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TROPO: A MICROCOMPUTER BASED TROPOSCATTER COMMUNICATIONS SYSTEM DESIGN PROGRAM

by

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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.

TROPO: A Microcomputer Based Troposcatter Communications System Design Program

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requirements for the degree of

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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 probabilty 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 environmemt 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 Zawislan [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.

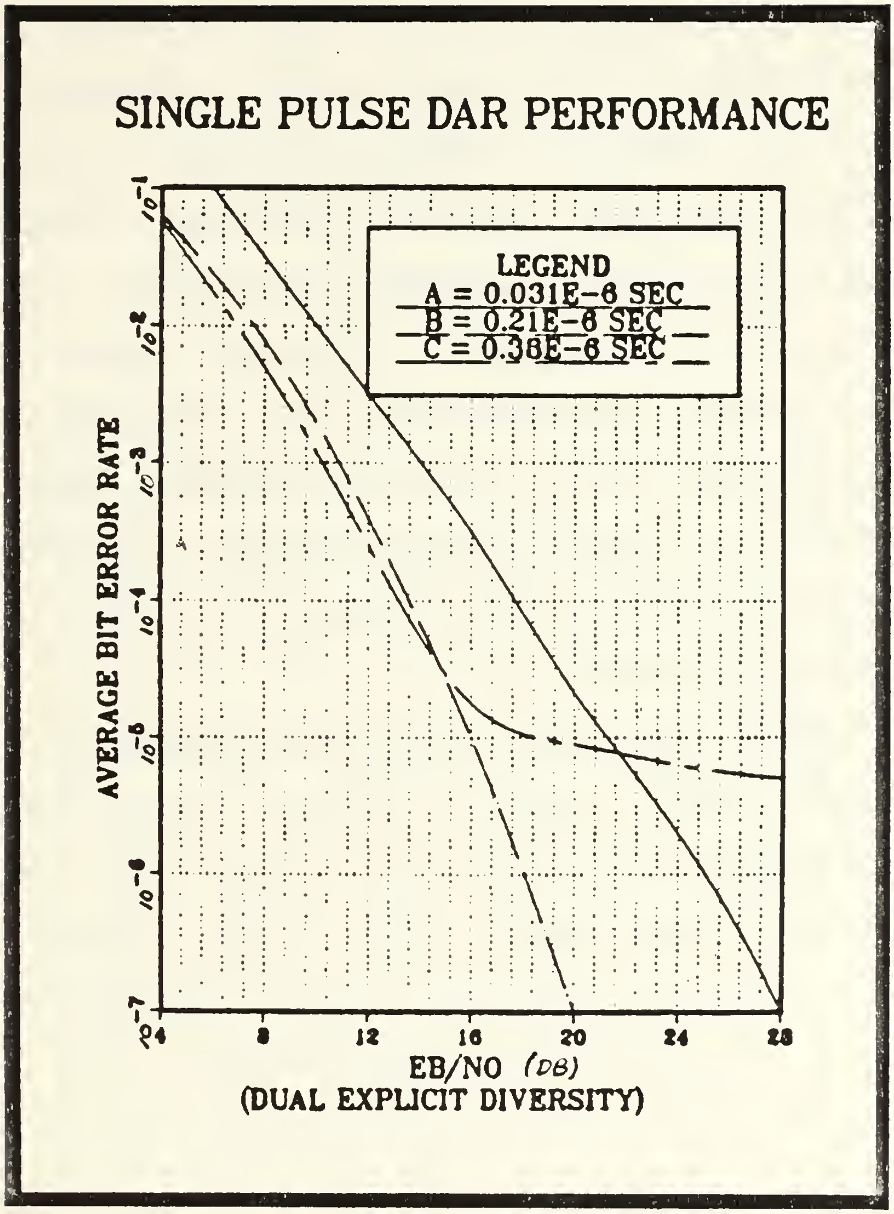


Figure 1-1 Distortion Adaptive Receiver Performance

(After Zawislan, 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 capabilty of a main-frame computer [Ref. 7]. A version of this program, called "FDUCT", 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 "FDUCT" 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 "FDUCT" 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 negitive.

II. TROPOSHERIC 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 negitive 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 quanitities, caused by atmospheric turbulence, will produce random flucuations 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]:

$$Re^{j\theta} = \sum_{i=1}^{m} A_i \; e^{j\Phi_i} \tag{2-1}$$

where m is the number of "blobs" in the scattering volume, A_j is the amplitude, and ϕ_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]:

$$\Delta\Phi = \frac{4\pi \; h \; \sin\gamma}{\lambda} \tag{2-2}$$

where γ = transmitter, receiver antenna elevation angle

h = mean thickness of the scatter volume (m)

λ = 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 2π. 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 2π [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

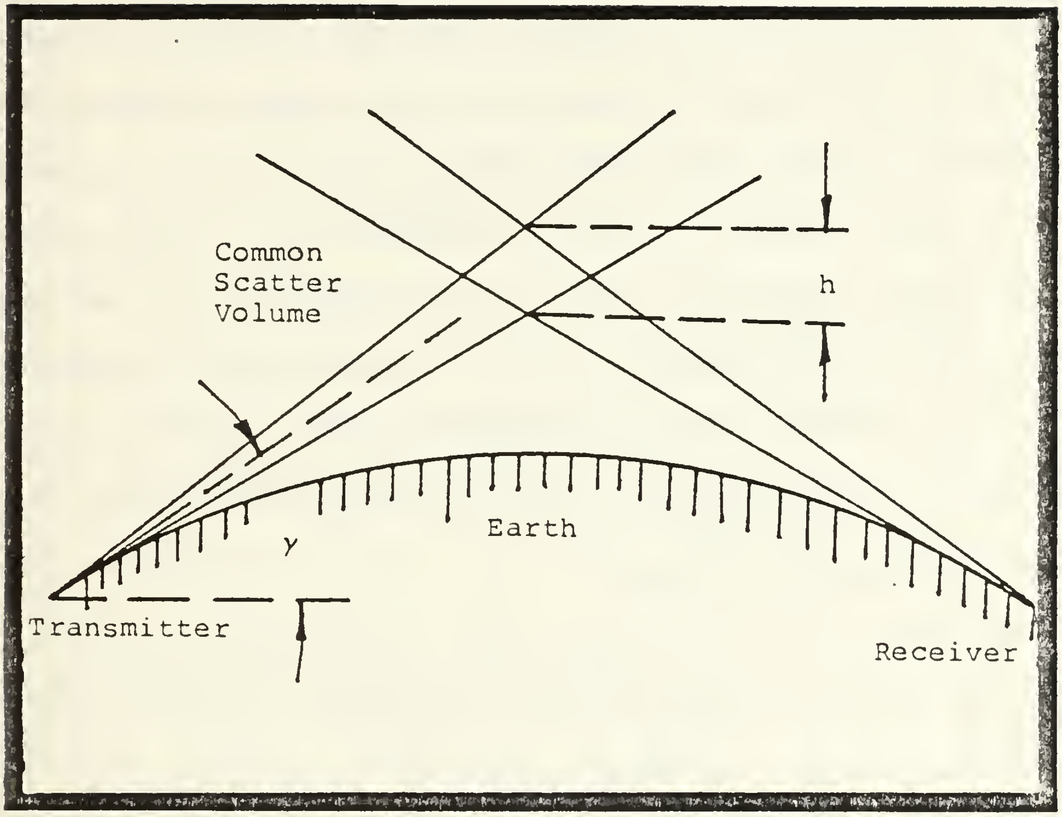


Figure 2-1 Scatter Volume Geometry

(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]:

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

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

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

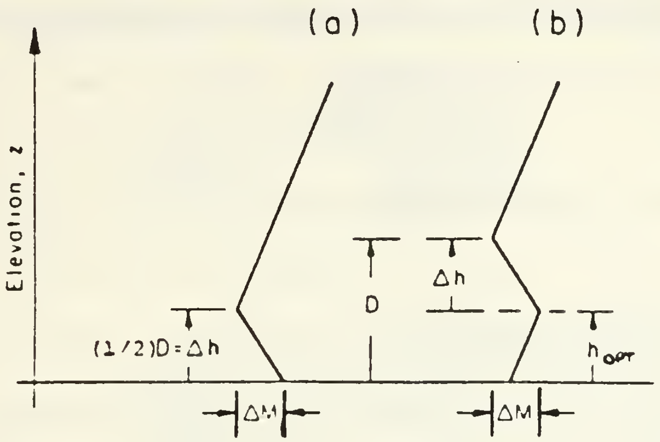
where h is the altitude in meters above the surface. The modified refractivity accounts for the curvature of the earth so the presence of ducting can be easily determined by observing the M-gradient on the M versus height plot.

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 negitive than 0 M-units/km, and

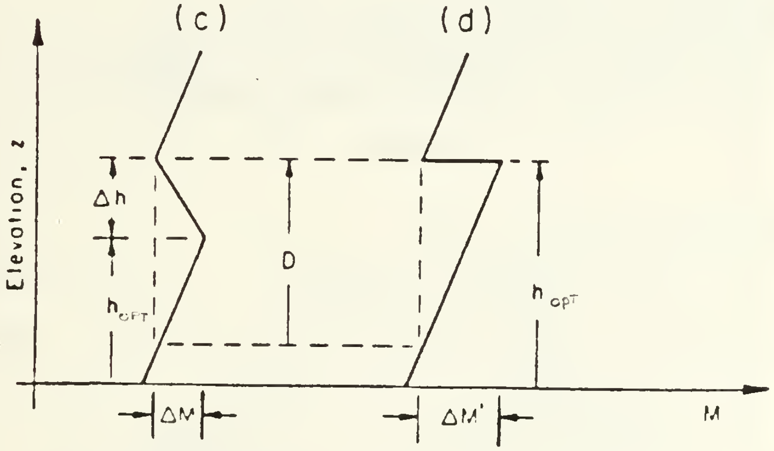
(2) this gradient should continue over a height of many wavelengths. The important duct parameters are the duct thickness, D, the intensity, M, and the optimum coupling height, H_{opt}. A piecewise linear approximation to the modified refractivity (tri-linear) profile for several types of ducts are shown 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. 8-12].

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



(a) Ground-based layer,
Ground-based duct

(b) Elevated layer,
Ground-based duct



(c) Elevated layer,
Elevated duct

(d) Elevated layer and
duct approximated with
an M-discontinuity.

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

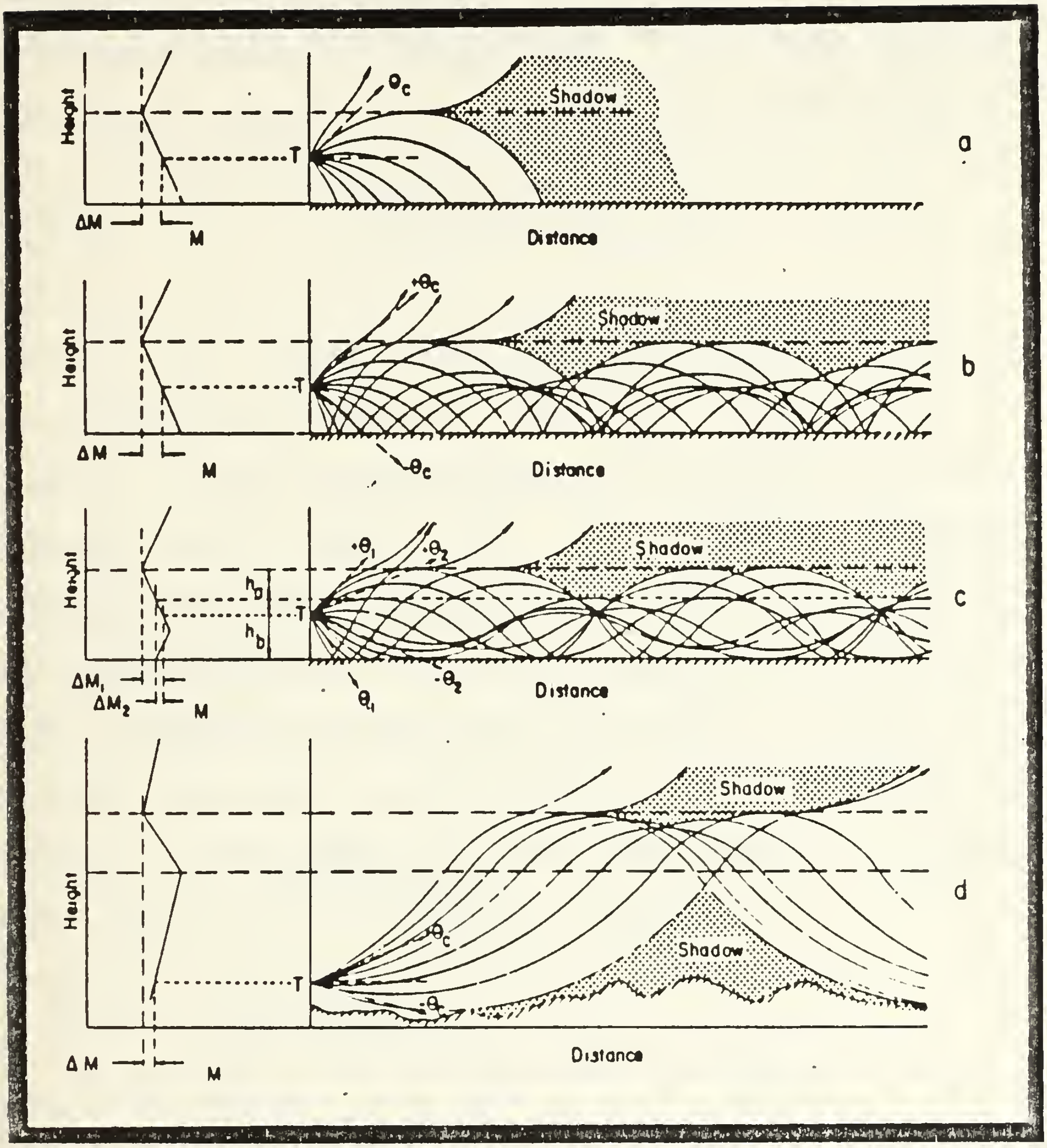


Figure 2-3 Propagation Effects of Ducts

(After Hall, Ref. 9:p. 31)

