40), TYPE1(10),
INTEGER SYSZ, KJ, RESPON, LEV, DELTAM, DUCI, SET,
*FLAG*4, ALAM, ALONG, BLAT, BLONG, P, SP, SLA, CIA, CIB, SLB, CP, LP,
*DA, SM, KM, DM, DEG, RADIAN, PI, CONV, LPI, LP2, KKR, SNP, SMA, SNB,
**DB, DEGA, DC, DEGB, CSA, CSB, AZA, AZB, DEGC, DEG1, DA1,
*THI, ATH, KI, KAD, BIST, ELEV, MELEV, HTS, HKS, TAN, TH, RANTH, HS, NS,
**DIST1, ELEV1, AMELEV1, DIST2, MELEV2, DIST3, THETA1, THETA2,
**RH, TH, DLT, DRN, IR, HLT, DLR, TAND, TANDT, AGN, RAGN, PRES, TAMP,
*WVP, ALP, BIF, BGR, BGRATE, CNK, LC, ALT, DRN, MALL, HOPT, NPDBM, PIM, DELTAK1,
**PTUBM*4, DELTAP, DELTAV, DELTAF, LAMBDA, CL, LS, HCG, WGL, WNA, XT,
*TAKE2, RA, ALP, HA, BETA, LAMBDA, CON, LI, HO, HS, HCG, WGL, WNA, XT,
**FYK, RRD, AA, ALP, BB, YY, Z, ZP, P, UNDP, P, PPGD, THETA, FIT,
*FADE, TBM, CCM, NBO, Y, P, NDBM, LDF, SNR, LD, FG, P, N, WGD, THETA, FIT,
**TAMR, YMEAN, YMEAN, DBOT, DBOT, N,
*YINT, XMEAN, YMEAN, DBOT, DBOT, N

```

```

CHARACTER*4 ID1
CHARACTER*6 TYPE
CHARACTER*35 PATH
CHARACTER*20 TYPE1 TYPE2, TYPED
CHARACTER*4 Y, N, ST, P, ANS
CHARACTER*3 A11, A12, B11, B12

```

```

OPEN (7, FILE='LPT1:', STATUS='NEW')
DATA KA, D/6.378E6/1, N/1, N/1, STOP/1, STOP/1, Y/Y, Y/
TYPE1='ELEVATED'
TYPE2='SURFACE'
LD1 = 'NA'
PI=4*(ATAN(1.))
CONV=2*PI/360.

```

```

***** IDENTIFY VARIABLES *****
***** IDENTIFY VARIABLES *****

```

```

BIF = IF BANDWIDTH (HZ)
BW = TRANSMISSION BANDWIDTH (HZ)
CCN = UNLICENSED CHANNEL NOISE (DBA0)
CL = WAVEGUIDE CONNECTOR/JOINT LOSS
CNA = CARRIER-TO-NOISE RATIO (DB)
DELTA = COMMON TERRAIN OBSTACLE FACTOR
DIN = DIVERSITY IMPROVEMENT FACTOR
DIST = INCREMENTAL TERRAIN DISTANCE POINT ARRAY
DIST1 = TERRAIN POINT SORTING ARRAY
DIST2 = TERRAIN DISTANCE PLOTTING DATA ARRAY

```

|        |                     |                   |                           |
|--------|---------------------|-------------------|---------------------------|
| DIST3  | TEMPORARY           | TERRAIN POINT     | ARRAY                     |
| DLR    | RECVR               | OBSTACLE          | DISTANCE                  |
| DL1    | TRANS               | OBSTACLE          | DISTANCE                  |
| DS     | DISTANCE            | BETWEEN           | HORIZON OBSTACLES         |
| EBN    | BIT ENERGY/SPECTRAL | NOISE DENSITY     | (DB)                      |
| ELEV1  | INCREMENTAL         | TERRAIN ELEVATION | POINT ARRAY               |
| ELEV2  | ELEVATION           | POINT SORTING     | ARRAY                     |
| FADE   | TERRAIN ELEVATION   | PLOTTING          | DATA ARRAY                |
| FIT    | FAD MARGIN          | THRESHOLD         |                           |
| FREQ   | OPERATING           | FREQUENCY         | (MHZ)                     |
| HLK    | RECVR               | OBSTACLE          | ELEVATION                 |
| HLT    | TRANS               | OBSTACLE          | ELEVATION                 |
| HO     | ESTIMATED           | SCATTER VOLUME    | BASE ALTITUDE             |
| HRS    | TOTAL               | TRANS ANT         | ELEVATION                 |
| HS     | AVERAGE             | ANTENNA           | HEIGHT                    |
| LA     | RAINFALL            | ATMOSPHERIC       | ABSORPTION LOSS           |
| LC     | APERTURE-TO-MEDIUM  | COUPLING          | LOSS                      |
| LD     | KNIFE-EDGE          | DIFFRACTION       | LOSS                      |
| LDF    | CHANNEL             | LOADING           | FACTOR                    |
| LS     | FREQUENCY           | SCATTER           | LOSS                      |
| LT     | BASIC               | MEDIAN            | TRANSMISSION LOSS         |
| LW     | WAVEGUIDE           | LOSS              |                           |
| NBAO   | MINIMUM             | STANDARD          | CHANNEL NOISE (DBAO)      |
| NF     | RECEIVER            | NOISE FIGURE      | (DB)                      |
| NS     | SURFACE             | REFRACTIVITY      | (N-UNITS) AT ELEVATION    |
| PB     | PROBABILITY         | OF BIT            | ERROR                     |
| PM     | PROBABILITY         | OF SYMBOL         | ERROR                     |
| PN     | PREEMPHASIS         | IMPROVEMENT       | FACTOR                    |
| PT     | RECEIVED            | NOISE             | THRESHOLD (DBW)           |
| RATE   | TRANSMIT            | POWER             | (DBW)                     |
| RAGN   | TRANSMISSION        | DATA RATE         | (BITS/SEC)                |
| RANTH  | RECVR               | ANT GAIN          | (DB)                      |
| RK     | RECVR               | ANTENNA           | HEIGHT                    |
| RSDBM  | DISTANCE            | TO RECEIVER       | RADIO HORIZON             |
| RTH    | RECEIVED            | SIGNAL LEVEL      | (DBM)                     |
| RI     | RECVR               | TERMINAL          | ELEVATION                 |
| SNK    | SURFACE             | REFRACTIVITY      | (N-UNITS) MEAN SEA LEVEL  |
| TAGN   | SIGNAL-TO-NOISE     | RATIO             | (DB)                      |
| TAMH   | TRANS               | ANT DIAMETER      | (M)                       |
| THETA  | TRANS               | ANTENNA           | HEIGHT                    |
| THETA1 | DISTANCE            | ANTENNA           | TRANSMITTER RADIO HORIZON |
| THETA2 | SCATTER             | ANGLE             | (RAD)                     |
| TH1    | TRANS               | ANGLE             | (RAD)                     |
| TH2    | RECVR               | ANGLE             | (RAD)                     |
| TH3    | TRANS               | TERMINAL          | ELEVATION (M)             |

CC

```

C
C
C
WGL = WAVEGUIDE LENGTH(HETERS)
WGL = WAVEGUIDE LOSS PER UNIT LENGTH (DB/100 METER)

CALL CLEAR
WRITE(*,101)
FORMAT(//)
PROGRAM "TROPO": A TROPOSPHERIC SCATTER COMMUNICATIONS
*****
SYSTEM DESIGN PROGRAM
*****
VERSION 1.0 - 1985
*****
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
NAVAL POSTGRADUATE SCHOOL MONTEREY, CALIFORNIA 93943
SEPTEMBER 1985//

101 ENTER (1) TO CONTINUE .....')
READ(*,590) RESPON
IF (RESPON.NE.999) CONTINUE
CALL CLEAR
WRITE(*,*) DO YOU NEED INSTRUCTIONS? YES(1)/NO(2)
READ(*,590) RESPON
GOTO (102,100),RESPON

102 CALL CLEAR
103 WRITE(*,103)
FORMAT(//)
***** INSTRUCTIONS *****
THE PROGRAM WILL SEQUENCE THROUGH SEVERAL SCREENS.
SELECTION MENUS WILL REQUIRE A SINGLE INTEGER RESPONSE.
ALL NUMERICAL INPUT DATA ARE CONSIDERED REAL VALUES.
HENCE A DECIMAL POINT IS REQUIRED. ALL INTEGER RESPONSES WILL BE SPECIFIED.
PROGRAM RESULTS WILL BE PRINTED OUTPUT AND CANNOT BE STORED FOR A REPEATED RUN.
TERRAIN DATA POINTS CAN BE STORED IN AN EXTERNAL DATA FILE.
THE PROGRAM WAS DESIGNED TO COMPUTE PERFORMANCE PREDICTIONS FOR NUMEROUS TROPOSCATTER TERMINAL EQUIPMENT, INCLUDING THE DIGITAL RADIO, AN/TRC-170.

104 TERRAIN PROFILE PLOT: THE PRINTER PLOT WILL PROVIDE A LINEAR TERRAIN PROFILE WITH RESPECT TO A SELECTED TRANSMITTER SITE. EXTERNAL TERRAIN PLOTTING METHODS CAN BE USED AND NEAR OBSTACLE DATA CAN BE OBTAINED INDEPENDENTLY.
***** RADIOSONDE DATA ANALYSIS: IF REAL-TIME RADIOSONDE WEATHER DATA CANNOT BE OBTAINED, STATISTICAL INFORMATION *****

CALL CLEAR
WRITE(*,104)
FORMAT(//)
104 TERRAIN PROFILE PLOT: THE PRINTER PLOT WILL PROVIDE A LINEAR TERRAIN PROFILE WITH RESPECT TO A SELECTED TRANSMITTER SITE. EXTERNAL TERRAIN PLOTTING METHODS CAN BE USED AND NEAR OBSTACLE DATA CAN BE OBTAINED INDEPENDENTLY.
***** RADIOSONDE DATA ANALYSIS: IF REAL-TIME RADIOSONDE WEATHER DATA CANNOT BE OBTAINED, STATISTICAL INFORMATION *****

```

```

$13X. . . TION ON ELEVATED TROPOSPHERIC DUCTS CAN BE USED.
$13X. . . IF THE SELECTED ELEVATED DUCT PARAMETERS DO NOT MEET
$13X. . . THE HEIGHT MODEL SPECIFICATIONS, THE HEIGHT GAIN
$13X. . . VALUE AT THE AVERAGE TRANSMIT/RECEIVE ANTENNA HEIGHT
$13X. . . MUST BE EXTERNALLY COMPUTED AND ENTERED. . . //
$13X. 1X. . . ENTER (1) TO BEGIN PROBLEM . . . . .
READ (**, 590) RESPON
IF (RESPON.NE.999) CONTINUE

```

```

C 100 CALL CLEAR
      WRITE (**, 501)
      WRITE (**, 500)
      READ (**, 510) ALAT
      WRITE (**, 520) ALONG
      READ (**, 530) BLAT
      WRITE (**, 540) BLONG
      WRITE (**, 550)
      WRITE (**, 560) ALAT, ALONG
      WRITE (**, 570) BLAT, BLONG
      WRITE (**, 580)
      READ (**, 590) RESPON
      GOTO (100, 200) RESPON
200 P=(ALONG-BLONG)
      SP=SIN(P*CONV)
      SLA=SIN(ALAT*CONV)
      CLA=COS(ALAT*CONV)
      SLB=SIN(BLAT*CONV)
      CLB=COS(BLAT*CONV)
      CP=COS(P*CONV)
      LP1=SLA*SLB
      LP2=CLA*(CLB*CP)
      DA=ATAN((LP1+LP2)/(SQRT(1-((LP1+LP2)**2))))
      RADIANS=360/(2*PI)
      DAI=(PI/2.)-LA
      DEG=DAI*RADIANS
      SM=(DEG*60.0)*1.1516
      KM=(DEG*60.0)*1.85325
      SND=SIN(DEG*CONV)
      SNP=SP/SND
      SNA=SMP*CLB
      SNB=SNP*CLA
      DEGA=RADIANS*(ATAN(SNA/(SQRT(1-(SNA**2))))))
      DEGB=ABS(DEGA)
      DEGB=RADIAN*(ATAN(SNB/(SQRT(1-(SNB**2))))))
      DEGB=ABS(DEGB)
      CSA=({(SLB)} - {(LP1+LP2)*SLA}) / {(SND*CLA)}
      CSB=({(SLA)} - {(LP1+LP2)*SLB}) / {(SND*CLB)}

```