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

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

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 decribes the situation when the M-gradient is not constant within the duct. If a transmitter is positioned in the height region h_a, then rays within the $\pm\theta_1 = \pm\sqrt{(2\ \Delta M_1\ X\ 10^{-6})}$ range will remain in the duct with bounces as depicted in Figure 2-3b. Similarly rays transmitted within the $\pm\theta_2 = \pm\sqrt{(2\ \Delta M_2\ X\ 10^{-6})}$ range are trapped within the height range h_b. Finally a surface-based duct from an elevated layer 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 randomnly 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 -4
II	0.2 sec.< Outage <5 sec.	7.5X10-5
III	5 sec.< Outage <1 min.	7.5X10-3
IV	2 < Outages/min. < 5	2.5X10-4
V	5 < Outages/min.	1.0X10

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 distinquish 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]:

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

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

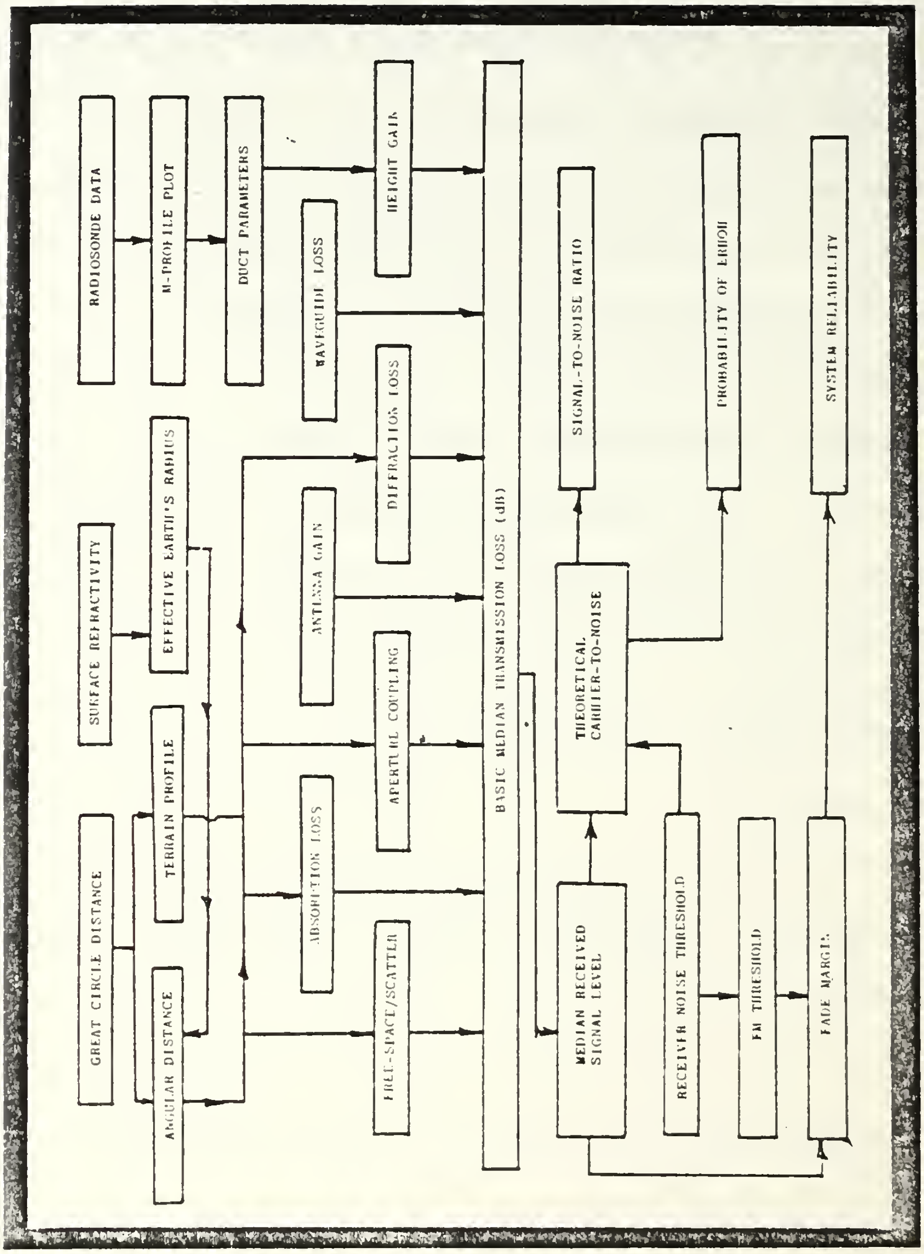


Figure 3-1 Program "TROPO" Module Block Diagram

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]:

$$N_s = N_o \exp(-0.03222h_s) \tag{3-2}$$

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.

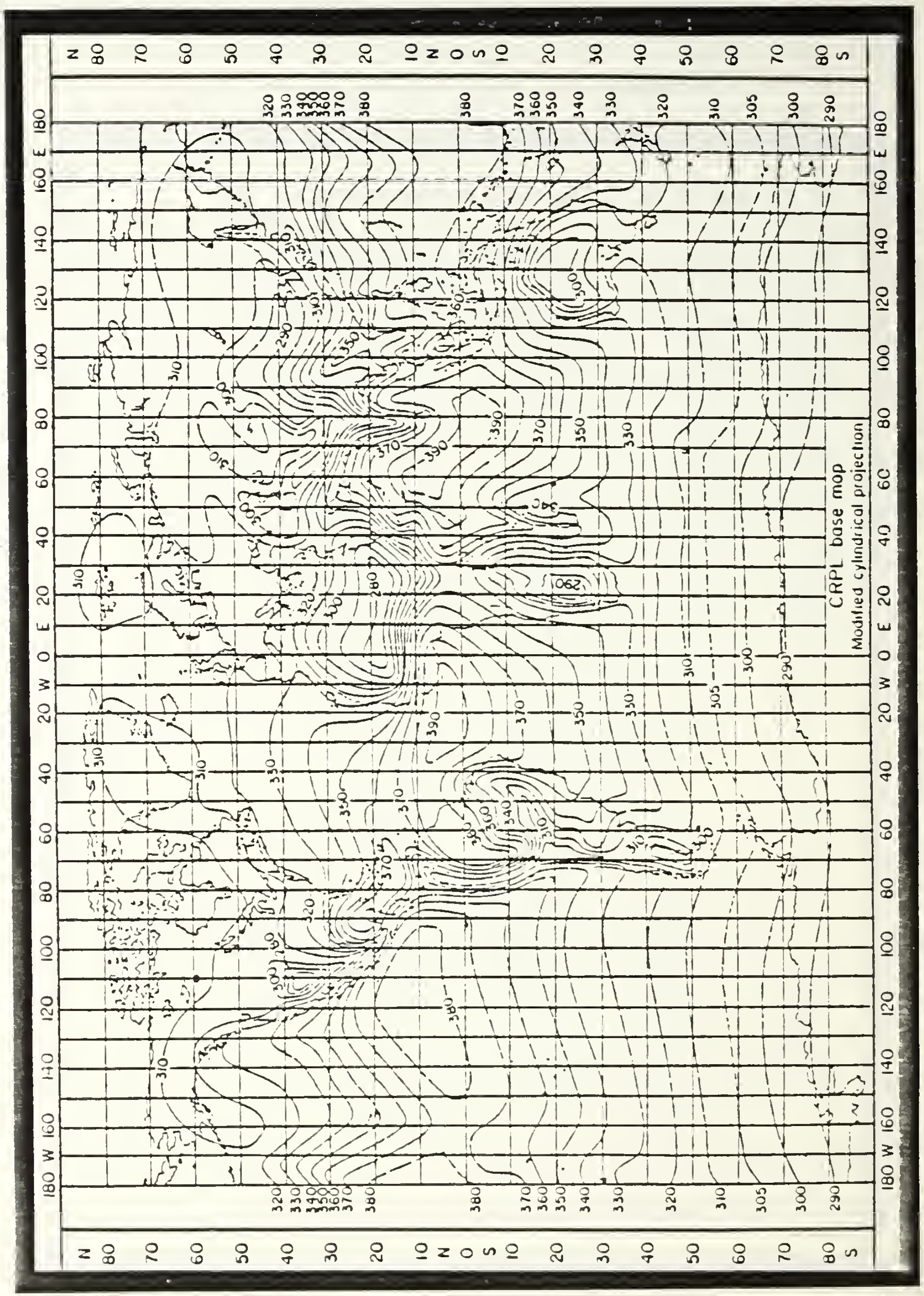


Figure 3-2 Monthly Surface Refractivity (Sea Level)

(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]:

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

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 surfave. 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]:

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

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]:

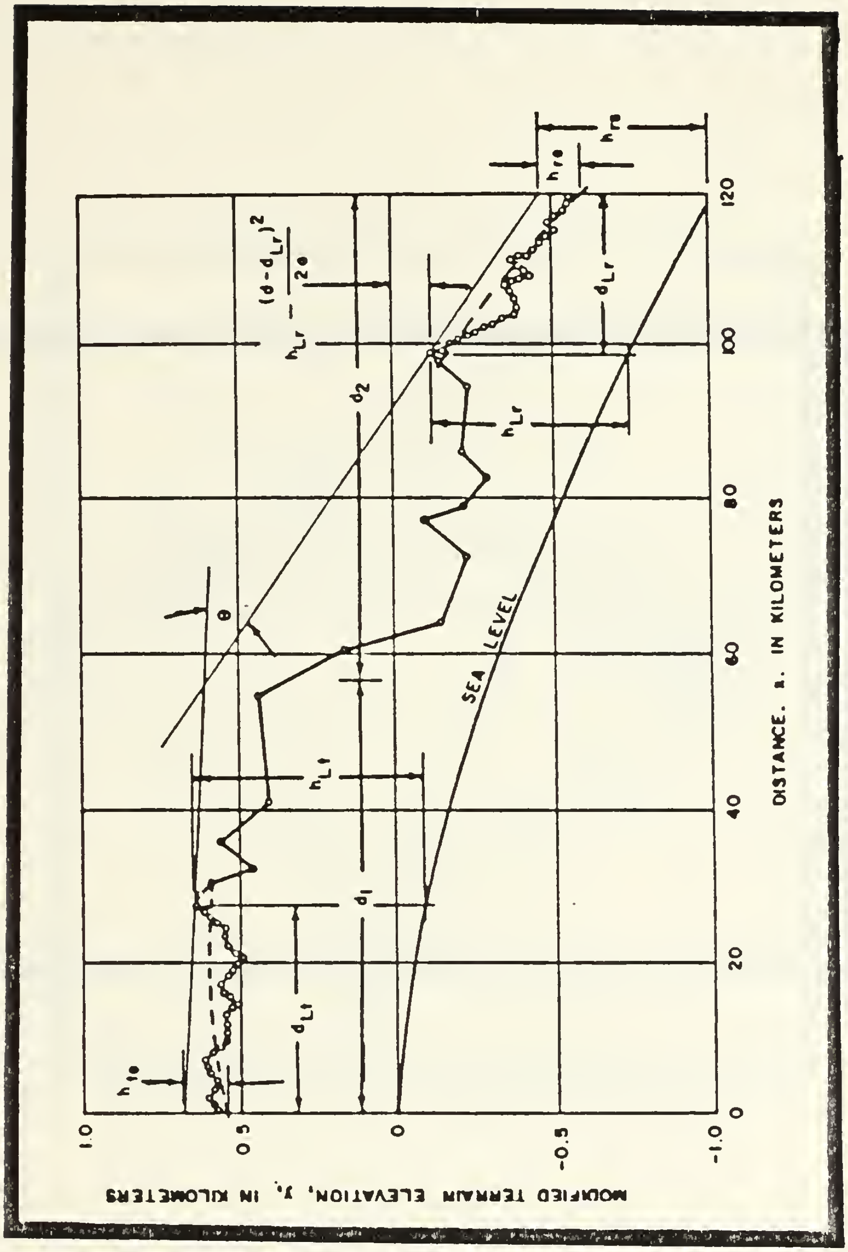


Figure 3-3 Linear Terrain Profile Plot Example

(After Panter, Ref. 12:p. 382)

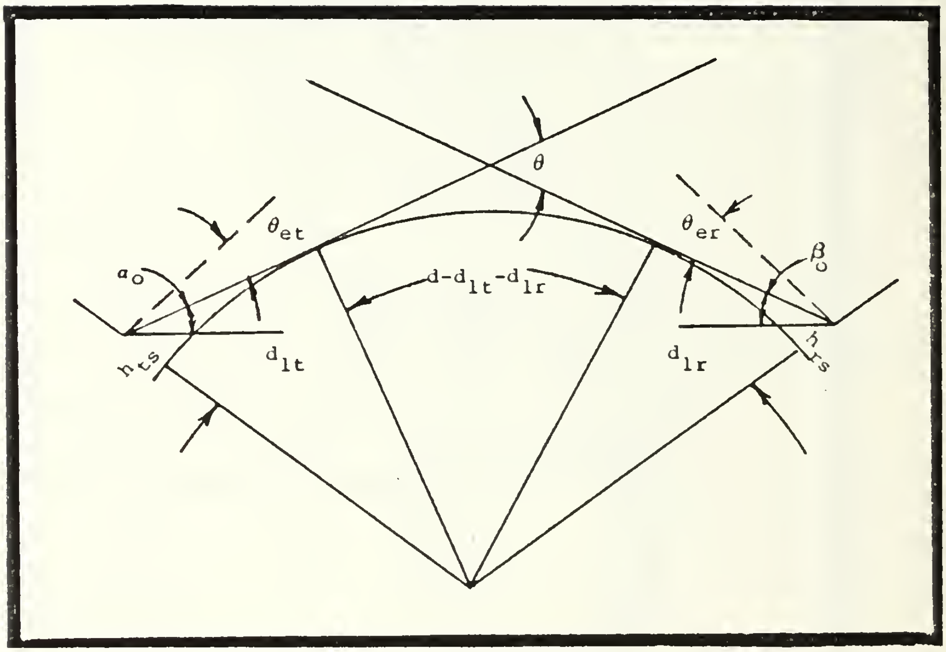


Figure 3-4a Smooth Earth Path

(After Panter, Ref. 12:p. 385)

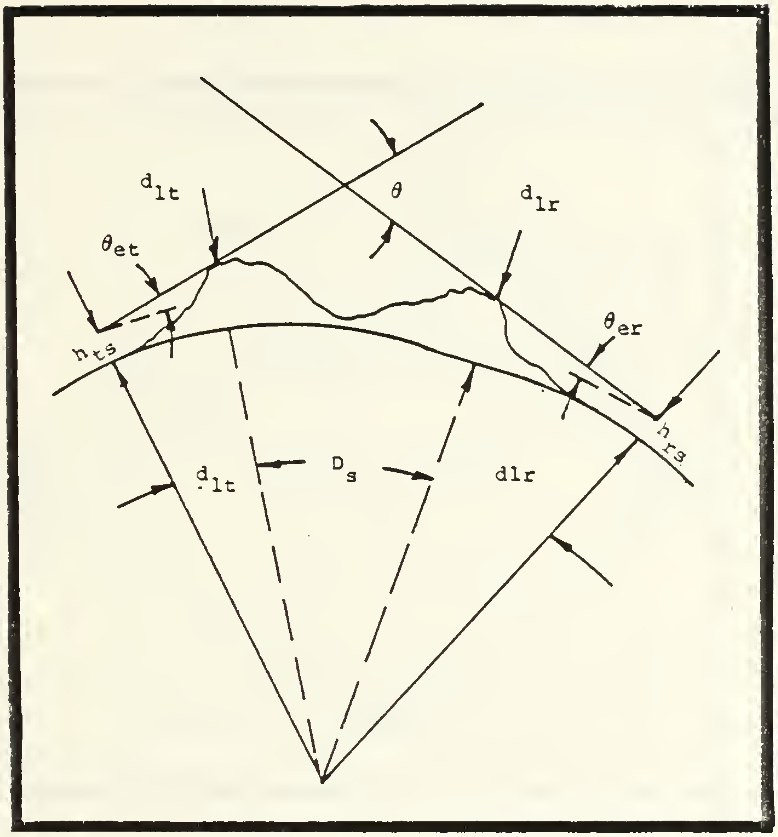


Figure 3-4b Near Obstacle Path

(After Panter, Ref. 12:p. 386)

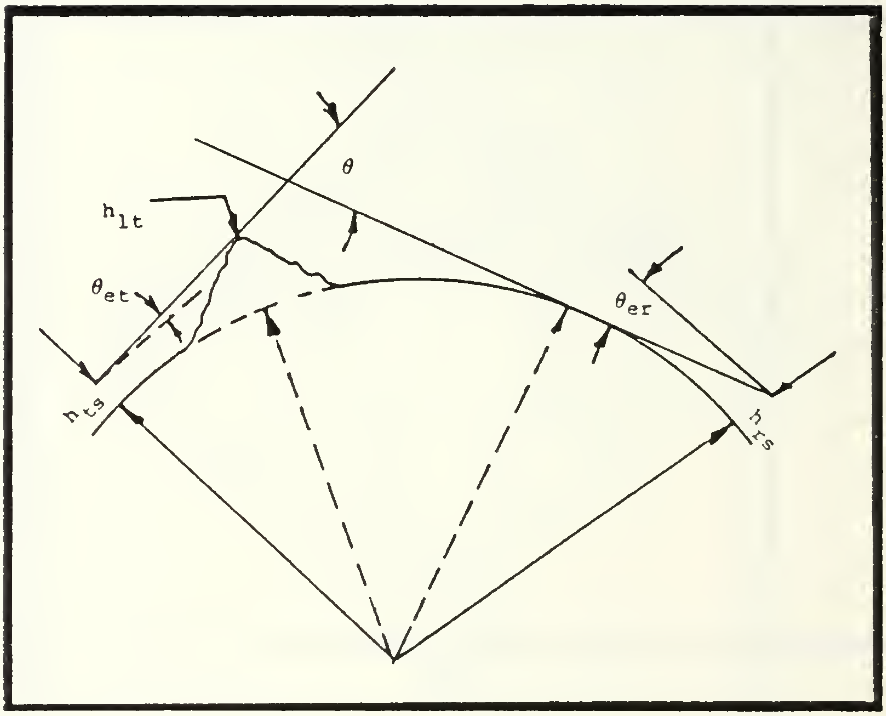


Figure 3-4c Near Obstacle/Smooth Earth Path

(After Panter, Ref. 12:p. 385)

a. Type I Radio Horizon/Radio Horizon

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

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

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

b. Type II Obstacle Horizon/Obstacle Horizon

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

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

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

c. Type III Obstacle Horizon/Radio Horizon

θ_{et} = (Same as Equation 3-5c)
θ_{er} = (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 α_{oo} and β_{oo} are calculated as:

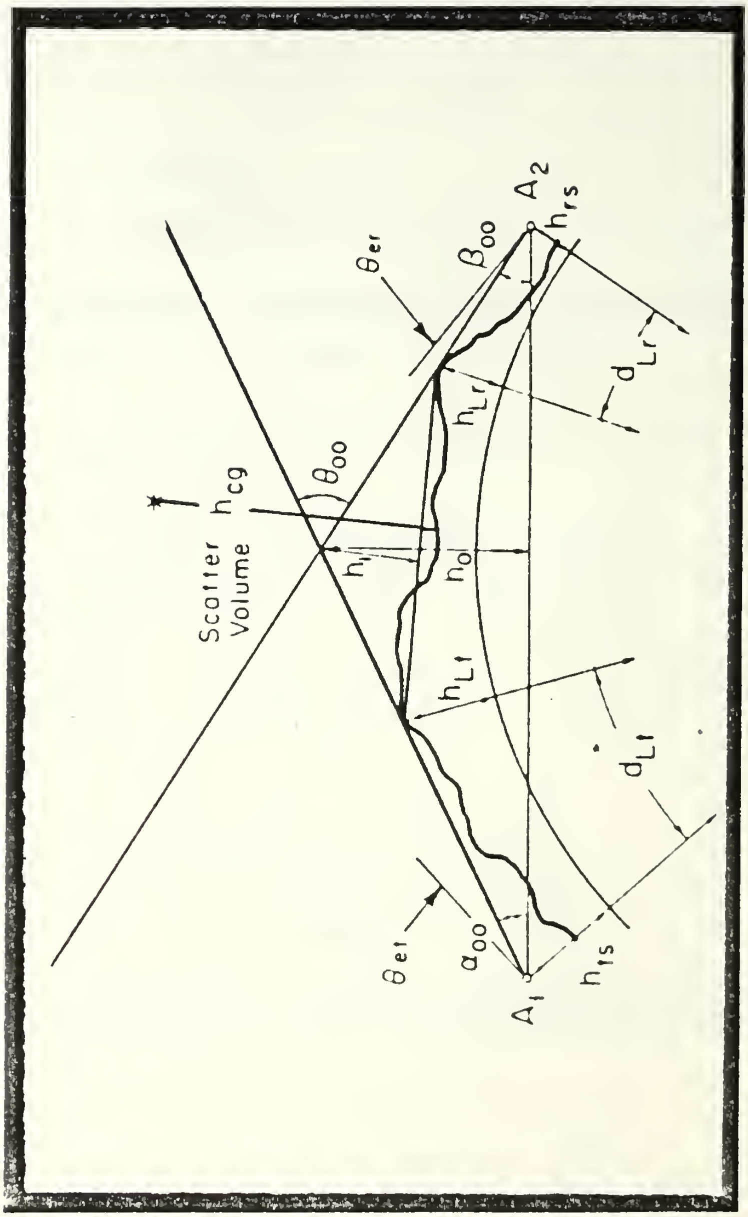


Figure 3-5 Typical Path Geometry

(After Ref. 18:p.8-6)

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

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

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:

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

The ratio α_{oo} and β_{oo} defines the path symmetry factor [Ref. 18:p. 4-7]:

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

The following equation will calculate the heigth 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

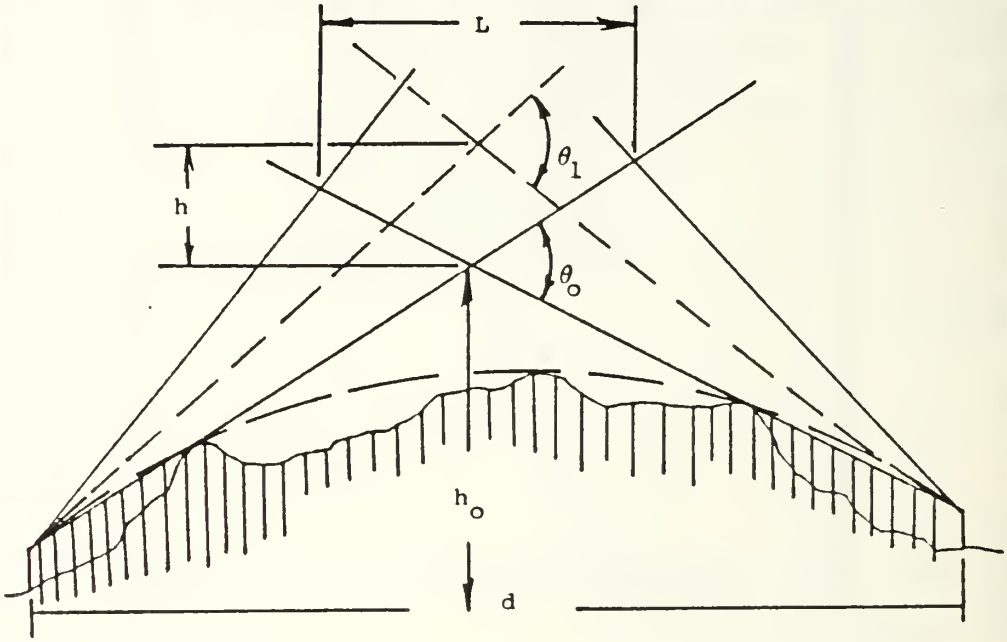


Figure 3-6 Common Scatter Volume Dimension

(After Du Castel, Ref. 19:p. 145)

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

$$h_o = \frac{S\ d\theta}{(1 + S)^2} \qquad (3\text{-}5i)$$

where S = symmetry factor

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

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

where $\theta_1 = 1.15\theta_0$

θ_0 = scatter angle

The maximum longitudinal dimension, L, is:

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

where d = great circle path distance (m)

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

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

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]:

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

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

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

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 3.1σ in decibels below the median, where σ is the standard deviation of the log-normal distribution. The worst-hour median loss can be determined as:

Worst-Hour Median Loss = Median Annual Path Loss

+ Difference of Annual-to-Worst-Month Median Loss

+ $3.1\ \sigma_{wm}$

where σ_{wm} = standard deviation of the worst-month

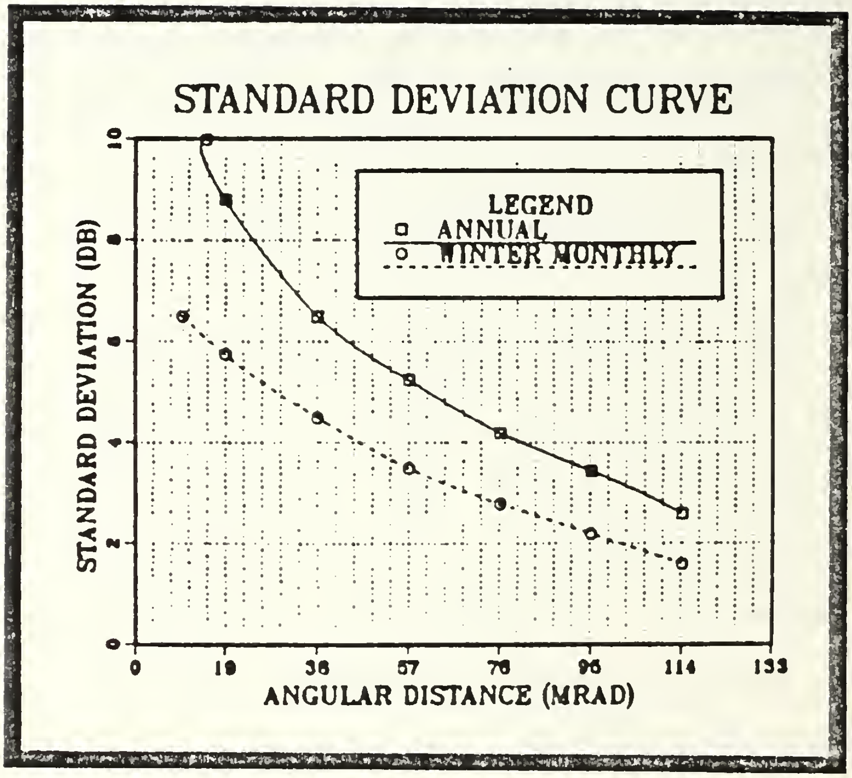


Figure 3-7 Annual and Winter Monthly Standard Deviation

(After Panter, Ref. 12:p. 359)

distribution obtained from Fiqure 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:

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

where D = aperture diameter (feet)

An illunimation 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:

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

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.