```

DEGC1=RADIAN*(ATAN((CSA)/(SQRT(1-(CSA**2))))))
DEGC=(PI/2. )-DEGC1
DEGD1=RADIAN*(ATAN((CSB)/(SQRT(1-(CSB**2))))))
DEGD=(PI/2. )-DEGD1
IF (DEGA.GE.0) THEN
  IF (DEGA.LE.10.0) THEN
    DEGA=DEGA
  ENDIF
ENDIF
IF (DEGA.GE.80.0) THEN
  IF (DEGA.LE.90.0) THEN
    DEGA=DEGC
  ENDIF
ENDIF
IF (SNA.GE.0) THEN
  IF (CSA.GE.0) THEN
    AZA=DEGA
  ELSE
    AZA=(180.)-DEGA
  ENDIF
ELSE
  IF (CSA.GE.0) THEN
    AZA=(360.)-DEGA
  ELSE
    AZA=(180.)+DEGA
  ENDIF
ENDIF
IF (DEGB.GE.0) THEN
  IF (DEGB.LE.10.0) THEN
    DEGB=DEGB
  ENDIF
ENDIF
IF (DEGB.GE.80.0) THEN
  IF (DEGB.LE.90.0) THEN
    DEGB=DEGD
  ENDIF
ENDIF
IF (SNB.GE.0) THEN
  IF (CSB.GE.0) THEN
    AZB=(360.)-DEGB
  ELSE
    AZB=(180.)+DEGB
  ENDIF
ELSE
  IF (CSB.GE.0) THEN
    AZB=DEGB
  ELSE
    AZB=(180.)-DEGB
  ENDIF

```

```

550 FORMAT (//13X, 'SITE DESIGNATOR', 6X, 'LATITUDE', 6X, 'LONGITUDE')
560 FORMAT (//21X, 'TRANS', 6X, F8.2, 6X, F8.2)
570 FORMAT (//21X, 'RECVR', 6X, F8.2, 6X, F8.2)
580 FORMAT (//11X, 'ANY COORDINATE CHANGES? YES(1)/NO(2)')
590 FORMAT (//11)
500 FORMAT (//11X, 'ENTER TRANS SITE LATITUDE (DEG).')
501 FORMAT (//)
$13X, 'SITE LOCATION INPUT INFORMATION'
$13X, 'ENTER LATITUDE/LONGITUDE VALUES AS A SINGLE REAL'
$13X, 'NUMBER. MINUTES MUST BE CONVERTED TO A DECIMAL'
$13X, 'FRACTION OF A DEGREE. ALL DEGREES NORTH AND WEST'
$13X, 'ARE POSITIVE REAL. ALL DEGREES SOUTH AND EAST ARE'
$13X, 'NEGATIVE REAL VALUES.'
$13X, 'EXAMPLE: LATITUDE 35 DEGREES/38 MINUTES SOUTH'
$13X, 'ENTER AS: - 35.633 DEGREES')
510 FORMAT (//F8.2)
520 FORMAT (//11X, 'ENTER TRANS SITE LONGITUDE (DEG).')
530 FORMAT (//11X, 'ENTER RECVR SITE LATITUDE (DEG).')
540 FORMAT (//11X, 'ENTER RECVR SITE LONGITUDE (DEG).')

CALL CLEAR
WRITE(*, 1101)
1101 FORMAT (//)
$13X, 'YOU HAVE THE OPTION TO ENTER THE TRANSMITTER AND'
$13X, 'RECEIVER RESPECTIVE RADIO HORIZON DISTANCE (KM)'
$13X, 'ELEVATION (M). SELECT YOUR OPTION:'
$13X, '(1) ..... ENTER RADIO HORIZON DATA'
$13X, '(2) ..... ENTER TERRAIN PROFILE DATA POINTS'
READ (*, 590), RESPON
GOTO (1105, 1102), RESPON
1102 WRITE (*, 703) KM
WRITE (*, 704) Z
FLAG = 0
GOTO 1150

C INPUT PATH TERRAIN ELEVATION AND DISTANCE TO DETERMINE
C TERRAIN PROFILE.
C
C WRITE(*, 620)
620 FORMAT (//)
$13X, 'DO YOU WISH TO ENTER TERRAIN DATA FROM AN'
$13X, 'EXTERNAL DATA FILE. THIS FILE SHOULD BE'
$13X, 'NAMED: TERRAIN.TXT AND FORMATTED AS 1E10.J'
$13X, 'COLUMN 1: DISTANCE (KILOMETERS) TO ELEVATION'
$13X, 'COLUMN 2: ELEVATION (METERS)'
$13X, 'YES(1) OR NO(2)'
READ (*, 90), RESPON
IF (RESPON.EQ.1) THEN

```

```

CCCCCCCCCCCCCCCC
51      REMIND(2)
DO      51 I = 152
        READ(2,603)DIST(I),ELEV(I)
        CONTINUE
        RESPON = 3
        ELSE
        CONFINE
        ENDIF
        IF (RESPON.EQ.3) THEN
        ELSE GOTO 1105
        ENDIF
        CALL CLEAR
        WRITE(*,1104)
        1104 $FORMAT(/
        WRITE(*,1110)
        1110 $FORMAT(/,13X,'DISTANCE (KM) TO RADIO HCRIZON/OBSTACLE ',
        $FROM TRANSMITTER SITE')
        READ(*,1111)DLT
        DLF = DLT*1.0E3
        1111 $FORMAT(F6.2)
        WRITE(*,1112)
        1112 $FORMAT(/,13X,'TRANSMITTER RADIO HORIZON TERRAIN ',
        $ELEVATION (METERS)')
        READ(*,1113)HLR
        WRITE(*,1113)
        1113 $FORMAT(/,13X,'DISTANCE (KM) TO RADIO HORIZON/OBSTACLE ',
        $FROM RECEIVER SITE')
        READ(*,1111)LLR
        DLF = DLR*1.0E3
        WRITE(*,1114)
        1114 $FORMAT(/,13X,'RECEIVER RADIO HORIZON TERRAIN ',
        $ELEVATION (METERS)')
        READ(*,1111)HLR
        GOTO 1151
        1105 ELAG = 1
        1150 CALL CLEAR
        690 WRITE(*,690)
        690 $FORMAT(/,1X,'ENTER TRANSMITTER TERRAIN ELEVATION (METERS)')
        READ(*,700)THT
        WRITE(*,691)
        691 $FORMAT(/,1X,'ENTER TRANSMIT ANTENNA HEIGHT (METERS)')
        READ(*,700)TANTH
        ELEV(1) = THT + TANTH
        DIST(1) = 000.0
        WRITE(*,692)
        692 $FORMAT(/,1X,'ENTER RECEIVER TERRAIN ELEVATION (METERS)')
        READ(*,700)RTH

```

```

693 WRITE(*,693) ENTER RECEIVER ANTENNA HEIGHT (METERS)
    FORNAT(700) RANTH
    READ(*,700) RANTH
    ELEV(Z)=RTH+RANTH
    DIST(Z)=KM*1.0E3
    IF(FLAG.EQ.1) GO TO 1120
    ***** AVERAGE ANTENNA HEIGHT *****
    C ***** HT. (METERS) TO (THOUSANDS OF FEET) *****
    1151 HS=(THT*TANTH+RTH+RANTH)/2.
    C ***** CONVERT AVE. ANT. HT. (METERS) TO (THOUSANDS OF FEET) *****
    HS=(HS*3.281)/1000.
    IF(FLAG.EQ.0) THEN
    DO 3 I=1,Z-2
    L=I+1
    WRITE(*,705) L DIST1(I)
    READ(*,700) DIST1(I)*.6E3
    DIST1(I)=DIST1(I)
    WRITE(*,707) L
    READ(*,700) ELEV1(I)
3 CONTINUE
    ELSE CONTINUE
    ENDIF
    WRITE(*,701) RESPON
    READ(*,590) RESPON
    GOTO(750,751,752),RESPON
750 R1=289.0
751 R1=315.0
752 GOTO 803
    ***** EFFECTIVE EARTH'S RADIUS EQUATION: *****
    C *****
    603 WRITE(*,710) R1
    READ(*,700) R1
    ***** HS=HS-2*HS) *R1
    NS=EXP(-3.22E-2*HS)
    KR=RAD*(1-(EXP((NS*5.577E-3)) *0.04665))
    WRITE(*,711) R1,NS,KR
    IF(FLAG.EQ.0) THEN
    READ(*,590) DO YOU WANT TO SAVE TERRAIN DATA? YES(1)/NO(2)
    IF( WRITE(*,590) RESPON
    READ RESPON.EQ.1) THEN
    IF (CLOSE(2,STATUS='DELETE')
    OPEN(2,FILE='C:TERRAIN.DAT',STATUS='NEW')
    DO 50 I=1,Z
    WRITE(2,603) DIST(I),ELEV(I)
50 CONTINUE
    ENDIF
    MELEV(I)=(DIST(I)**2)/(KR*2.0)
    DO 4 MELEV(I)=ELEV1(I)-((DIST1(I)**2)/(KR*2.0))
4 CONTINUE

```



```

753 $ MELEV(Z) = ELEV(Z) - ((DIST(Z)**2) / ((KR*2.0)))
WRITE(7,901) CHAR(27),CHAR(15)
FORMAT(7,753)
3X,'DISTANCE',3X,'TERRAIN ELEV',
3X,'MODIFIED ELEV')
I=1
WRITE(7,706) I,DIST(1),ELEV(1),MELEV(1)
DO 6 I=1,Z-2
L=I+1
WRITE(7,706) L,DIST(1),ELEV(1), MELEV(1)
CONTINUE
WRITE(7,706) Z,DIST(Z),ELEV(Z),MELEV(Z)
WRITE(7,917) CHAR(27),CHAR(18)
WRITE(7,754)
FORMAT(7,754)
C ***** PLOTTING DATA ARRAY (DIST2/MELEV2) *****
754
DIST2(1) = DIST(1)
MELEV2(1) = MELEV(1)
DO 13 I=1,Z-2
L=I+1
DIST2(L) = DIST(I)
MELEV2(L) = MELEV(I)
CONTINUE
DIST2(Z) = DIST(Z)
MELEV2(Z) = MELEV(Z)
FORMAT(7,703)
/15X,'SURFACE REFRACTIVITY (SELECT)',
/15X,'.....289 N-UNITS (STANDARD)',
/15X,'.....315 N-UNITS (M. GERMANY)',
/15X,'.....OTHER.'
FORMAT(7,703)
13X,'HOW MANY TERRAIN POINTS? (LESS THAN 40)://'
13X,'EACH TERRAIN POINT DISTANCE WILL INCREASE FROM://'
13X,'THE TRANSMITTER SITE. THE FINAL ENTRY MUST BE://'
13X,'LESS THAN THE PATH RANGE OF ',F8.1,' KILOMETERS.')
FORMAT(7,704)
1X,'ENTER POINT( ',I2,' ) DISTANCE (KM) ',
FORMAT(7,705)
3X,'POINT( ',I2,' ) F10.3 3X,F10.3)
FORMAT(7,706)
1X,'ENTER POINT( ',I2,' ) TERRAIN HEIGHT (METERS)')
FORMAT(7,710)
1X,'ENTER SURFACE REFRACTIVITY.'
C *** DEBUG COMMENTS TO CHECK TERRAIN NEAR OBSTACLE SEARCH ***
C REMOVE TO SWITCH ON PRINTOUT CHECK
CALL SORT2(MELEV1,DIST1,Z-2)
CDEBUG DO 8 I=1,Z-2
C WRITE(7,*) DIST1(I),MELEV1(I)
C CONTINUE
DLT=DIST1(Z-2)
HLT=MELEV1(Z-2)
CDEBUG WRITE(7,*) MAXADIST=,DIST1(Z-2),MAXAELEV=,MELEV1(Z-2)

```