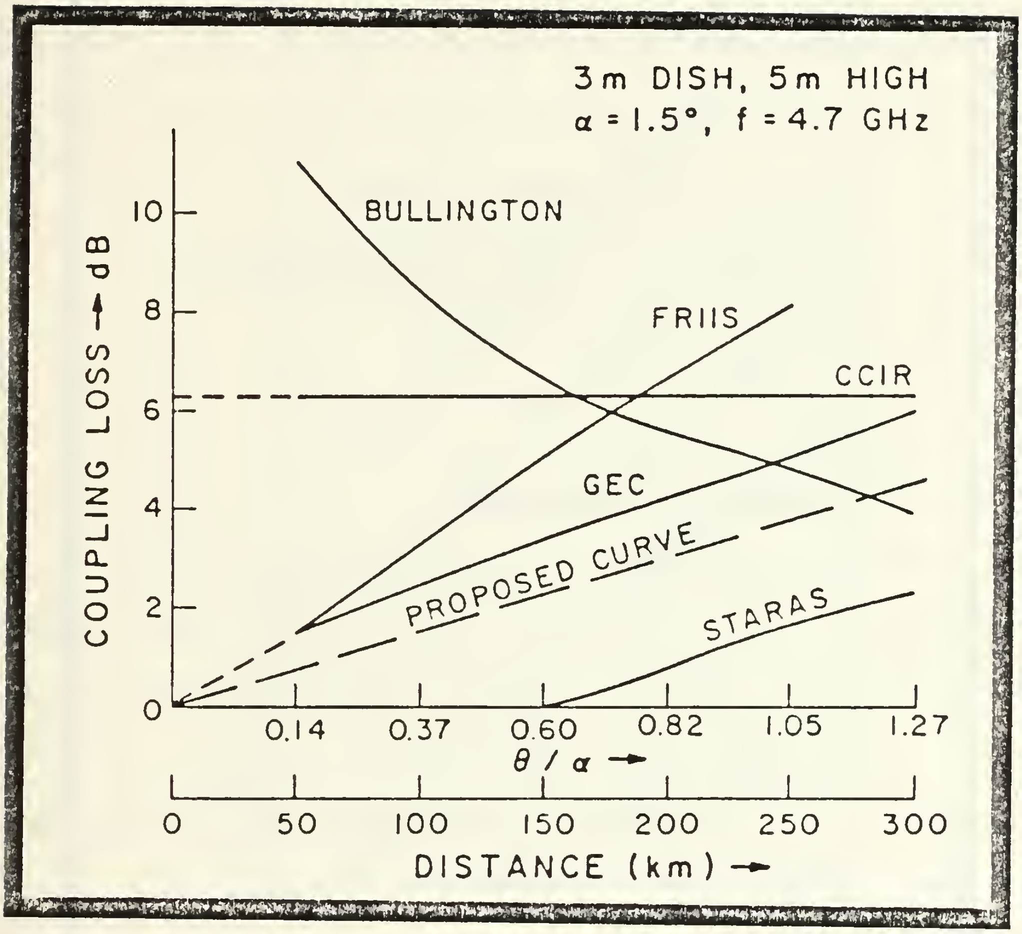


Figure 3-8 Aperture-to-Medium Coupling Loss

(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)

θ = 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

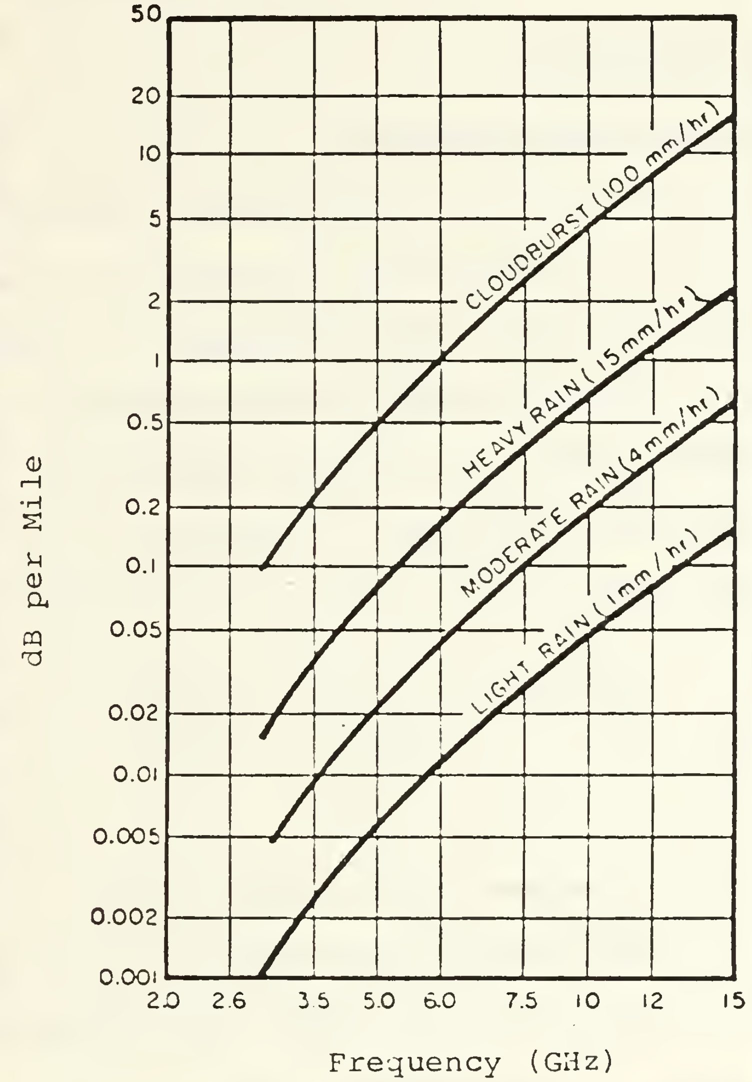


Figure 3-9 Estimated Atmospheric Absorption

(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:

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

where P_t = transmitter power output (dBW)
L_T = total median transmission loss (Equation 3-1)

The receiver noise threshold level is written as:

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

where -204 dBW = thermal noise constant

NF = receiver noise figure (dB)

B_{IF} = receiver IF bandwidth (Hz)

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

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

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 probabilty 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]:

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

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:

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

where μ = correlation coefficient

$$\mu = \sqrt{\frac{\overline{\gamma}_c}{1 + \overline{\gamma}_c}} \qquad \text{(for coherent PSK)}$$

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

where γ_c = average received E_b/N_o per channel

γ_b = average received E_b/N_o 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:

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

where M = 2 (for BPSK signaling)

M = 4 (for QPSK signaling)

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

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

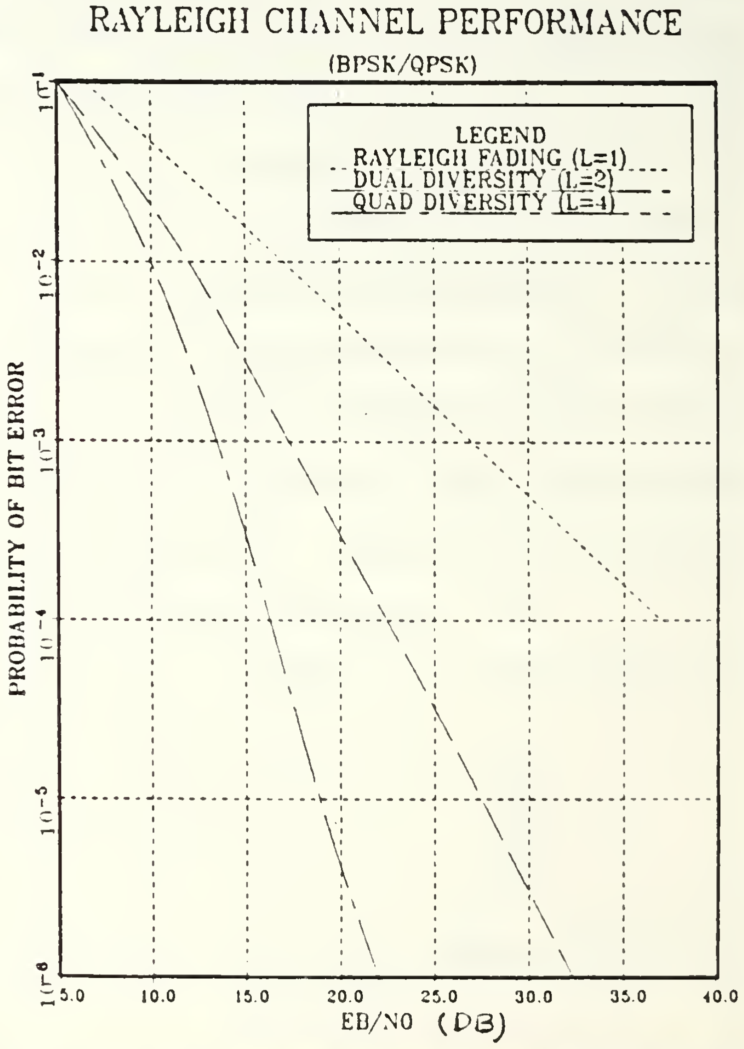


Figure 3-10 Probability of Error (BPSK/QPSK)

(After Proakis, Ref. 14:p. 492)

where $k = \log_2 M$

The graphs of P_M versus E_b/N_o 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_b/N_o 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:

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

where d = path distance (meters)

θ = scatter angle (mrad)

θ_{et} = transmitter take-off angle (mrad)

θ_{er} = receiver take-off angle (mrad)

The time dispersion (multipath spread) relative to the

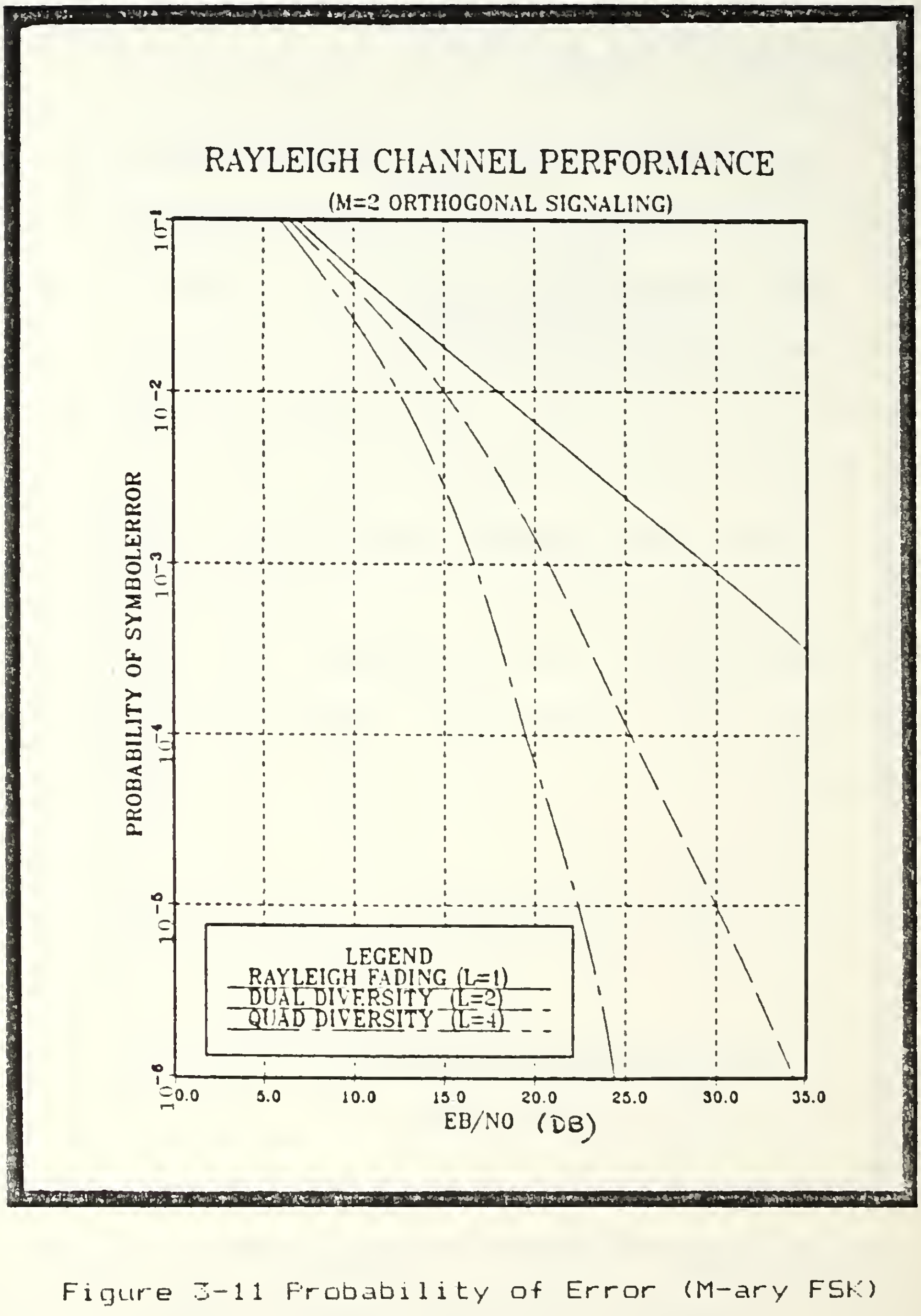


Figure 3-11 Probability of Error (M-ary FSK)

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

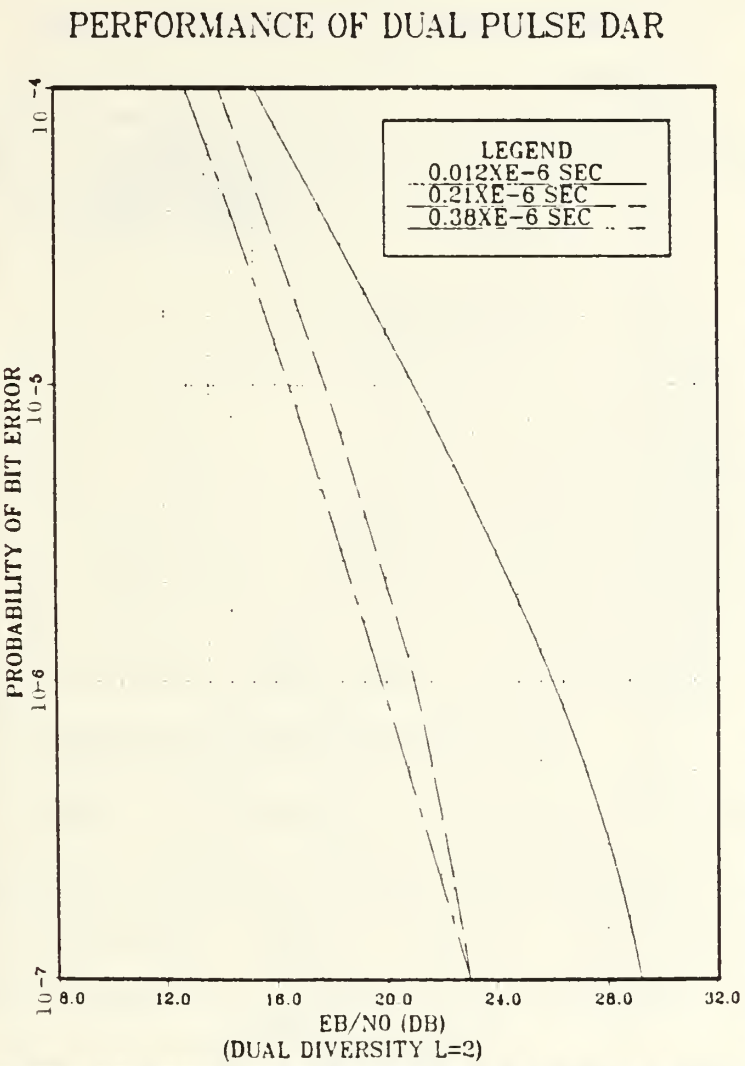


Figure 3-12 DAR Performance - Dual Diversity

(After Zawislan, Ref. 4:p. 4)

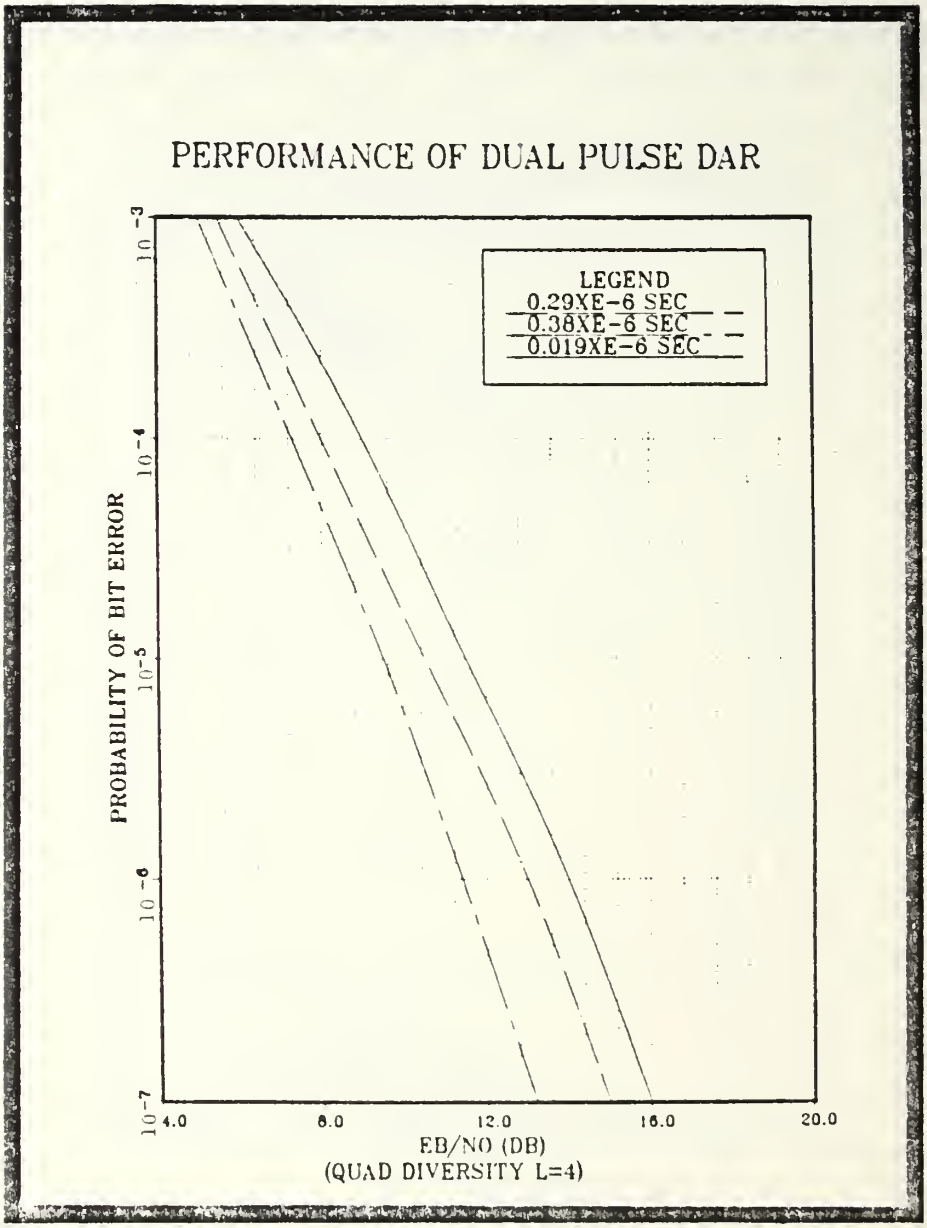


Figure 3-13 DAR Performance - Quad Diversity

(After Zawislan, Ref. 4:p. 4)

average time delay for unequal antenna beamwidths is:

$$\Delta = \frac{\delta}{2c} = \frac{\delta}{2(3X10^{8}\ m/s)} \qquad (3\text{-}17b)$$

where $c = 3X10^{8}$ m/sec

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

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

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 Reliabilty

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 Propagation Reliability (%)	Fade Margin (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:

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

where N_p = "practical noise threshold"

$N_p = P_n$ (dBm) + FM improvement

$P_n = -174$ dBm + $10 \log_{10} B_{IF}$ + 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 availabilty. Barnett's procedure begins by defining U_{ndp} as the nondiversity annual outage probability and r as the fade occurrence factor:

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

If F is the fade margin in decibels:

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

For the worst month:

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

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 occurrance:

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

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:

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

The annual nondiversity availability percentage is:

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

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]:

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

and in the vertical as:

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

where D = parabolic antenna diameter (m)

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

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

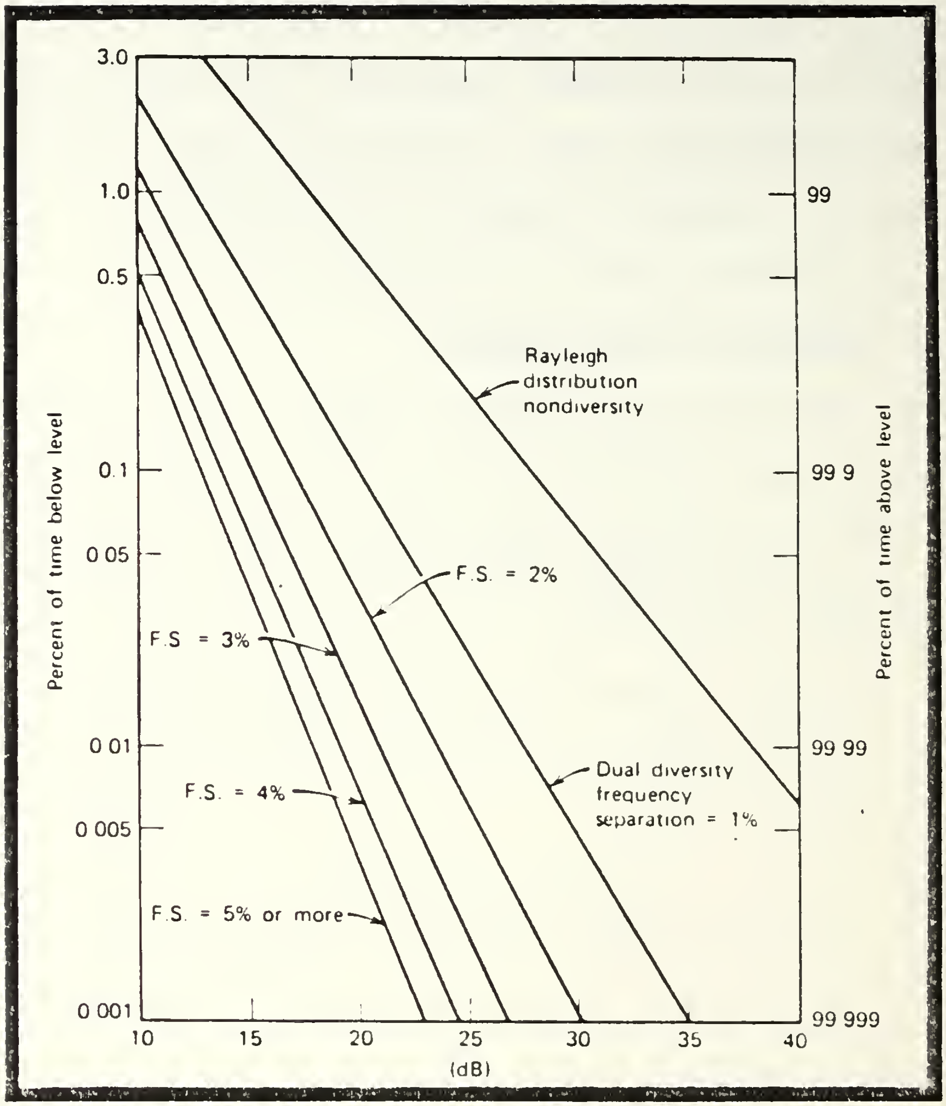


Figure 3-14 Approximate Interference Fading Distribution versus Order of Diversity and Frequency Separation (After Ref. 18:p. 2-46)