```

CALL INVERT(ELEV1,Z-2)
HOLD=ELEV(1)
ELEV(Z)=ELEV(Z)
ELEV(Z)=HOLD
WRITE(7,*)DIST(1),ELEV(1)
DO 15 I=2,Z-1
  DIST3(I)=DIST2(I)
CONTINUE
DO 9 I=1,Z-2
  DIST1(I)=(KM*1.0E3)-DIST3(Z-I)
  MELEV(I)=ELEV1(I)-((DIST1(I)**2)/(KR*2.))
  WRITE(7,*)DIST(I),ELEV(I),MELEV(I)
CONTINUE
WRITE(7,*)DIST(Z),ELEV(Z)
CALL SORT(MELEV,DIST,Z-2)
MELEV(1)=ELEV(1)
WRITE(7,*)DIST(1),ELEV(1),MELEV(1)
DO 11 I=1,Z-2
  WRITE(7,*)DIST1(I),ELEV1(I),MELEV1(I)
CONTINUE
MELEV(Z)=ELEV(Z)-((DIST(Z)**2)/(KR*2.0))
WRITE(7,*)DIST(Z),ELEV(Z),MELEV(Z)
DLR=DIST1(Z-2)
HLR=MELEV(Z-2)
WRITE(7,*)MAXBDIST=,DIST1(Z-2),MAXBELEV=,MELEV1(Z-2)
WRITE(7,*)MAXBDIST2=,DIST2/MELEV2
DO 14 I=1,Z
  WRITE(7,*)DIST2(I),MELEV2(I)
CONTINUE
ELSE CONTINUE
ENDIF
***** DELTA REPRESENTS THE SINGLE KNIFE-EDGE *****
***** OBSTACLE TOLERANCE INTERVAL *****
DELTA = 100.0
HTS = TAN(H+TH)
HRS = RANT(2*KR*HRS)
RH = SORT(2*KR*HTS)
TH = SORT(SINGLE KR*HTS)
***** DIFFRACTION MODE *****
IF((DLT.LE.DLR+DELTA).AND.(DLR.LE.DLT+DELTA))GOTO 1000
***** NEAR OBSTACLES *****
IF((DLT.LE.BOTH TERMINALS AT NEAR OBSTACLES)
***** GOTO 1100 *****
IF((DLT.LE.DOUBLE SMOOTH EARTH DIFFRACTION
***** GOTO 1200 *****
IF((DLT.EQ.TH).AND.(DIR.EQ.RH))GOTO 1200
***** NEAR OBSTACLE AT TRANSMITTER AND SMOOTH EARTH AT RECV *****
IF((DLT.LE.TH).AND.(DIR.EQ.RH))GOTO 1300
***** NEAR OBSTACLE AT RECV AND SMOOTH EARTH AT TRANSMITTER *****

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1000 IF ((DLT.EQ.TH).AND.(DIR.LT.RH)) GOTO 1400
      THETA1 = (((HLT-HTS)/DLT) - (DLT/{2*KB}))
      THETA2 = (((HLR-HRS)/DLR) - (DLR/{2*KR}))
      PATH = 'KNIFE-EDGE DIFFRACTION MODE'
      PROFILE = 99
      GOTO 1800
1100 THETA1 = (((HLT-HTS)/DLT) - (DLT/{2*KR}))
      THETA2 = (((HLR-HRS)/DLR) - (DLR/{2*KR}))
      PATH = 'NEAR OBSTACLE PATH MODE'
      GOTO 1800
1200 THETA1 = -TH/KR
      THETA2 = -RH/KR
      PATH = 'SMOOTH EARTH PATH MODE'
      GOTO 1800
1300 THETA1 = (((HLT-HTS)/DLT) - (DLT/{2*KR}))
      THETA2 = -RH/KR
      PATH = 'NEAR OBSTACLE/SMOOTH EARTH PATH'
      GOTO 1800
1400 THETA1 = -TH/KR
      THETA2 = (((HLR-HRS)/DLR) - (DLR/{2*KB}))
      PATH = 'SMOOTH EARTH/NEAR OBSTACLE PATH'
1800 ALPHA = (KM*1.OE3)/(2*KR) + (HTS-HRS)/(KM*1.OE3)
      BETA = (KM*1.OE3)/(2*KR) + (HRS-HIS)/(KM*1.OE3)
      THETA1 = ALPHA + BETA
      THETA2 = ALPHA/BETA
      S = (KM*1.OE3) - DLT - DLR
      HO = (S*DS*THETA)/(F10.3**2)
      F03 = (2X,F10.3,2X,F10.3)
      F153 = (2Y,F15.3,2Y,F15.3)
603 IF (FLAG.EQ.1) GOTO 1500
      WRITE(*,*) 'DO YOU NEED A TERRAIN PROFILE PLOT? YES (1)/NO (2)'
      READ(*,590) RESPON
      GOTO (760,1500) RESPON
760 CALL PLOT(2,DIST2,MELEV2)

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***** LONG-TERM MEDIAN BASIC TRANSMISSION LOSS *****
      INPUT PARAMETERS AND CALCULATION
1500 CALL CLEAR
      WRITE(*,*) 'ENTER THE OPERATING FREQUENCY (MHZ)'
      READ(*,1501) FREQ
      WRITE(*,1501) FREQ
1501 F03 = (2X,F10.3)
      WRITE(*,1501) F03
      WRITE(*,1502) 'ENTER TRANSMIT ANTENNA DISH DIAMETER (FEET)'
      READ(*,1502) TAND
1502 F072 = (F7.2)
      WRITE(*,1502) F072
      WRITE(*,1503) 'ENTER RECEIVER ANTENNA DISH DIAMETER (FEET)'
      READ(*,1503) RAND

```

```

1503 FORMAT(F7.2)
      TAGN = {20*LOG10(FREQ)} + {20*LOG10(LAND)} - 52.6
      ANTG = TAGN + RAGN
      GOTO 300
C ***** DIFFRACTION LOSS *****
1620 HG = 0.0
1600 LAMDA = 3.0E8/(FREQ*1.0E6)
C ***** CONVERT TAKE-OFF ANGLES TO DEGREES *****
      TAKE1 = THETA1*57.2958
      TAKE2 = THETA2*57.2958
      LD = 0.0
      IF (PROFILE.EC.99) THEN
        LD = 20*LOG10(2*PI*THETAD*(SQRT(DLT/LAMDA)))
      ELSE
        DIFF = 0
        LD = LD1
      ENDIF
C ***** APERTURE-TO-MEDIUM COUPLING LOSS *****
      DD = (KM + 50.0)/50.0
      LC = -0.8929*(0.8655*DD) - (0.0131*(DD**2))
C ***** FREE-SPACE/SCATTER LOSS *****
      LS = 30*LOG10(FREQ) + 20*LOG10(SM) + 0.2*(NS-310.0) + 10*THETAD + 57.0
C ***** HAVEGUIDE ATTENUATION *****
      CALL CLEAR
      WRITE(*,400)
      FORMAT(//)
      *13X, ***** SELECT THE APPROPRIATE WAVEGUIDE TYPE:
      *13X, (1) ..... WR229 (R40) RIGID
      *13X, (2) ..... WR18 (R48) RIGID
      *13X, (3) ..... EM44 (FLEXIBLE)
      *13X, (4) ..... RESPON
      READ(*,590) RESPON
      GOTO 1459
1450 WRITE(*,*) 'INCORRECT DATA ENTRY. PLEASE TRY AGAIN'
1459 WRITE(*,401)
401 FORMAT(//)
      *13X, ENTER THE TOTAL SYSTEM WAVEGUIDE LENGTH (FEET)
      *13X, YOU SHOULD INCLUDE ADDITIONAL WAVEGUIDE FOR
      *13X, ALL ANTENNAS AT BOTH TERMINAL SITES.
      READ(*,402,ERR=1450) WGD

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```

402 FORMAT(F5.2)
WGD = WGD*3.281/100.0
GOTO(403,404,405,406),RESPON
403 WGL = 2.4
404 GOTO 410
405 WGL = 4.0
406 GOTO 410
407 WGL = 4.5
408 GOTO 410
409 WGL = 5.0
410 GOTO 1458
1451 WRITE(*,*) 'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
1458 WRITE(*,*) 'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
407 FORMAT(//)
*13X, ENTER THE WAVEGUIDE LOSS PER 100 METER (DB)
READ(*,408)WGL
408 FORMAT(F5.2)
410 LW = WGL*WGD

```

C C \*\*\*\*\* WAVEGUIDE CONNECTION LOSS \*\*\*\*\*

```

GOTO 1457
1452 WRITE(*,*) 'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
1457 WRITE(*,*) 'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
1460 FORMAT(//)
*13X, ENTER THE TOTAL NUMBER OF WAVEGUIDE CONNECTIONS.*/
READ(*,491)ERR=1452)CCN
491 FORMAT(F3.0)
CL = CCN*0.06

```

C C \*\*\*\*\* RAINFALL ATMOSPHERIC ABSORPTION LOSS (DB) \*\*\*\*\*

```

CALL CLEAR
WRITE(*,420)
420 FORMAT(//)
*13X, ***** RAINFALL ATMOSPHERIC ABSORPTION *****
*13X, ENTER CURRENT RAINFALL RATE: {100 MM/HR}
*13X, {1} ..... CLOUDBURST {15 MM/HR}
*13X, {2} ..... HEAVY RAIN { 4 MM/HR}
*13X, {3} ..... MODERATE RAIN { 1 MM/HR}
*13X, {4} ..... LIGHT RAIN
*13X, {5} ..... NEGLECT RAINFALL
READ(*,421,422,423,424,425),RESPON
421 RR = 0.5
422 GK = 0.07
423 RR = 0.02
430 GOTO

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```

424 RR = 0.005
GOTO 430
425 RR = 0.0
430 LA = RR*(KM*0.62137)

LT = LS+LD+LC+CL+LA+LW+ANTG-HG
TG = ANTIG + HG
CALL CLEAR
WRITE(*,1430)
1430 FORMAT(//***** TRANSMITTER POWER *****//)
$//
GOTO 1456
1453 WRITE(*,*) 'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
1456 WRITE(*,431)
431 FORMAT(//
*13X,ENTER THE TRANSMITTER OUTPUT POWER (WATTS): ' )
READ(*,F7.2,ERR=1453)WATT
432 FORMAT(F7.2)
PT = LOG10(WATT)
PTDBM = PT + 30.0
RS = PT - LT
GOTO 1455
1454 WRITE(*,*) 'DATA ENTRY ERROR. PLEASE TRY AGAIN.'
1455 CALL CLEAR
433 WRITE(*,433)
433 FORMAT(//***** RECEIVER PARAMETER INPUT *****//)
$13X, //
$13X, //
$13X,ENTER RECEIVER NOISE FIGURE (DECIBELS):'//
$13X,REMARK ..143/144
$13X,** AN/GRC-143/144 RECEIVER NOISE FIGURE: 5.5'
$13X,** AN/TARC-170 DIGITAL RADIO TERMINAL: 4.0'
READ(*,F4.1,ERR=1454)NF
434 FORMAT(F4.1)
435 WRITE(*,435)
435 FORMAT(//
*13X,ENTER THE RECEIVER IF BANDWIDTH (MHZ):'//
*13X,REMARK ..143/144 IF BANDWIDTH: 70 MHZ'//
*13X,** AN/GRC-143/144 IF BANDWIDTH: 70 MHZ'//
*13X,** AN/TARC-170 IF BANDWIDTH: 70 MHZ'//
*13X,** AN/GRC-201 IF BANDWIDTH: 2 MHZ'//
READ(*,F6.3)BIF
436 FORMAT(F6.3)
BIF = BIF*1.0E6
***** FREQUENCY AND SPACE DIVERSITY *****
SEPARATION REQUIREMENT

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TAMR = THETA1*1.0E3
TMR = THETA2*1.0E3
TMR = THETA*1.0E3
TAND = TAND*0.3048
DELTAH = 0.36*SORT(TAND**2+1600)
DELTAV = 0.36*SORT(TAND**2+225)
DELTAF = (1.44*FREQ/(KM*INR))*SQRT(TAND**2+225)

```

```

PN = -204.0 + NF + 10*LOG10(BIF)
NPDBM = -174.0 + NF + 10*LOG10(BIF) + 10.0
CNK = RS - FN
KSDBM = RS + 30.0
PNDBM = PN + 30.0
FIT = PNDBM + 10.0
FADE = RSDBM - FIT

```

\*\*\*\*\* SYSTEM PATH RELIABILITY CALCULATION \*\*\*\*\*

```

470 CALL CLEAR
WRITE(*,470)
FORMAT(//)
13X, // SELECT THE APPROPRIATE TERRAIN DESCRIPTION.
13X, // {1} ..... SMOOTH EARTH, OVER WATER, DESERT.
13X, // {2} ..... ROLLING HILLS, RUGH TERRAIN
13X, // {3} ..... MOUNTAINOUS TERRAIN.
READ(*,590) RESPON
GOTO(471,472,473), RESECN

```