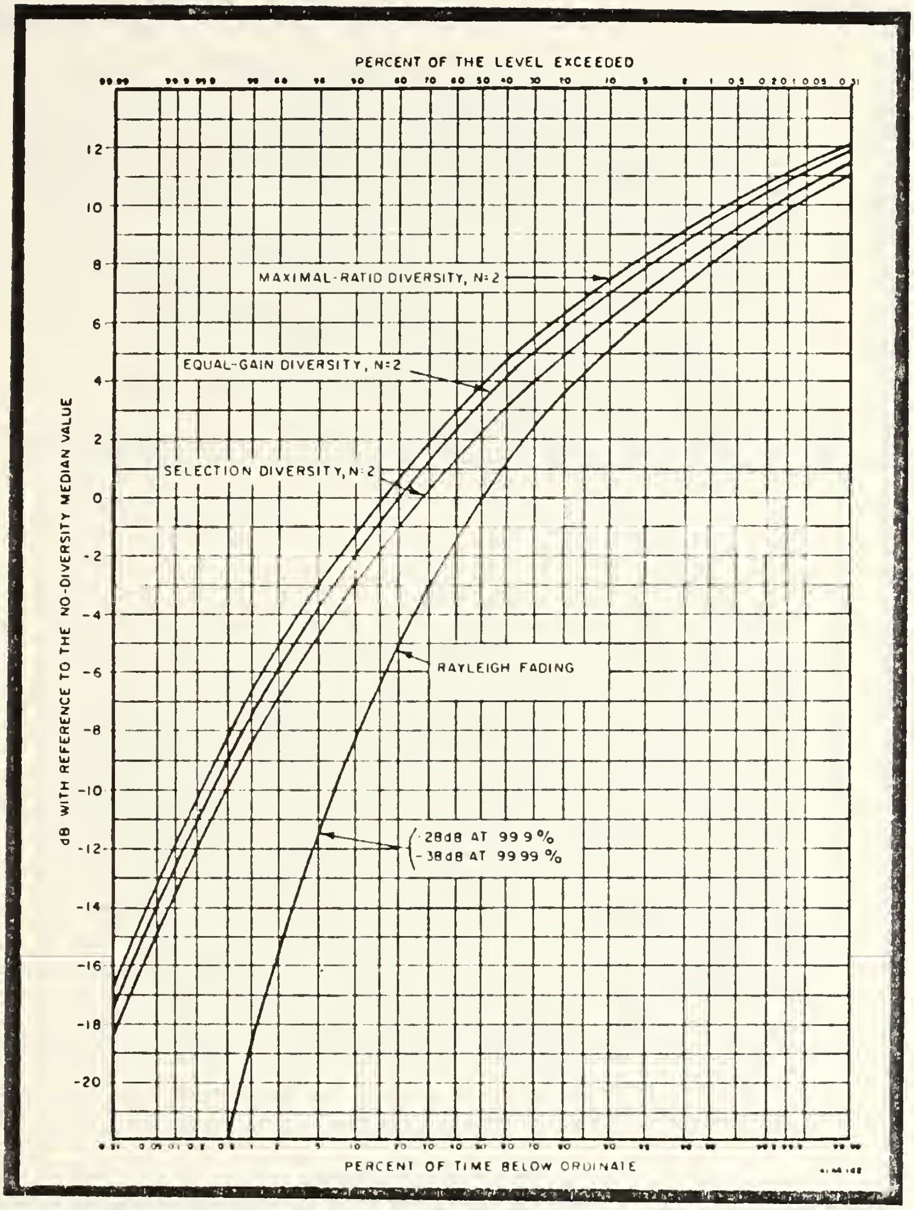


Figure 3-15 Short-Term Fading (Dual Diversity)

(After Ref. 18:p. 4-11)

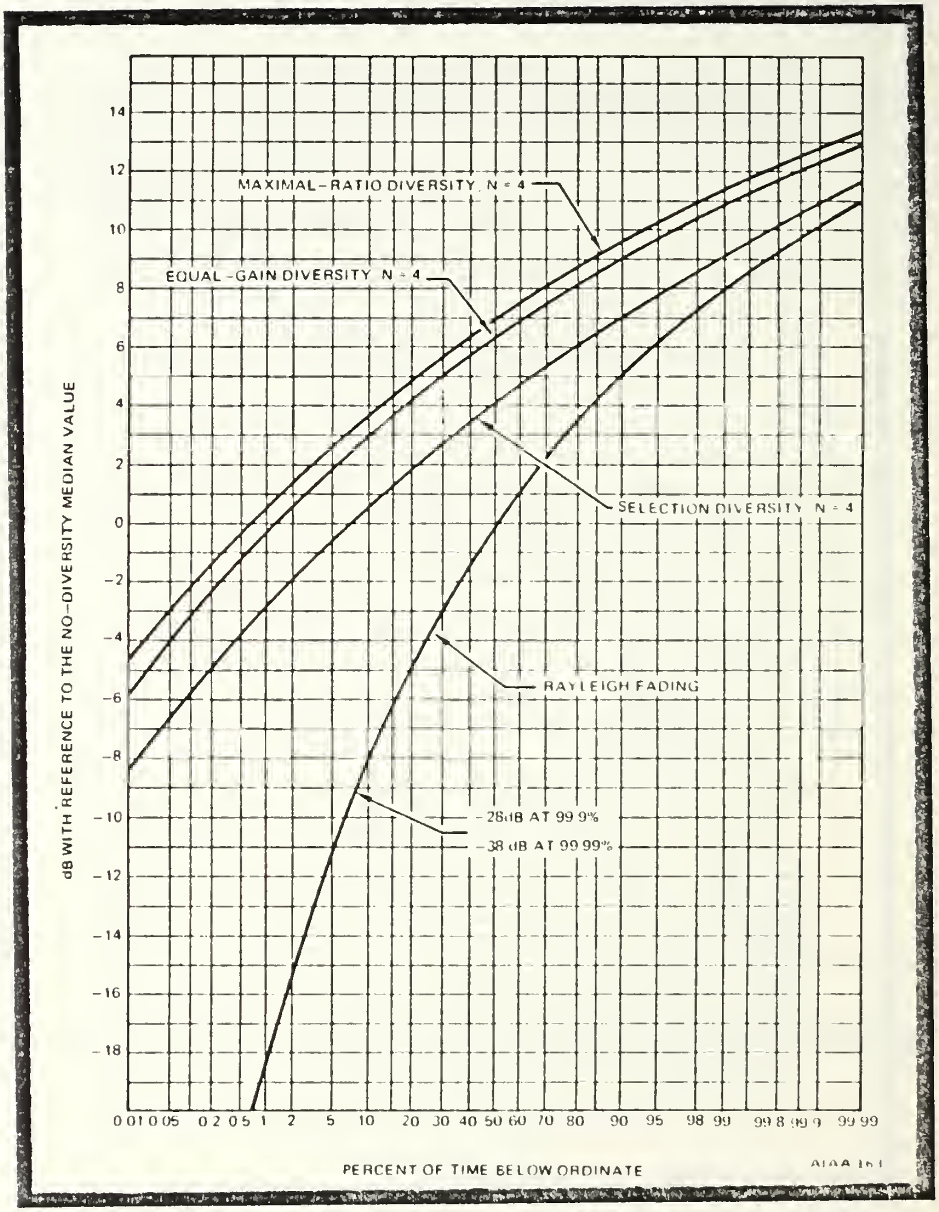


Figure 3-16 Short-Term Fading (Quad Diversity)

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

where f = transmitter frequency (MHz)

θ = 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 Bandwith

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

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

where F_p = peak frequency deviation (Hz)

F_m = 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:

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

and

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

where L = path length (nautical miles)

pWp = picowatts psophometrically weighted measured at, or referred to, a zero transmission level point.

The term 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 dBa is referred to is -85 dBm. To obtain dBa0, it is required to calculate the number of dB above this reference power the signal is. For flat voice channels, the corrected reference level is -82 dBm and the expression for dBa0 is:

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

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]:

$$SNR = CNR + D_{im} + FM_{im} - L_f + P_{im} \qquad (3\text{-}27)$$

where 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

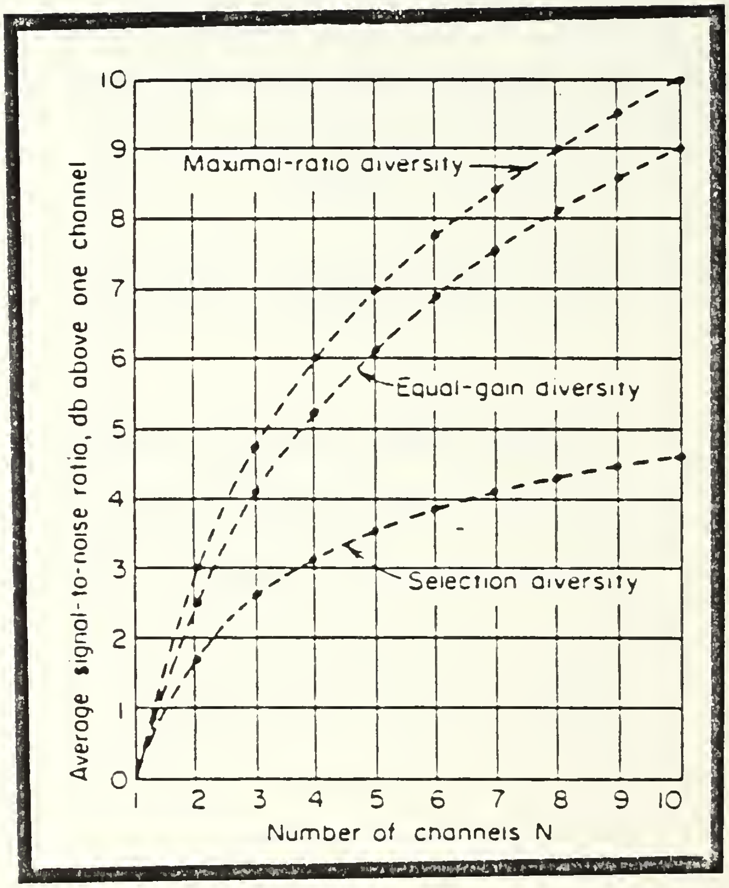


Figure 3-17 SNR Improvement from Diversity Techniques

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

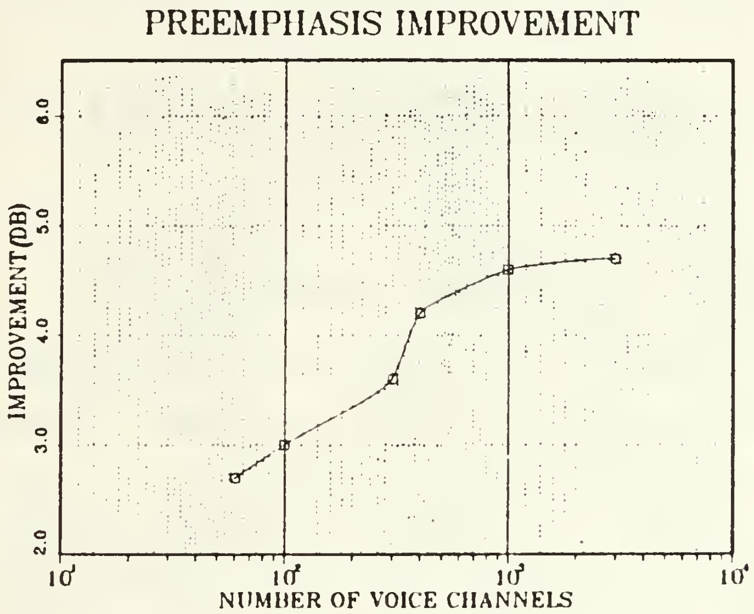


Figure 3-18 Preemphasis Improvement for FDM Channels

(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 troposhperic duct. The calculation must provide a result that was within 10 dB of the PDUCT 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 occurrance 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 (48-49N/09-11E)	1452	4	115
Essen, FRG (51-23N/06-58E)	1412	3	106
Hannover, FRG (52-28N/09-41E)	1376	4	109
Rheine, FRG (52-16N/07-25E)	1257	3	113
Idar-Oberstein, FRG (49-41N/07-19E)	1151	3	88
Emden, FRG (53-22N/07-13E)	1071	4	124
Goch, FRG (51-40N/06-10E)	1044	6	172
Greifswald, FRG (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 FDUCT 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 cooresponded 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.