```

471 AA = 4.0
GOTO 480
472 AA = 1.0
GOTO 480
473 AA = 0.25
GOTO 480
480 RMM = AA*1.0E-5*((FREQ/1.0E3)/4)*(SM**3)
WRITE(*,481)
FORMAT(//)

```

```

13X, // SELECT THE APPROPRIATE CLIMATE DESCRIPTION.
13X, // {1} ..... HOT HUMID COSTAL AREA
13X, // {2} ..... TEMPERATE SUBARCTIC AREA
13X, // {3} ..... VERY DRY CLIMATE
READ(*,590) RESPON
GOTO(482,483,484), RESPON

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```

482 BB = 0.5
GOTO 490
483 BB = 0.25
GOTO 490
484 BB = 0.125
GOTO 490
490 RYR = BB*RMM
UNDP = RYR*10**(-FADE/10)
REL = 100*(1 - UNDP)
IF(REL.LT.0.0) REL = 0.0

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```

IF (REL.GT.100.0) REL = 100.0
CALL CLEAR
WRITE(*,492)
492 FORMAT(//)
$13X, // MODULATION TECHNIQUES *****//
$13X, // SELECT THE TYPE OF MODULATION: //
$13X, // (1) ..... FM/FDD (ANALOG) //
$13X, // (2) ..... DIGITAL //
READ (*,590) RESPON
GOTO {499,493} RESPON
*****
* PROBABILITY OF BIT ERROR *****
* DIGITAL MODULATION *****
* *****
* *****
493 CALL CLEAR
WRITE(*,437)
437 FORMAT(//)
$13X, // DIGITAL MODULATION PARAMETERS *****//
$13X, //
$13X, // ENTER THE TRANSMISSION DATA RATE (KBITS/SEC): ( )
*13X, // RATE = RATE*1.0E3
439 FORMAT(F10.3)
EBN = NF + 204 - 10*LOG10(RATE)
CALL CLEAR
WRITE(*,440)
440 FORMAT(//)
$13X, // SELECT THE SYSTEM ORDER OF DIVERSITY: //
$13X, // (1) ..... DUAL DIVERSITY //
$13X, // (2) ..... QUAD DIVERSITY //
READ (*,590) RESPON
IF (RESPON.EQ.1) L=2
IF (RESPON.EQ.2) L=4
CALL CLEAR
WRITE(*,441)
441 FORMAT(//)
$13X, // SELECT THE SYSTEM MODULATION TECHNIQUE: //
$13X, // (1) ..... BPSK (COHERENT) //
$13X, // (2) ..... DBPSK //
$13X, // (3) ..... QPSK (COHERENT) //
$13X, // (4) ..... DQPSK //
$13X, // (5) ..... COHERENT PCM/FM FSK //
$13X, // (6) ..... NCNCOHERENT PCM/FM FSK //
$13X, // (7) ..... M-ARY FSK (RAYLEIGH CHANNEL) //
$13X, // (8) ..... AN/IRC-112/121 (RADIO SET) //
$13X, // (9) ..... AN/IRC-170V (1-3) (RADIO SET) //
READ (*,590) RESPON
IF (RESPON.EQ.1) GOTO 451
IF (RESPON.EQ.2) GOTO 452

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452 KK = 1.0
    EBN = (EBN/L)*KK
    U = EBN/(1+EBN)
    GOTO 460
451 KK = 1.0
    EBN = (EBN/L)*KK
    U = SORT(EBN/(1+EBN))
    GOTO 460
454 KK = 2.0
    EBN = (EBN/L)*KK
    U = EBN/(1+EBN)
    GOTO 460
453 KK = 2.0
    EBN = (EBN/L)*KK
    U = SORT(EBN/(1+EBN))
    GOTO 460
455 DD = SORT(EBN*0.5)
    IF (DD.LT.0.0) GOTO 900
    IF (DD.GE.1.5) GOTO 465
    E1 = Erf(X)
    E2 = 1.0 - E1
    PB = 0.5 * E2
    GOTO 900
    Erf(X)
    E2 = 0.5 * E1
    GOTO 900
    Erf(X)
    PB = 0.5 * E2
    GOTO 900
    PB = 0.5 * EXP(-EBN*0.5)
    GOTO 900
    PB = U/(SORT(2-U**2))
    ZZ = (1-U**2)/(4-(2*(U**2)))
    IF (L.EQ.2) PB = 0.5*(1-PP*(1+2*ZZ))
    IF (L.EQ.4) PB = 0.5*(1-PP*(1+2*ZZ+6*(ZZ**2)+20*(ZZ**2*ZZ)))
    GOTO 900

```

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457 CALL CLEAR
442 WRITE(*,442)
    FORMAT(//)
*13X, 'SELECT THE APPROPRIATE N-ARY SIGNALING
*13X, ' (1) ..... BINARY FSK (N = 2)
*13X, ' (2) ..... QUADRATURE FSK (N = 4)
    READ(*,50) RESPON
    GOTO(443,444) RESPON
443 IF (L.EQ.2) THEN

```

```

X = (EBN-5)/5
YY = -0.71535-0.53574*X-0.0658*(X**2)
PM = 10**YY
ELSE X = EBN/5
YY = -0.3931-0.1267*X-0.202*(X**2)
PM = 10**YY
ENDIF
PB = PM
GOTO 900
IF(L.EQ.2) THEN
X = (EBN-5)/5
YY = -0.5387-0.8139*X-0.0252*(X**2)
PB = 10**YY
ELSE X = EBN/5
YY = -0.2369-0.177*X-0.2553*(X**2)
PB = 10**YY
ENDIF
PB = (2/3)*PB
CALL CLEAR
WRITE(*,1409)
FORMAT(//)
$13X, '***** AN/TRC-170 DIGITAL TROPOSCATTER *****' /
$13X, 'SYSTEM DESIGN MODULE: // '
$13X, 'SELECT THE APPROPRIATE RF BANDWIDTH: // '
$13X, '(1) ..... 3.5 MHZ / '
$13X, '(2) ..... 7.0 MHZ / '
READ(*,590) RESPON
IF(RESPO.EQ.1) BW = 3.5E6
IF(RESPO.EQ.2) BW = 7.0E6
EBN = CNR + 10*LOG10(EM) - 10*LOG10(RATE)
***** CALCULATE MULTIPATH DELAY (SEC) *****
DELAY = (3**KM*1.0E3*(THETA**2))/(16**3.0E8)
*****
* AN/TRC-170 DIGITAL TROPOSCATTER TERMINAL
* DUAL-PULSE DARB CURVE FIT EONS. FIG(S) 3-12/13
*****
IF(BW.NE.3.5E6) GOTO 453
IF(L.EQ.2) THEN
X = (EBN-4)/4
IF(DELAY.LE.0.115E-6) Q = -1.1195-0.8773*X+4.63E-3*(X**2)
IF(DELAY.GT.0.115E-6) .AND.
8(DELAY.LT.0.295E-6) Q = -1.4555-0.7683*X-0.07939*(X**2)
IF(DELAY.GE.0.295E-6) Q = -2.269-0.6488*X-7.1564*(X**2)
ELSE X = EBN/4

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IF (DELAY.LE.0.115E-6) Q=-1.064-1.144*X-7.5E-2*(X**2)
IF ((DELAY.GT.0.115E-6).AND.
&(DELAY.LT.0.295E-6)) Q = -0.886-1.508*X-1.63E-2*(X**2)
IF (DELAY.GE.0.295E-6) Q=-1.307-1.003*X-0.2113*(X**2)
ENDIF
PB = 10**Q
GOTO 900
CALL CLEAR
SET = 1
WRITE (*,1481)
FORMAT (//
1481 $13X, ' ***** FM/FDM SYSTEM DESIGN MODULE *****')
SYS = 1
WRITE (*, 498)
FORMAT (//
498 *13X, ' SELECT THE SYSTEM ORDER OF DIVERSITY:
*13X, '(1) ..... DUAL DIVERSITY
*13X, '(2) ..... QUAD DIVERSITY
READ (*,590) RESPON
IF (RESPON.EQ.1) L=2
IF (RESPON.EQ.2) L=4
WRITE (*,1482)
FORMAT (//
1482 $13X, ' SELECT DIVERSITY COMBINING TECHNIQUE:
*13X, '(1) ..... MAXIMAL RATIO COMBINER
*13X, '(2) ..... EQUAL GAIN COMBINER
*13X, '(3) ..... SELECTOR COMBINER')
READ (*,590) RESPON
GOTO (1483,1486,1488), RESPON
1483 IF (L.EQ.2) DIM = 4.0
IF (L.EQ.4) DIM = 6.0
GOTO 1490
1486 IF (L.EQ.2) DIM = 2.5
IF (L.EQ.4) DIM = 5.2
GOTO 1490
1488 IF (L.EQ.2) DIM = 1.5
IF (L.EQ.4) DIM = 3.0
GOTO 1490
1493 WRITE (*,*) ' REAL DATA ENTRY ERROR. TRY AGAIN'
1490 WRITE (*,1491)
FORMAT (//
1491 $13X, ' ENTER THE NUMBER OF ANALOG VOICE CHANNELS: ')
READ (*,1492) ERR=1493) VC
FORMAT (E3.0)
IF (VC.LE.0.0) THEN
PIM = 3.0
ELSE
PIM = 4.0
ENDIF
LDF = -10.0 + 10*LOG10(VC)

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///
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///

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308 * READ (*, 306) WVP (I)
WRITE (/, 308) ALT (FT) * .2X, PRESS (MB) * .5X, TEMP (C) * .5X,
FORMAT (/, 3X) VAPOR PRESS (MB)
309 WRITE (*, 309) ALT (I), PRES (I), TEMP (I), WVP (I)
FORMAT (5X, F8.1, 6X, F6.1, 6X, F4.1, 14X, F6.1)
316 WRITE (/, 316)
FORMAT (/)
317 * ANY DATA CORRECTIONS? ("Y" OR "N")
$1X, * RESPOND WITH UPPERCASE IN SINGLE QUOTATIONS'
$1X, GOTO 317
WRITE (*, 334)
READ (*, * , ERR=310) ANS
IF (ANS.EC.N) GOTO 311
IF (ANS.EC.N) CONTINUE
TEMP (I) = TEMP (I) + 273.15
PT = WVP (I) / TEMP (I)
WWT = WVP (I) / (TEMP (I) ** 2)
RN (I) = (7.6 * PT) - (5.6 * WWT) + (3.75E5 * WWT)
RH (I) = RN (I) + ALT (I) * 4.8E-2
TEMP (I) = TEMP (I) - 273.15
21 CONTINUE
DO 22 I = 1, LEV
22 I = ALT (I+1) - ALT (I)
DAIT (I) = DAIT (I) / 1000.
DRN (I) = RN (I+1) - RN (I)
NGRAD (I) = DRN (I) / DAIT (I)
NGRAD (LEV) = 0.0
IF ((NGRAD (I) .GE. -48.0) .AND. (NGRAD (I) .LT. -24.0)) THEN
COND (I) = 1.0
TYPE (I) = 'SUPER'
ENDIF
IF ((NGRAD (I) .GE. -24.0) .AND. (NGRAD (I) .LE. 0)) THEN
COND (I) = 2.0
TYPE (I) = 'NORMAL'
ENDIF
IF (NGRAD (I) .GT. 0) THEN
COND (I) = 3.0
TYPE (I) = 'SUB'
ENDIF
IF (NGRAD (I) .LT. -48.0) THEN
COND (I) = 4.0
TYPE (I) = 'TRAP'
ENDIF
22 CONTINUE
***** CONVERT ALTITUDE FEET TO KILOMETERS *****
DO 23 I = 1, LEV
MALT (I) = (ALT (I) / 5280.) * 1.609
23 CONTINUE

```

```

J=1
DO 25 I=1,LEV
IF ((COND(I).EQ.4.0).AND.(COND(I+1).NE.4.0)) THEN
HOPT = MALT(I)
M2 = RM(I)
DTOP = MALT(I+1)
M1 = RM(I+1)
DELTA = M2 - M1
IF ((M1.GT.RM(I-1)).AND.(M1.LT.RM(I))) THEN
*****LEAST SQUARES LINE EQUATION *****
SUMX2 = 0.0
SUMY2 = 0.0
SUMXY = 0.0
SUMX = RM(I-1) + RM(I)
SUMX2 = RM(I-1)**2 + RM(I)**2
SUMY = MALT(I-1) + MALT(I)
SUMXY = RM(I-1)*MALT(I-1) + RM(I)*MALT(I)
XMEAN = SUMX/2
YMEAN = SUMY/2
SLOPE = (SUMXY - SUMX*YMEAN)/(SUMX2 - SUMX*YMEAN)
YINT = YMEAN - SLOPE*XMEAN
DBOT = SLOPE*M1 + YINT
DTHK = DTOP - DBOT
TYPE1 = TYPE1
ELSE IF (M1.LE.RM(1)) THEN
DTHK = DTOP
TYPE2 = TYPE2
ENDIF
ENDIF
IF ((COND(I).EQ.4.0).AND.(COND(I+1).EQ.4.0)) THEN
WRITE(*,323)
FORMAT(1X,'PLEASE ENTER RADIOSONDE DATA AGAIN, BUT DELETE',
1X,'LEVEL (I2,') DATA. THIS CONDITION WILL PERMIT',
1X,'A COMBINED TRAPPED LEVEL TO BE IDENTIFIED')
ENDIF
IF (COND(I).EQ.4.0) THEN
DUCT = 2
ELSE
DUCT = 1
ENDIF
CONTINUE 333
WRITE(*,1X,'DO YOU WANT AN ENVIRONMENTAL DATA LISTING?',
*,'(Y" OR "N"')')
GO TO 318
319 WRITE(*,334) 'YOU HAVE ENTERED AN INCORRECT RESPONSE.',
334 FORMAT(//1X,'TRY AGAIN')
318 READ(*,*,ERR=319) ANS

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IF (ANS.EQ. N) GOTO 312
IF (ANS.EQ. 1) CONTINUE
WRITE (7, 901) CHAR (27), CHAR (15)
WRITE (7, 313) 18X, '*** ENVIRONMENTAL DATA LIST ***'
313 WRITE (7, 314) 18X, '*** ENVIRONMENTAL DATA LIST ***'
314 WRITE (7, 314) 18X, 'PRESS: 3X, TEMP: 3X, VAPOR PRESS: 3X, ALT: 3X, N/KFT: 3X, M UNITS: 3X, CONDITION:'
315 WRITE (7, 315) LEVEL: 2X, (MB) '4X, (C) '7X, (MB) '4X, (FEET) '
DO 24 I = 1, LEV
WRITE (7, 322) I, PRES (I), WVP (I), ALT (I), RM (I), NGRAD (I),
*RM (I), TYPE (I)
322 WRITE (7, 322) I, PRES (I), WVP (I), ALT (I), RM (I), NGRAD (I),
*RM (I), TYPE (I)
322 WRITE (7, 323) I, WVP (I), ALT (I), RM (I), NGRAD (I),
*WVP (I), ALT (I), RM (I), NGRAD (I)
24 CONTINUE
312 WRITE (7, 312) 18X, 'TRAP ' THEN
IF (TYPE (I) .EQ. 'TRAP ' ) THEN
WRITE (7, 324) TYPE (I), HOPT, DTHK, DELTAM
CALL CLEAR
WRITE (*, 324) TYPE (I), HOPT, DTHK, DELTAM
FORMAT (//13X 'TROPOSPHERIC DUCT DETECTED, TYPE: ' A10
//13X ' OPTI NUM COUPLING HEIGHT.....', F6.3, ' KM',
//13X ' DUCT THICKNESS.....', F6.3, ' KM',
//13X ' DUCT INTENSITY (M-UNITS) .....', I3)
ELSE CONTINUE
CONTINUE
ENDIF
40 CONTINUE
WRITE (7, 917) CHAR (27), CHAR (18)
WRITE (*, 332) 'DO YOU WANT A M-PROFILE PLOT? YES (1) / NO (2) '
332 FORMAT (//1X, 'DO YOU WANT A M-PROFILE PLOT? YES (1) / NO (2) ')
320 GOTO 321
321 WRITE (*, 332) 'YOU HAVE ENTERED AN INCORRECT RESPONSE, TRY AGAIN'
321 READ (*, 590, ERR=320) RESPON
IF (RESPON.EQ. 1) THEN
WRITE (*, 332) 'PREPARE PRINTER .....PLOTTING BEGINS.....'
CALL PLOT1 (LEV, NALT, RM)
ELSE CONTINUE
ENDIF
IF (DUCT.EQ. 2) GOTO 1700
350 GOTO 1600
CALL CLEAR
WRITE (*, 327) '***** ENTER DUCT PARAMETER DATA *****'
GOTO 1327
1325 WRITE (*, *) 'REAL DATA ENTRY ERROR. TRY AGAIN.'

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1327 WRITE(*,327)
327 FORMAT(/,IX, : ENTER DUCT OPTIMUM COUPLING HEIGHT : /
          (KILOMETERS ABOVE MEAN GROUND LEVEL) : )
325 READ(*,325)ERR=1325) HOPT
    FORMAT(F8.2)
    GOTO 1329
1328 WRITE(*,328) REAL DATA ENTRY ERROR. TRY AGAIN.
1329 FORMAT(/,IX, : ENTER DUCT THICKNESS (KILOMETERS) : )
328 READ(*,325;ERR=1328) LTHK
    GOTO 372
371 WRITE(*,*) INTEGER DATA ENTRY ERROR. PLEASE TRY AGAIN.
372 FORMAT(/,
          $IX, : ENTER DUCT INTENSITY (M-UNITS),
          (AS TWO-DIGIT INTEGER VALUE) : )
370 READ(*,370;ERR=371) DELTAM
    FORMAT(F12.2)
    GOTO 1700
360 CALL CLEAR
    WRITE(*,*)
    ***** HEIGHT GAIN INPUT *****
330 READ(*,326) EG
    FORMAT(/,IX, : ENTER HEIGHT GAIN (DB) : )
326 READ(*,326) EG
    FORMAT(F7.2)
    GOTO 1600
*****
***** ELEVATED DUCT HEIGHT GAIN ESTIMATE MODULE *****
*****
*****
** DETERMINE AVE. ANTENNA ELEV. FACI CR 'X' (0.005 KM = 1.0,
285 KM = 15.0 INCREMENT = 0.020 KM)
** X = (HS + 0.015)/0.02
** DETERMINE RANGE FACTOR 'RF' (75 KM = 1.0, 325 KM = 6.0,
1700 INCREMENT = 50 KM)
** RF = ((KM - 25)/50) - 1
** IF (DELTA AM. GT. 0.5) GOTO 880
** IF ((DTHK.LE.0.085) .OR. (DTHK.GE.0.120)) GOTO 880
** IF (HOPT.GT.1.5) GOTO 880
** IF ((HOPT.LE.1.5) .AND. (HOPT.GT.1.425)) GOTO 800
** IF ((HOPT.LE.1.425) .AND. (HOPT.GT.1.4)) GOTO 810
** IF ((HOPT.LE.1.4) .AND. (HOPT.GT.1.3)) GOTO 820
** IF ((HOPT.LE.1.3) .AND. (HOPT.GT.1.2)) GOTO 830
** IF ((HOPT.LE.1.2) .AND. (HOPT.GT.1.125)) GOTO 840
** IF ((HOPT.LE.1.125) .AND. (HOPT.GT.1.06)) GOTO 850
** IF ((HOPT.LE.1.06) .AND. (HOPT.GT.1.0)) GOTO 860
** IF ((HOPT.LE.1.0) .AND. (HOPT.GT.0.8)) GOTO 870

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880 IF (HOPT.LT.0.8) CONTINUE
CALL CLEAR
WRITE(*,881)
FORMAT(/,13X,HEIGHT GAIN (DB) CANNOT BE ESTIMATED
13X,BECAUSE CURRENT ELEVATED DUCT PARAMETERS
13X,EXCEEDED MODEL RELIABILITY. ENTER HEIGHT GAIN
13X,OBTAINED FROM AN ALTERNATIVE METHOD
13X,**** ELEVATED DUCT LIMITATION ****
13X,
13X,OPT. CUFFLING HEIGHT: 0.800<KM<1.500
13X,DUCT THICKNESS: 0.085<KM<0.120
13X,DUCT INTENSITY: 0.0<M-UNITS<5.0
WRITE(*,590) ENTER (1) TO CONTINUE .....
IF (RESPON.NE.999) CONTINUE
GOTO 360
***** ELEVATED DUCT DATA *****
PA 1.452 KM
HOPT: 4.0 M-UNITS
DELTA M: *****
***** ELEVATED DUCT DATA *****
***** DTHK: 0.111 KM *****
*****
800 IF ((FREQ.GE.4500.) .AND. (FREQ.LT.4600.)) THEN
HG1 = 0.1702 - 0.0069*X + 0.0010*(X**2)
HG2 = 0.1248 - 0.0007*X + 0.0007*(X**2)
FREQ1 = 4500.
DELTR1 = -11.2
DELTR2 = -12.0
ENDIF
IF ((FREQ.GE.4600.) .AND. (FREQ.LT.4700.)) THEN
HG1 = 0.1248 - 0.0007*X + 0.0007*(X**2)
HG2 = 0.1953 - 0.0085*X + 0.0011*(X**2)
FREQ1 = 4600.
DELTR1 = -12.0
DELTR2 = -10.83
ENDIF
IF ((FREQ.GE.4700.) .AND. (FREQ.LT.4800.)) THEN
HG1 = 0.1953 - 0.0085*X + 0.0011*(X**2)
HG2 = 0.1425 - 0.0003*X + 0.0007*(X**2)
FREQ1 = 4700.
DELTR1 = -10.83
DELTR2 = -11.42
ENDIF
IF ((FREQ.GE.4800.) .AND. (FREQ.LT.4900.)) THEN
HG1 = 0.1425 - 0.0003*X + 0.0007*(X**2)
HG2 = 0.1310 - 0.0015*X + 0.0007*(X**2)
FREQ1 = 4800.
DELTR1 = -11.42
DELTR2 = -12.02
ENDIF
IF ((FREQ.GE.4900.) .AND. (FREQ.LT.5000.)) THEN

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HG1 = 0.1310 - 0.0015*X + 0.6007*(X**2)
HG2 = 0.1511 - 0.0021*X + 0.0008*(X**2)
FREQ1 = 4900.
DELTA1 = -12.02
DELTA2 = -11.78
ENDIF
IF (FREQ-GE. 5000.) GOTC 890
IF (FREQ-EQ. 5000.) HGE = 0.1511 - 0.0021*X + 0.0008*(X**2)
DELTA = -11.78
HGE = DELTA*HF + (20*LOG10(HGE))
GOTO 891
***** ELEVATED DUCT DATA *****
PG ***** DTHK: 0.0994 KM *****
* HOPT: 1.412 KM *****
* DELTAM: 3.0 M-UNITS *****
*****
* IF (FREQ-GE. 4500.) AND. (FREQ-LT. 4600.) THEN
HG1 = 0.1492 + 0.0005*X + 0.0007*(X**2)
HG2 = 0.1142 - 0.0009*X + 0.0007*(X**2)
FREQ1 = 4600.
DELTA1 = -10.7
DELTA2 = -12.9
ENDIF
IF (FREQ-GE. 4600.) AND. (FREQ-LT. 4700.) THEN
HG1 = 0.1142 - 0.0009*X + 0.0007*(X**2)
HG2 = 0.1170 - 0.0004*X + 0.0007*(X**2)
FREQ1 = 4600.
DELTA1 = -12.9
DELTA2 = -12.87
ENDIF
IF (FREQ-GE. 4700.) AND. (FREQ-LT. 4800.) THEN
HG1 = 0.1170 - 0.0004*X + 0.0007*(X**2)
HG2 = 0.1445 - 0.0025*X + 0.0008*(X**2)
FREQ1 = 4700.
DELTA1 = -12.87
DELTA2 = -12.61
ENDIF
IF (FREQ-GE. 4800.) AND. (FREQ-LT. 4900.) THEN
HG1 = 0.1445 - 0.0025*X + 0.0008*(X**2)
HG2 = 0.1030 - 0.0001*X + 0.0006*(X**2)
FREQ1 = 4800.
DELTA1 = -12.61
DELTA2 = -13.53
ENDIF
IF (FREQ-GE. 4900.) AND. (FREQ-LT. 5000.) THEN
HG1 = 0.1030 - 0.0001*X + 0.0006*(X**2)
HG2 = 0.1286 - 0.0010*X + 0.0008*(X**2)
FREQ1 = 4900.
DELTA1 = -13.53
DELTA2 = -12.63

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ENDIF
IF (FREQ-NE-5000.) GOTC 890
IF (FREQ-EO-5000.) THEN
  HGE = 0.1286 - 0.0010*X + 0.0008*(X**2)
  DELTA = -12.63
  HGE = DELTA*RF + (20*LOG10 (HGE))
ENDIF
GOTO 891
*****
* HOLT: 1.376 KM           DTHK: 0.107 KM
* DELTA:M:*****
* ***** ELEVATED DUCT DATA *****
* *****
820 IF ((FREQ-GE.4500.) .AND. (FREQ-LT.4600.)) THEN
  HG1 = 0.1212 + 0.0009*X + 0.0006*(X**2)
  HG2 = 0.1609 - 0.0038*X + 0.0010*(X**2)
  FREQ1 = 4500.
  DELTA1 = -12.59
  DELTA2 = -12.5
ENDIF
IF ((FREQ-GE.4600.) .AND. (FREQ-LT.4700.)) THEN
  HG1 = 0.1609 - 0.0038*X + 0.0010*(X**2)
  HG2 = 0.1887 - 0.0005*X + 0.0010*(X**2)
  FREQ1 = 4600.
  DELTA1 = -12.5
  DELTA2 = -11.95
ENDIF
IF ((FREQ-GE.4700.) .AND. (FREQ-LT.4800.)) THEN
  HG1 = 0.1887 - 0.0005*X + 0.0010*(X**2)
  HG2 = 0.1294 - 0.0002*X + 0.0008*(X**2)
  FREQ1 = 4700.
  DELTA1 = -11.95
  DELTA2 = -12.43
ENDIF
IF ((FREQ-GE.4800.) .AND. (FREQ-LT.4900.)) THEN
  HG1 = 0.1294 - 0.0002*X + 0.0008*(X**2)
  HG2 = 0.1478 + 0.0008*X + 0.0008*(X**2)
  FREQ1 = 4800.
  FREQ2 = 4900.
  DELTA1 = -12.43
  DELTA2 = -12.51
ENDIF
IF ((FREQ-GE.4900.) .AND. (FREQ-LT.5000.)) THEN
  HG1 = 0.1478 + 0.0008*X + 0.0008*(X**2)
  HG2 = 0.1842 - 0.0039*X + 0.0010*(X**2)
  FREQ1 = 4900.
  DELTA1 = -12.51
  DELTA2 = -11.67
ENDIF
IF (FREQ-NE-5000.) GOTC 890

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IF (FREQ. EQ. 5000.) THEN 0.0039*X + 0.0010*(X**2)
HGE = 0.1842 - 11.67
DELTA = -11.67
HGE = DELTR*RF + (20*LOG10(HGE))
ENDIF
GOTO 891
***** ELEVATED DUCT DATA ***** DTHK: 0.112 KA *****
* PC *****
* HOPT: 1.257 KM *****
* DELTAM: 4.0 M-UNITS *****
*****
***** (FREQ. GE. 4500.) .AND. (FREQ. LT. 4600.) THEN
HG1 = 0.1489 + 0.0036*X + 0.0007*(X**2)
HG2 = 0.1285 + 0.0019*X + 0.0007*(X**2)
FREQ1 = 4500.
DELTR1 = -12.0
DELTR2 = -11.88
ENDIF
IF ((FREQ. GE. 4600.) .AND. (FREQ. LT. 4700.)) THEN
HG1 = 0.1285 + 0.0019*X + 0.0007*(X**2)
HG2 = 0.1947 + 0.0001*X + 0.0010*(X**2)
FREQ1 = 4600.
DELTR1 = -11.88
DELTR2 = -10.78
ENDIF
IF ((FREQ. GE. 4700.) .AND. (FREQ. LT. 4800.)) THEN
HG1 = 0.1947 + 0.0009*X + 0.0010*(X**2)
HG2 = 0.1509 + 0.0009*X + 0.0008*(X**2)
FREQ1 = 4700.
DELTR1 = -10.78
DELTR2 = -11.96
ENDIF
IF ((FREQ. GE. 4800.) .AND. (FREQ. LT. 4900.)) THEN
HG1 = 0.1509 + 0.0009*X + 0.0008*(X**2)
HG2 = 0.1020 + 0.0012*X + 0.0006*(X**2)
FREQ1 = 4800.
DELTR1 = -11.96
DELTR2 = -12.60
ENDIF
IF ((FREQ. GE. 4900.) .AND. (FREQ. LT. 5000.)) THEN
HG1 = 0.1020 + 0.0012*X + 0.0006*(X**2)
HG2 = 0.1399 - 0.0035*X + 0.0009*(X**2)
FREQ1 = 4900.
DELTR1 = -12.60
DELTR2 = -12.19
ENDIF
IF (FREQ. EQ. 5000.) GOTC 890
IF (HGE = 0.1399 - 0.0035*X + 0.0009*(X**2))
DELTA = -12.19

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HGE = DELTR*RF + (20*LOG10(HGE))
ENDIF
GOTO 891
***** ELEVATED DUCT DATA ***** DTHK: 0.089 KM *****
** HOFT: 1.151 KM *****
** DELTAM: 3.0 M-UNITS *****
*****
840 IF ((FREQ-GE.4500.) - ANL.(FREQ-LT.4600.)) THEN
HG1 = 0.1333 + 0.0032**X + 0.0006**{X**2}
HG2 = 0.1192 - 0.0002**X + 0.0008**{X**2}
FREQ1 = 4500.
DELTR1 = -11.2
DELTR2 = -13.12
ENDIF
IF ((FREQ-GE.4600.) - ANL.(FREQ-LT.4700.)) THEN
HG1 = 0.1192 - 0.0002**X + 0.0008**{X**2}
HG2 = 0.1243 + 0.0012**X + 0.0008**{X**2}
FREQ1 = 4600.
DELTR1 = -13.12
DELTR2 = -12.77
ENDIF
IF ((FREQ-GE.4700.) - ANL.(FREQ-LT.4800.)) THEN
HG1 = 0.1243 + 0.0012**X + 0.0008**{X**2}
HG2 = 0.1067 + 0.0011**X + 0.0007**{X**2}
FREQ1 = 4700.
DELTR1 = -12.77
DELTR2 = -13.60
ENDIF
IF ((FREQ-GE.4800.) - ANL.(FREQ-LT.4900.)) THEN
HG1 = 0.1709 + 0.0011**X + 0.0007**{X**2}
HG2 = 0.1709 - 0.0032**X + 0.0010**{X**2}
FREQ1 = 4800.
DELTR1 = -13.60
DELTR2 = -12.81
ENDIF
IF ((FREQ-GE.4900.) - ANL.(FREQ-LT.5000.)) THEN
HG1 = 0.1789 - 0.0032**X + 0.0010**{X**2}
HG2 = 0.1789 - 0.0009**X + 0.0011**{X**2}
FREQ1 = 4900.
DELTR1 = -12.81
DELTR2 = -12.65
ENDIF
IF (FREQ-NE.5000.) GOTC 890
IF (FREQ-EQ.5000.) THEN
HGE = 0.1789 - 0.0009**X + 0.0011**{X**2}
DELTR = -12.65
HGE = DELTR*RF + (20*LOG10(HGE))
ENDIF
GOTO 891

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***** ELEVATED DUCT DATA *****
* PH 1.077 KM ***** DTHK: 0.116 KM *****
* DELTAM: 4.0 M-UNITS *****
*****
850 IF ((FREQ-GE.4500.) .AND.(FREQ-LT.4600.)) THEN
    HG2 = 0.2049 - 0.0005*X + 0.0011*(X**2)
    FREQ1 = 0.1375 - 0.0021*X + 0.0009*(X**2)
    DELTR1 = 4500.
    DELTR2 = -12.25
ENDIF
IF ((FREQ-GE.4600.) .AND.(FREQ-LT.4700.)) THEN
    HG2 = 0.1375 - 0.0021*X + 0.0009*(X**2)
    FREQ1 = 4600.
    DELTR1 = -12.73
    DELTR2 = -12.27
ENDIF
IF ((FREQ-GE.4700.) .AND.(FREQ-LT.4800.)) THEN
    HG2 = 0.1581 - 0.0034*X + 0.0011*(X**2)
    FREQ1 = 4700.
    DELTR1 = -12.27
    DELTR2 = -12.64
ENDIF
IF ((FREQ-GE.4800.) .AND.(FREQ-LT.4900.)) THEN
    HG2 = 0.1298 + 0.0005*X + 0.0008*(X**2)
    FREQ1 = 0.0986 + 0.0016*X + 0.0007*(X**2)
    DELTR1 = 4800.
    DELTR2 = -12.64
ENDIF
IF ((FREQ-GE.4900.) .AND.(FREQ-LT.5000.)) THEN
    HG2 = 0.0986 + 0.0016*X + 0.0007*(X**2)
    FREQ1 = 0.1200 + 0.0000*X + 0.0008*(X**2)
    DELTR1 = 4900.
    DELTR2 = -13.50
ENDIF
IF ((FREQ-GE.5000.) .AND.(FREQ-LT.5000.)) THEN
    HG2 = 0.1200 + 0.0000*X + 0.0008*(X**2)
    DELTR1 = -13.23
    DELTR2 = -13.23
ENDIF
IF (FREQ-GE.5000.) GOTC 890
IF (FREQ-EQ.5000.) THEN
    HGE = 0.1200 + 0.0000*X + 0.0008*(X**2)
    DELTR = -13.23
    HGE = DELTR*RF + (20*LOG10(HGE))
ENDIF
GOTO 891
***** ELEVATED DUCT DATA *****
* PH 1.044 KM ***** DTHK: 0.103 KM *****
* DELTAM: *****
*****

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C      * DELTAM: 6.0 M-UNITS *****
C      * ***** THEN
C 860 IF((FREQ.GE.4500.) .AND. (FREQ.LT.4600.)) THEN
      HG1 = 0.1524 - 0.0039**X + 0.0011**{X**2}
      HG2 = 0.0581 + 0.0017**X + 0.0007**{X**2}
      FREQ1 = 4500.
      DELTR1 = -12.89
      DELTR2 = -13.97
      ENDIF
      IF((FREQ.GE.4600.) .AND. (FREQ.LT.4700.)) THEN
      HG1 = 0.0981 + 0.0017**X + 0.0007**{X**2}
      HG2 = 0.1375 - 0.0006**X + 0.0009**{X**2}
      FREQ1 = 4600.
      DELTR1 = -13.97
      DELTR2 = -12.50
      ENDIF
      IF((FREQ.GE.4700.) .AND. (FREQ.LT.4800.)) THEN
      HG1 = 0.1375 - 0.0006**X + 0.0009**{X**2}
      HG2 = 0.1482 - 0.0013**X + 0.0009**{X**2}
      FREQ1 = 4700.
      DELTR1 = -12.50
      DELTR2 = -10.95
      ENDIF
      IF((FREQ.GE.4800.) .AND. (FREQ.LT.4900.)) THEN
      HG1 = 0.1482 - 0.0013**X + 0.0009**{X**2}
      HG2 = 0.1608 + 0.0013**X + 0.0007**{X**2}
      FREQ1 = 4800.
      DELTR1 = -10.95
      DELTR2 = -13.70
      ENDIF
      IF((FREQ.GE.4900.) .AND. (FREQ.LT.5000.)) THEN
      HG1 = 0.1008 + 0.0013**X + 0.0007**{X**2}
      HG2 = 0.1649 - 0.0019**X + 0.0010**{X**2}
      FREQ1 = 4900.
      DELTR1 = -13.70
      DELTR2 = -12.51
      ENDIF
      IF(FREQ.EQ.5000.) GOTO 890
      IF(FREQ.EQ.5000.) THEN
      HGE = 0.1649 - 0.0019**X + 0.0010**{X**2}
      DELTR = -12.51
      HGE = DELTR*RF + (20*LOG10(HGE))
      ENDIF
      GOTO 891
      * ***** ELEVATED DUCT DATA *****
      * PE HOPT: 0.951 KM *****
      * DELTAM: 4.0 M-UNITS *****
      * ***** DIHK: 0.117 KM *****
C      * ***** THEN
C 870 IF((FREQ.GE.4500.) .AND. (FREQ.LT.4600.)) THEN

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HG2 = 0.1621 + 0.0022*X + 0.0011*(X**2)
FREQ1 = 4500.
DELTR1 = -13.79
DELTR2 = -12.70
ENDIF
IF((FREQ-GE.4600.) .AND. (FREQ-LT.4700.)) THEN
  HG1 = 0.1001 + 0.0035*X + 0.0006*(X**2)
  HG2 = 0.1332 + 0.0018*X + 0.0009*(X**2)
  FREQ1 = 4600.
  DELTR1 = -12.70
  DELTR2 = -12.75
ENDIF
IF((FREQ-GE.4700.) .AND. (FREQ-LT.4800.)) THEN
  HG1 = 0.1332 + 0.0018*X + 0.0009*(X**2)
  HG2 = 0.1537 + 0.0002*X + 0.0010*(X**2)
  FREQ1 = 4700.
  DELTR1 = -12.75
  DELTR2 = -14.11
ENDIF
IF((FREQ-GE.4800.) .AND. (FREQ-LT.4900.)) THEN
  HG1 = 0.1537 + 0.0002*X + 0.0010*(X**2)
  HG2 = 0.1854 + 0.0074*X + 0.0009*(X**2)
  FREQ1 = 4800.
  DELTR1 = -14.11
  DELTR2 = -12.51
ENDIF
IF((FREQ-GE.4900.) .AND. (FREQ-LT.5000.)) THEN
  HG1 = 0.1854 + 0.0074*X + 0.0009*(X**2)
  HG2 = 0.1347 + 0.0008*X + 0.0009*(X**2)
  FREQ1 = 4900.
  DELTR1 = -12.51
  DELTR2 = -14.03
ENDIF
IF(FREQ.EQ.5000.) GOTC 890
IF(HGE = 0.1547 + 0.0008*X + 0.0009*(X**2)
  DELTR = -13.87
  HGE = DELTR*RF + (20*LOG10(HGE))
ENDIF
GOTO 891
890 D = (FREQ-FREQ1)/100.
C *** DETERMINE HEIGHT GAIN INCREMENT WEIGHTING FACTOR ***
IF((D-GE.0) .AND. (D-LT.0.333)) THEN
  HG = HG1
  DIF = DELTR1
ENDIF
IF((D-GE.0.333) .AND. (D-LT.0.667)) THEN
  HG = (HG1 + HG2)/2
  DIF = (DELTR1 + DELTR2)/2.

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ENDIF
IF((D.GE.0.667).-AND.(D.LE.1.0)) THEN
  HG = HG2
  DIF = DEITR2
ENDIF
HG = (DIF*RF) + (20*LCG10(HG))
GOTO 1600
891 HG = HGE
GOTO 1600

C DATA OUTPUT MODULE
500 WRITE(7,901) CHAR(27),CHAR(15)
501 FORMAT(' ',A1,A1)
CALL CLEAR
WRITE(*,1900)
1900 FORMAT(//,
$13X,*,*
$13X,*,*
$13X,*,*
$13X,*,*
PROBLEM PRINTER OUTPUT
)
524 FORMAT(7,924)
WRITE(*,1)
524 WRITE(7,902)
902 FORMAT('X',
$,
)
WRITE(7,903)
903 FORMAT(7,902)
WRITE(*,902)
IF(ALAT.LT.0.0) THEN
  A11 = 'S'
ELSE
  A11 = 'N'
ENDIF
IF(BLAT.LT.0.0) THEN
  B11 = 'S'
ELSE
  B11 = 'N'
ENDIF
IF(ALONG.LT.0.0) THEN
  A12 = 'E'
ELSE
  A12 = 'W'
ENDIF
IF(BLONG.LT.0.0) THEN
  B12 = 'E'
ELSE
  B12 = 'W'
ENDIF

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905 WRITE(7,905) ALAT, B11, BLAT, B11, ALONG, A12, BLONG, B12, TH1, RTH
FORMAT(//,15X) SITE TRANSMITTER RECEIVER /
$15X, LATITUDE: .4X, F8.2, 1X, A3, F8.2, 1X, A3,
$15X, LONGITUDE: .4X, F8.2, 1X, A3, F8.2, 1X, A3,
$15X, ELEVATION: .2X, F10.2, .M., 3X, F10.2, .M.)
*WRITE(7,951) PATH
905 FORMAT(//,15X) TERRAIN PROFILE TYPE: .A35)
WRITE(7,935) TAKE-OFF ANGLE: .F7.2, .MRAD, //
935 $ TAKE-OFF ANGLE: .F7.2, .MRAD, //
$ RECEIVER TAKE-OFF ANGLE: .F7.2, .MRAD, //
$ SCATTER (ANGULAR DISTANCE): .F10.2, .DEGREES, //
$ TRANSMITTER TAKE-OFF ANGLE: .F10.2, .DEGREES, //
$ RECEIVER TAKE-OFF ANGLE: .F10.2, .DEGREES, //
$ SCATTER (ANGULAR DISTANCE): .F10.2, .DEGREES, //
WRITE(7,952) FREQUENCY: .F7.2, .MHZ)
952 FORMAT(//,15X) TRANSMIT FREQUENCY: .F7.2, .MHZ)
WRITE(7,953) DELTAV
953 $ FOR QUAD DIVERSITY: .F7.2, .MHZ)
$ FOR QUAD DIVERSITY: .F7.2, .MHZ)
906 WRITE(7,906) AZA AZIMUTH AT TRANSMITTER (TO RECVR): .F6.2,
$ (DEGREES N. .)
907 WRITE(7,907) AZB AZIMUTH AT RECEIVER (TO TRANS): .F6.2,
$ (DEGREES N. .)
908 WRITE(7,908) SM KM GREAT CIRCLE PATH: .F8.2, .STATUTE MILES,
$ / .F8.2 DELTAV*3.2808
DELTAV = DELTAV*3.2808
954 WRITE(7,954) DELTAV
FORMAT(//,15X) MINIMUM RECOMMENDED ANTENNA VERTICAL
$ SEPARATION: .F5.1, .FEET)
955 WRITE(7,955) HO
FORMAT(//,15X) ESTIMATED SCATTER VOLUME BASE ALTITUDE: .,
$ F10.2, .METERS)
956 WRITE(7,956)
FORMAT(//,15X) BASIC MEDIAN TRANSMISSION LOSS FACTORS)
911 WRITE(7,911)
FORMAT(//,17X)
WRITE(7,902) LS
913 FORMAT(//
$15X, FREE-SPACE/SCATTER LOSS //
$15X, FREE-SPACE/SCATTER LOSS ..... ,F7.1, .DB)
925 $15X, WAVEGUIDE LOSS ..... ,F7.1, .DB)
WRITE(7,926) CL