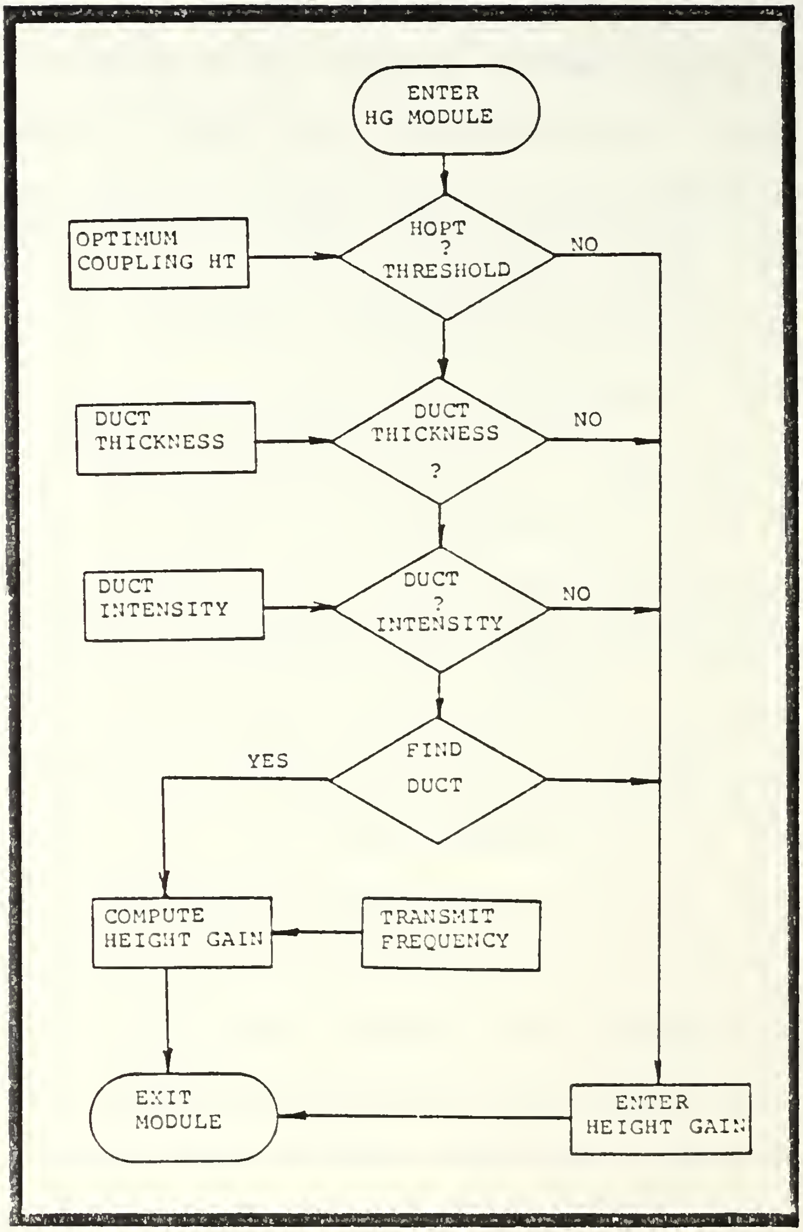


Figure 4-1 Height Gain Estimation Flowchart

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]:

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

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 TROPO 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

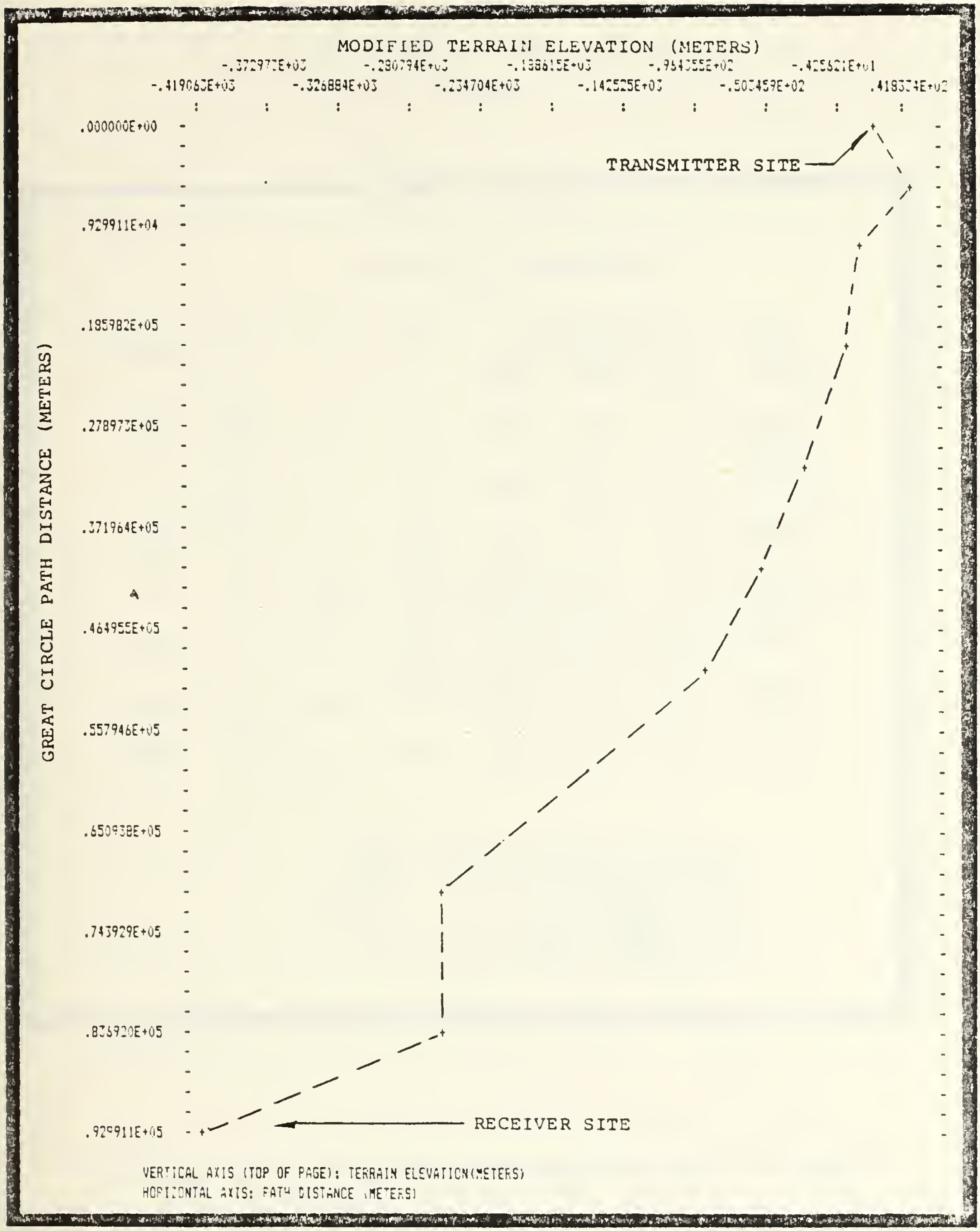
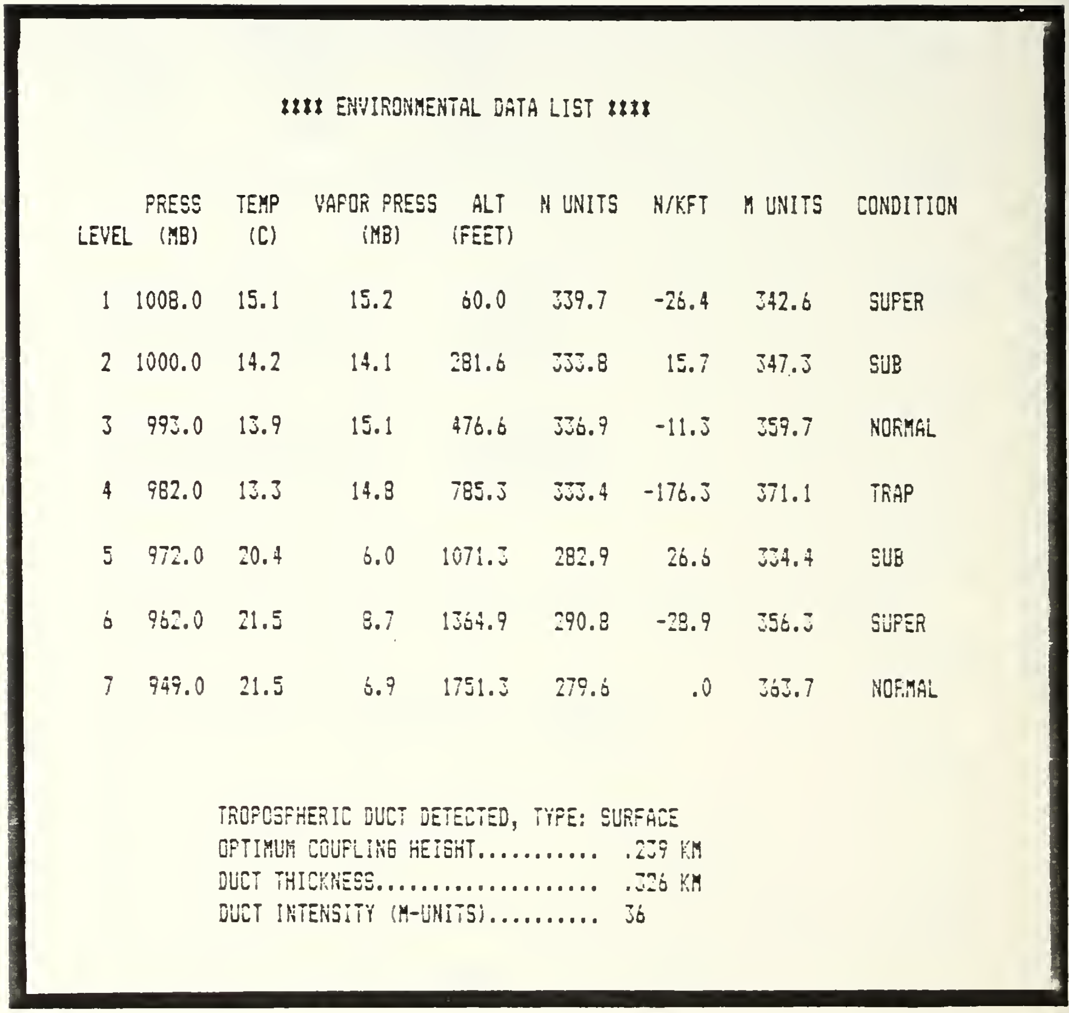


Figure 5-2 Example System Terrain Profile Plot



```
                **** ENVIRONMENTAL DATA LIST ****


      PRESS   TEMP   VAPOR PRESS   ALT    N UNITS   N/KFT    M UNITS   CONDITION
LEVEL  (MB)    (C)       (MB)     (FEET)

  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

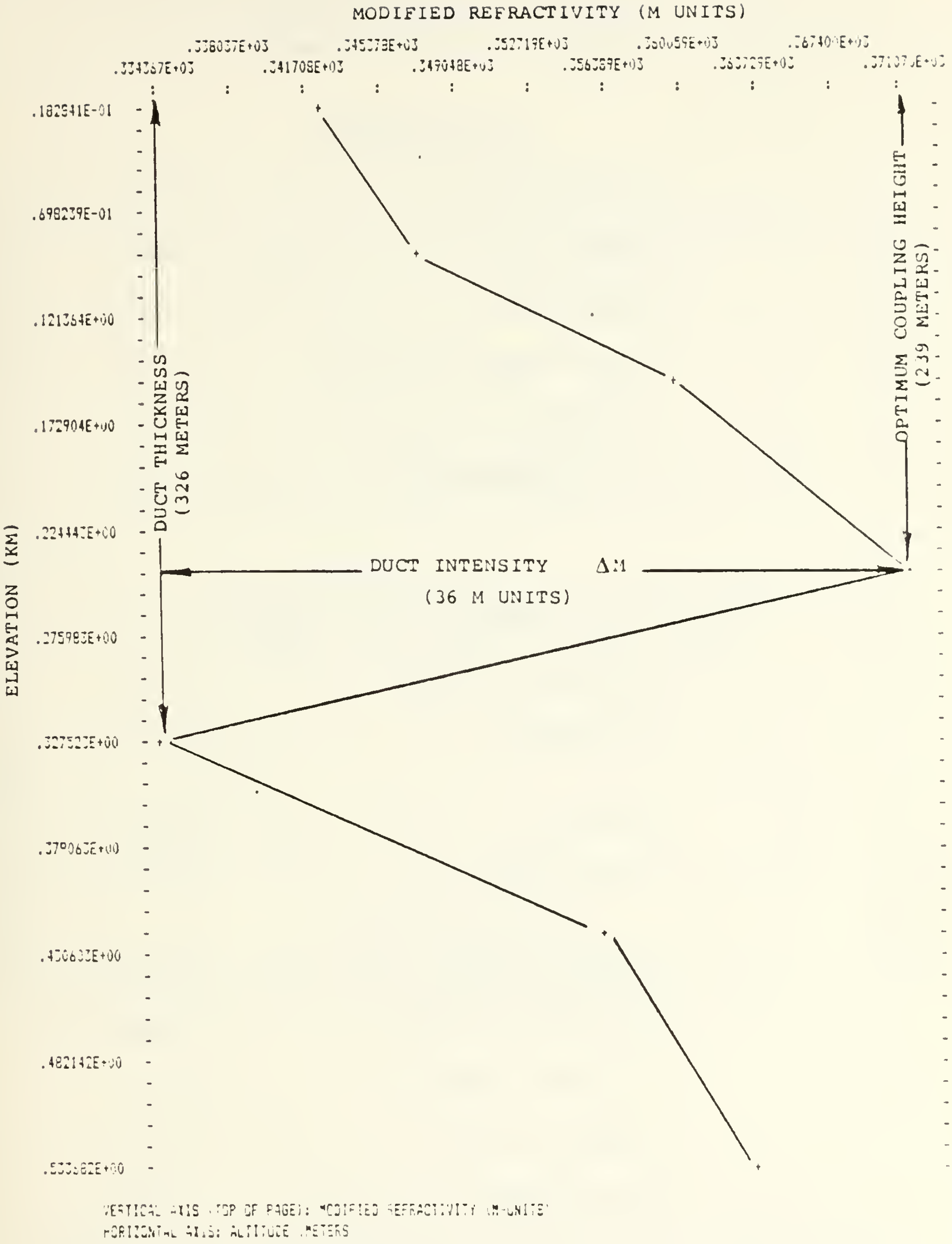


Figure 5-4 M-Profile Plot (Surface Duct)