```

```

926 FORMAT(//
$15X, 'CONNECTOR LOSS .....', F7.1, ' DB')
WRITE(7, 927) LC
927 FORMAT(//
$15X, 'APERTURE-TO-MEDIAN COUPLING LOSS .....', F7.1, ' DB')
IF (DIFF.EQ.0) THEN
WRITE(7, 958) LD
958 FORMAT(//
$15X, 'DIFFRACTION LOSS (IF APPLICABLE) .....', A4, ' DB')
ELSE
WRITE(7, 928) LD
928 FORMAT(//
$15X, 'DIFFRACTION LOSS (IF APPLICABLE) .....', F7.1, ' DB')
ENDIF
WRITE(7, 929) LA
929 FORMAT(//
$15X, 'RAINFALL ABSORPTION LOSS .....', F7.1, ' DB')
WRITE(7, 930) ANTG
930 FORMAT(//
$15X, 'ANTENNA SYSTEM GAIN .....', F7.1, ' DB')
WRITE(7, 931) HG
931 FORMAT(//
$15X, 'HEIGHT GAIN (IF APPLICABLE) .....', F7.1, ' DB')
WRITE(7, 932) TG
932 FORMAT(//
$15X, 'TOTAL SYSTEM GAIN .....', F7.1, ' DB')
WRITE(7, 933) LI
933 FORMAT(//
$15X, 'NET PATH LOSS .....', F7.1, ' DB')
WRITE(7, 934) FTDBM
934 FORMAT(//
$15X, 'TRANSMITTER POWER .....', F7.1, ' DEM')
C
WRITE(7, 914) ESDBM, PNDBM, FIT, CNR, FADE
914 FORMAT(//
$15X, 'MEDIAN RECEIVED SIGNAL .....', F7.1, ' DBM'//
$15X, 'RECEIVED NOISE THRESHOLD .....', F7.1, ' DBM'//
$15X, 'FM IMPROVEMENT THRESHOLD .....', F7.1, ' DB'//
$15X, 'THEORETICAL RF CNR .....', F7.1, ' DB'//
$15X, 'SYSTEM FADE MARGIN .....', F7.1, ' DB'//
)
C
WRITE(7, 957)
957 FORMAT(//
$15X, 'RECEIVED SIGNAL .....', F7.1, ' DBM'//
$15X, 'RECEIVED NOISE THRESHOLD .....', F7.1, ' DBM'//
$15X, 'FM IMPROVEMENT THRESHOLD .....', F7.1, ' DB'//
$15X, 'THEORETICAL RF CNR .....', F7.1, ' DB'//
$15X, 'SYSTEM FADE MARGIN .....', F7.1, ' DB'//
)
C
WRITE(7, 950) REL
950 FORMAT(//
$15X, 'RELATIVE TRANSMITTER POWER .....', F7.1, ' DBM'//
$15X, 'RELATIVE RECEIVER NOISE THRESHOLD .....', F7.1, ' DBM'//
$15X, 'RELATIVE FM IMPROVEMENT THRESHOLD .....', F7.1, ' DB'//
$15X, 'RELATIVE THEORETICAL RF CNR .....', F7.1, ' DB'//
$15X, 'RELATIVE SYSTEM FADE MARGIN .....', F7.1, ' DB'//
)

```

SYSTEM PERFORMANCE



```

C
C
C C C C
END
SUBROUTINE PLOT (Z,X,Y)
THIS SUBROUTINE WILL ELCT A ONE PAGE TERRAIN PROFILE
GRAPH ON THE PRINTER.
DIMENSION K(105),X(1),Y(1),XWRD(11),YWRD(11)
INTEGER K*1 K,BLANK
CHARACTER*5 IDOT,IDSH
DATA BLANK,'././IDOT','././IDSH','-'
CALL SORT2(X,Y,Z)
WRITE(*,*)'PREPARE PRINTER: TERRAIN PLOT BEGINS.....'
XRNGE = X(Z) - X(1)
YMAX = Y(1)
YMIN = Y(1)
DO 50 I=2,Z
IF(Y(I).LT.YMIN) YMIN = Y(I)
IF(Y(I).GT.YMAX) YMAX = Y(I)
XRNGE = YMAX - YMIN
XWRD(1) = X(1)
YWRD(1) = X(Z)
YWRD(1) = YMIN
YWRD(1) = YMAX
AY = 0.1*XRNGE
AX = 0.1*YRNGE
DO 60 I=1,10
XI = I-1
XWRD(I) = XWRD(1) + XI*AX
YWRD(I) = YWRD(1) + XI*AY
CO 65 I=1,105
K(I) = BLANK
DO 70 I=10,100,10
K(I) = '.'
SET THE PRINTER TO COMPRESS PRINT=132 CHAR PER LINE
WRITE(7,75) CHAR(27),CHAR(15)
FORMAT(7,A1,A1)
WRITE(7,80)(YWRD(I),I=1,11,2),
&(K(I),I=1,100),IDOT
80 FORMAT(1H/19X,5(8X,E12.6)/9X,6(8X,E12.6)/14X,100A1,5X,A5)
J=1
JJ=1
XL = 0.2*AX
XJ = J1
DO 100 I=1,104
K(I) = BLANK
K(105) = '.'

```

```

110 IF (J.GT.Z) GO TO 200
    IF (XWRD(1) + XJ*AL) - LI-X(J) GO TO 200
    B= (Y(J) - YWED(1))/AY*10.
    JB=IFIX(B)
    LOC =JB + 1
    IF (LOC.GT.101) LCC=101
    J=J+1
    IF (K(LOC).NE.BLANK) GC TO 190
    K(LOC)=I+1
    GO TO 110
190 K(LOC)=I+1
    GO TO 110
200 IF (J1.EC.0) GO TO 250
210 MJ=J1
220 IF (MJ-5) 270,240,230
230 MJ=MJ-5
    GO TO 220
240 JJ=JJ+1
250 WRITE(7,260) XWRD(JJ),IDSH,(K(I),I=1,105)
260 FORMAT(18X,A5,105A1)
    GO TO 290
270 WRITE(7,280) IDSH,(K(I),I=1,105)
280 FORMAT(18X,A5,105A1)
290 J1=J1+1
    IF (J.GT.Z) GC TO 300
    GO TO 90
300 IF (JJ.EQ.11) GO TO 320
305 DO 310 I=1,104
310 K(I)=BLANK
    GO TO 210
320 WRITE(7,35)
    35 FORMAT(/
    $15X,VERTICAL AXIS (TOP OF PAGE): TERRAIN ELEVATION',
    $:(METERS),/
    $15X,HORIZONTAL AXIS: PATH DISTANCE (METERS)')
C
C
    SET THE PRINTER TO NORMAL SPACING = 80 CHAR PER LINE
    WRITE(7,330) CHAR(27),CHAR(18)
    FORMAT(1X,A1,A1)
    WRITE(7,*)
    RETURN
    END
330
C
C
SUBROUTINE SCRT2(A,B,Z)
C
C
THIS SUBROUTINE PERFORMS AN IN PLACE SORT OF A
ONE DIMENSIONAL ARRAY USING THE SHELL-METZNER
METHOD. THEN HATCHES THAT ORDER IN A SECOND ARRAY
C
C
A = THE ARRAY TO BE SORTED TO ASCENDING ORDER

```

B = THE SECOND ARRAY TO BE ORDERED AS THE FIRST  
 Z = THE NUMBER OF ELEMENTS IN THE ARRAY  
 I = TEMPORARY ELEMENT HCLDER FOR SWAP

DIMENSION A(1), B(1)  
 INTEGER I, J, K, Z  
 REAL A, B, T

K=Z  
 5 IF(K.LE.1) GC TO 30  
 K=K/2

DO 20 J=1, Z-K  
 I=J  
 IF(A(I).LE.A(I+K)) GO TO 10  
 FIRST ARRAY CONTROLS ORDER

T=A(I)  
 A(I)=A(I+K)  
 A(I+K)=T

SECOND ARRAY  
 T=B(I)  
 B(I)=B(I+K)  
 B(I+K)=T

10 CONTINUE  
 20 CONTINUE  
 GOTO 5

30 RETURN  
 END

SUBROUTINE INVERT(A,N)

DIMENSION A(1)  
 INTEGER N, NN, J  
 REAL A, TEMP  
 NN=N/2  
 DO 88 J = 1, NN  
 TEMP = A(J)  
 A(J) = A(N+1-J)  
 A(N+1-J) = TEMP

88 CONTINUE  
 RETURN  
 END

SUBROUTINE SORT(A, B, N)

DIMENSION A(1), B(1)  
 INTEGER N, I, J  
 REAL A, B, TEMPA, TEMPB

I = 1

```

IF(I.LE.N-1) THEN
  J=I+1
  IF(J.LE.N) THEN
    IF(A(I).GT.A(J)) THEN
      TEMPA=A(I)
      TEMPB=B(I)
      A(I)=A(J)
      B(I)=B(J)
      A(J)=TEMPA
      B(J)=TEMPB
    ENDIF
    J=J+1
  ENDIF
  I=I+1
ENDIF
RETURN
END

SUBROUTINE PLOT1(Z,X,Y)
THIS SUBROUTINE WILL ELCT A ONE PAGE REFRACTIVITY
PROFILE CN THE PRINTER.
DIMENSION K(105),X(1),Y(1),X#ED(11),Y#RD(11)
INTEGER Z
CHARACTER*1 K, BLANK
CHARACTER*5 IDOT, IDSH
DATA BLANK / ' ', IDSH / ' -' /
CALL SORT2 (X,Y,Z)
XRNGE = X(Z) - X(1)
YMAX = Y(1)
YMIN = Y(Z)
DO 50 I=2,Z
  IF(Y(I).LT.YMIN) YMIN = Y(I)
  IF(Y(I).GT.YMAX) YMAX = Y(I)
  X#RD(I) = X(1)
  Y#RD(I) = YMAX - YMIN
  X#RD(I) = X(Z)
  Y#RD(I) = YMIN
  AY = 0.1*YRNGE
  AX = 0.1*XRNGE
  DO 60 I=1,10
    XI = I-1
    X#RD(I) = X#RD(1) + XI*AX
    Y#RD(I) = Y#RD(1) + XI*AY
    LC 65 I=1,105
    K(I) = BLANK
    DO 70 I=10,100,10
      K(I) = '.'

```

C  
C  
C  
C

50

60

65

70



C C

```

      SET THE PRINTER TO COMPRESS PRINT=132 CHAK PER LINE
      WRITE (7,75) CHAR(27),CHAR(15)
75  FORMAT ('A1,A1)
      WRITE (7,80) (YWRD(I), I=1,11,2),
80  FORMAT('1H//19X,5(8X,E12.6)/9X,6(8X,E12.6)/14X,100A1,5X,A5)
      J1=0
      JJ=1
      XL=0.2*AX
90  XJ=J1
      DO 100 I=1,104
100  K(I)=BLANK
      K(105)=-1
110  IF(J.GT.Z) GC TO 200
      IF((XWRD(1)+XJ*XL).LT.X(J)) GO TO 200
      B=Y(J)-YWRD(1)/AY*10.
      JB=IFIX(B)
      LOC=JB+1
      IF(LOC.GT.101) LOC=101
      J=J+1
      IF(K(LOC).NE.BLANK) GC TO 190
      K(LOC)=+
      GO TO 110
190  K(LOC)=+
      GO TO 110
200  IF(J1.EQ.0) GO TO 250
210  NJ=J1
220  IF(NJ-5) 270,240,230
230  NJ=NJ-5
      GO TO 220
240  JJ=JJ+1
250  WRITE(7,260) XWRD(JJ),IDSH,(K(I),I=1,105)
260  FORMAT('E18.6,A5,105A1)
      GO TO 290
270  WRITE(7,280) IDSH(K(I),I=1,105)
280  FORMAT('18X,A5,105A1)
290  J1=J1+1
      IF(J.GT.Z) GO TO 300
      GO TO 90
300  IF(JJ.EQ.11) GO TO 320
305  DO 310 I=1,104
310  K(I)=BLANK
      GO TO 210
320  WRITE(7,45)
45  FORMAT('
      $15X,VERTICAL AXIS (TCP OF PAGE): MODIFIED REFRACTIVITY ',
      $15X,VERTICAL AXIS (TCP OF PAGE): MODIFIED REFRACTIVITY ',
      $15X, HORIZONTAL AXIS: ALTITUDE (METERS) ')

```

```

C C SET THE PRINTER TO NORMAL SPACING = 80 CHAR PER LINE
WRITE(7,330) CHAR(27),CHAR(18)
330 FORMAT(1X,A1,A1)
RETURN
END
C FUNCTION ERF(X)
C
C INTEGER I
REAL X,X2,SUM,SUM1,TERM
DATA TOL/1.0E-5/, SQRTPI/ 1.772454/
C
ERF = 0.0
IF (X.EQ.0.0) GOTO 99
ERF = 1.0
IF (X.GT.4.0) GOTO 99
X2 = X*X
SUM = X
TERM = X
I = 0
I = I + 1
SUM1 = SUM*X2/(I + 0.5)
TERM = TERM + SUM1
SUM = TERM + SUM
IF (TERM.GE.TOL*SUM) GOTO 10
ERF = 2 * SUM * EXP(-X2)/SQRTPI
RETURN
END
10
C
C FUNCTION ERF(X)
C
C INTEGER I,J,TERMS
REAL X,X2,SUM,U,V,SQRTPI
DATA SQRTPI/ 1.772454/, TERMS/12/
C
X2 = X*X
V = 0.5/X2 + V*(TERMS + 1)
U = 1.0 + V*(TERMS + 1)
DO 10 J=1,TERMS
I = TERMS - J + 1
SUM = 1.0 + I*V/U
U = SUM
10 CONTINUE
ERFC = EXP(-X2)/(X * SUM * SQRTPI)
RETURN
END

```

## LIST OF REFERENCES

1. Freeman, R. L., Telecommunications Transmission Handbook, John Wiley & Sons, Inc., 1981.
2. Osterholz, J. L. and Mensch, J. R., System Design Considerations for Digital Troposcatter Transmission, paper presented at the Defense Communications Engineering Center, Reston, Virginia.
3. Monsen, P., Analog and Digital Transmission Performance Models for Troposcatter Links, paper presented at SIGNATRON, Inc., Lexington, Ma.
4. Zawislak, F., 2 GHz Digital Troposcatter Terminal, paper presented at the Rome Air Development Center, New Jersey.
5. Weston, J.D., Predicting the Propagation Effects of Elevated Tropospheric Ducts: An Investigation of One Tactically Useful Model, M.S. Thesis, Naval Postgraduate School, Monterey, California 93941, March 1983.
6. Electromagnetic Compatibility Analysis Center Technical Report ESD-TR-81-102, A Model to Calculate EM Fields in Tropospheric Duct Environments at Frequencies Through SHF, by S. Marcus and W. D. Stuart, September 1981.
7. Electromagnetic Compatibility Analysis Center Technical Note, Instructions for the Users of "DUCT" - A Computer Program for Calculating Fields in Tropospheric Duct Environments, by S. Marcus, December 1984.
8. Petke, D. C., A Numerical Investigation of the Power Distribution of Signals Propagating Through Elevated Tropospheric Ducts, M. S. Thesis, Naval Postgraduate School, Monterey, California 93941, October 1982.

9. Naval Postgraduate School Technical Report NPS-62-82-045PR, A Simple Model for the Computation of Height Gain in the Presence of Elevated Tropospheric Ducts, by J. B. Knorr, September 1982.
10. Nagel, L.M., MINIDUCT: Improvements to a Microcomputer Based Elevated Duct Circuit Code, M.S. Thesis, Naval Postgraduate School, Monterey, California 93941, December 1983.
11. Hall, M.P., Effects of the Troposphere on Radio Communications, Peter Peregrinus Ltd., New York, 1979.
12. Panter, F. F., Communications Systems Design - Line-of-Sight and Troposcatter Systems, McGraw-Hill, New York, 1972.
13. Beckmann, P., Probability in Communications Engineering, Harcourt, Brace & World, Inc., New York, 1967.
14. Proakis, J. G., Digital Communications, McGraw-Hill Book Co., 1983.
15. Technical Report No. 12-76, DCS Transmission System Performance, Defense Communications Engineering Center, November 1976.
16. Siller, C. A., "Multipath Propagation," IEEE Communications Magazine, v. 22, pp. 11-12, February 1984.
17. Knorr, J.B., Unpublished ECE 3600 lecture notes, Naval Postgraduate School, Monterey, California 93940, November 1984.
18. Department of the Navy, NAVEXLEX 0101.112, Naval Shore Electronics Criteria - Line-of-Sight and Tropospheric Scatter Communications Systems, Washington, DC, 1972.
19. Du Castel, F., Tropospheric Radiowave Propagation Beyond the Horizon, Pergamon Press, New York, 1966.
20. International Radio Consultative Committee, Vol. II., Propagation, pp. 143-173, International Telecommunication Union, Geneva, 1967.

21. Levin, L., "Troposcatter Aperture-Medium Coupling Loss", AGARD Conf. Proc. on Aspects of Electromagnetic Wave Scattering in Radio Communications, pp. 4.1 - 4.6, September 1977.
22. Yeh, L. P., "Simple Methods for Designing Troposcatter Circuits", I.R.E. Trans. C.S., pp. 193-198, September 1960.
23. Feher, K., Digital Communications: Satellite/Earth Station Engineering, Prentice-Hall, Englewood, NJ., 1981.
24. Sunde, E.O., "Digital Troposcatter Transmission and Modulation Theory", BSTJ, Vol. 43, January 1964.
25. White, R.F., Engineering Considerations for Microwave Communications Systems, Lenkurt Electric Corp., 1975.
26. Ortenburger, L.N., et al, Radiosonde Data Analysis II, Vol. 12, GTE Sylvania, Inc., December 1987.
27. Naval Ocean Systems Center Technical Report 659, IREPS Revision 2.2 User's Manual, by C.R. Hattan and W.L. Patterson, 21 October 1983.

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