```
-------------------------------------------------------------------------
                 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

              RAINFFALL 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

              THEORECTICAL RF CNR ......................   16.3 DB

              SYSTEM FADE MARGIN .......................    6.3 DB
```

Figure 5-5 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)

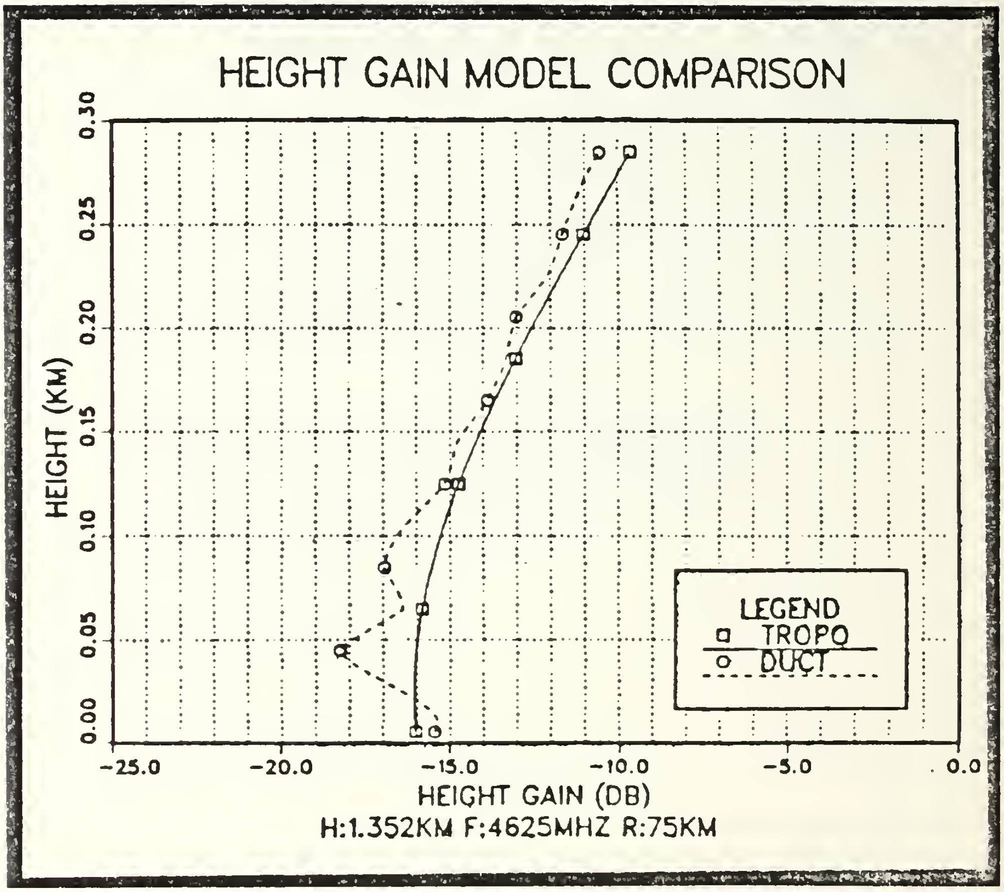


Figure 5-6a Height Gain Model Comparison

(Frequency: 4625.0 MHz)

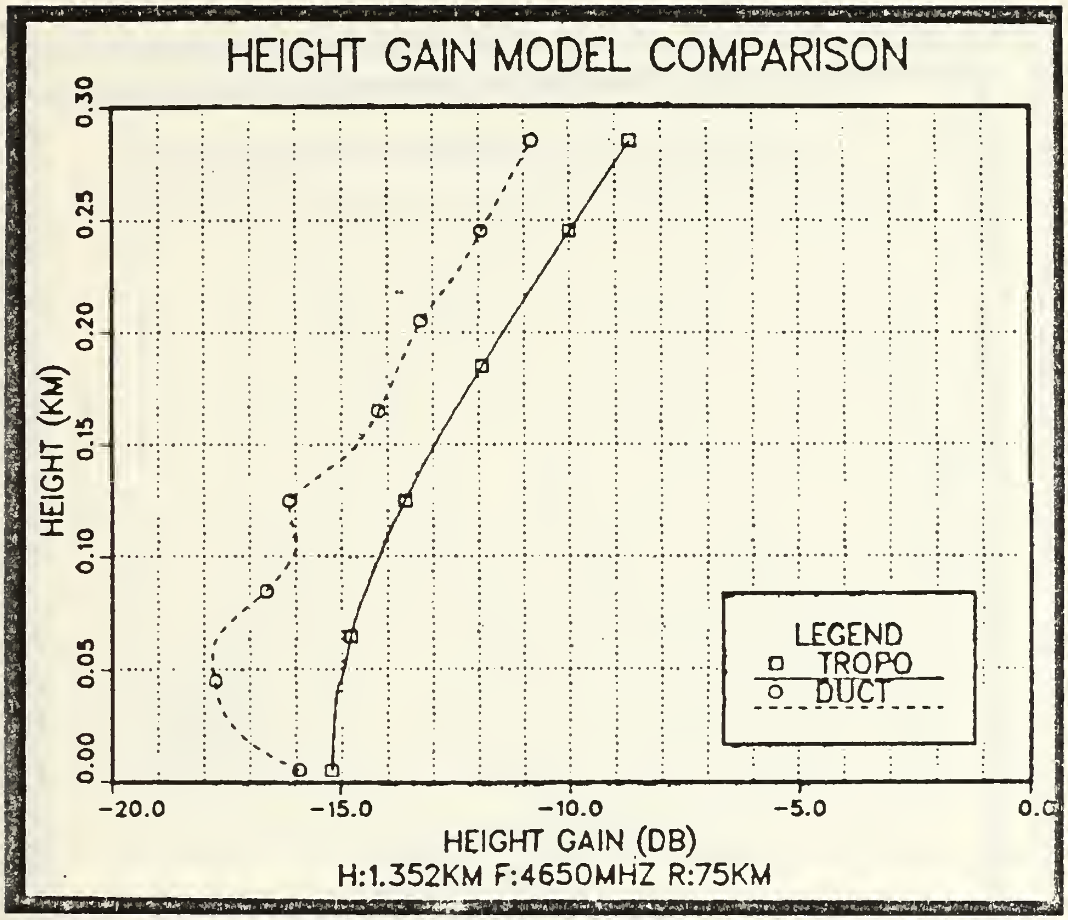


Figure 5-6b Height Gain Model Comparison

(Frequency: 4650.0 MHz)

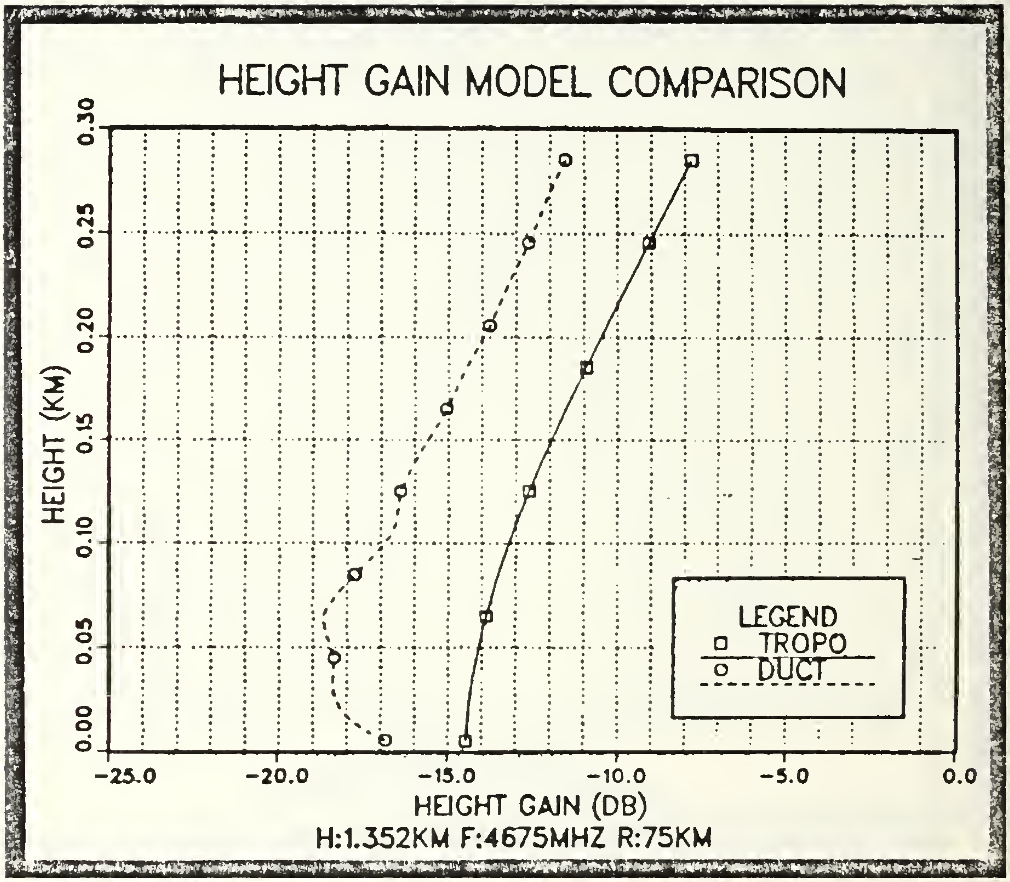


Figure 5-6c Height Gain Model Comparison

(Frequency: 4675.0 MHz)

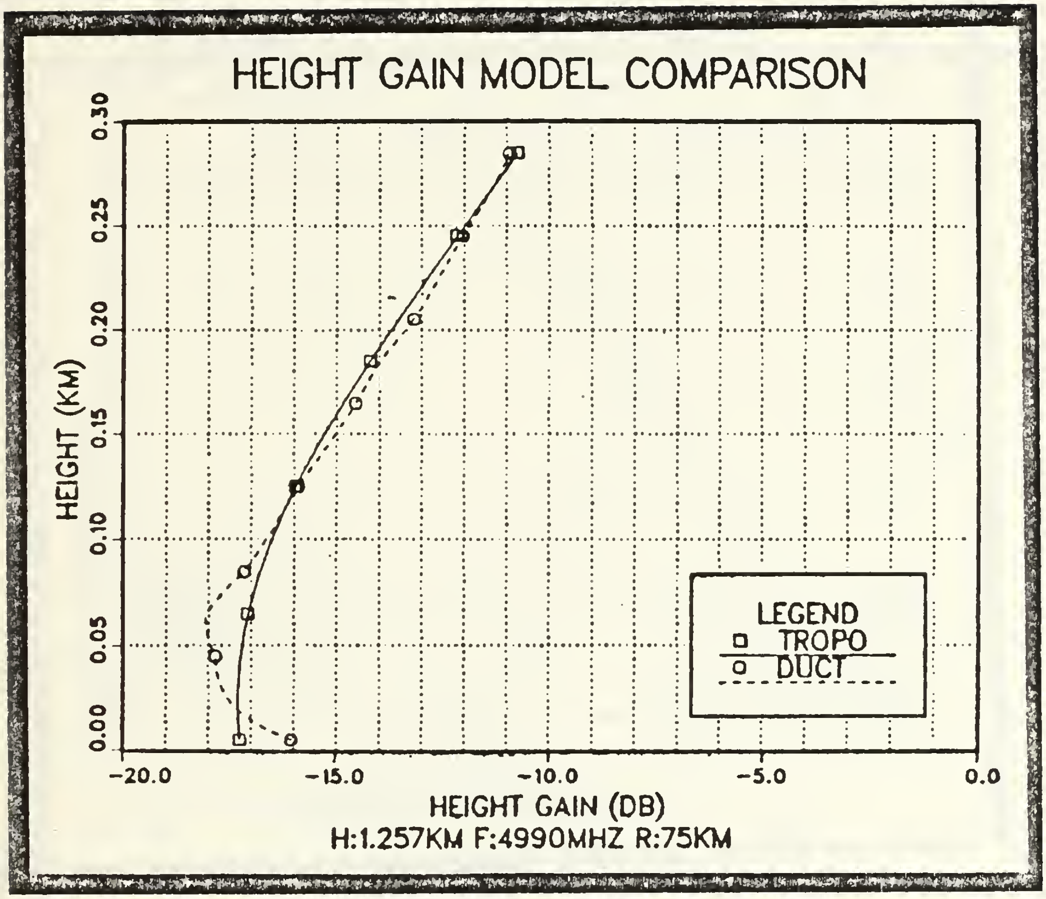


Figure 5-7a Height Gain Model Comparison

(Range: 75 Kilometers)

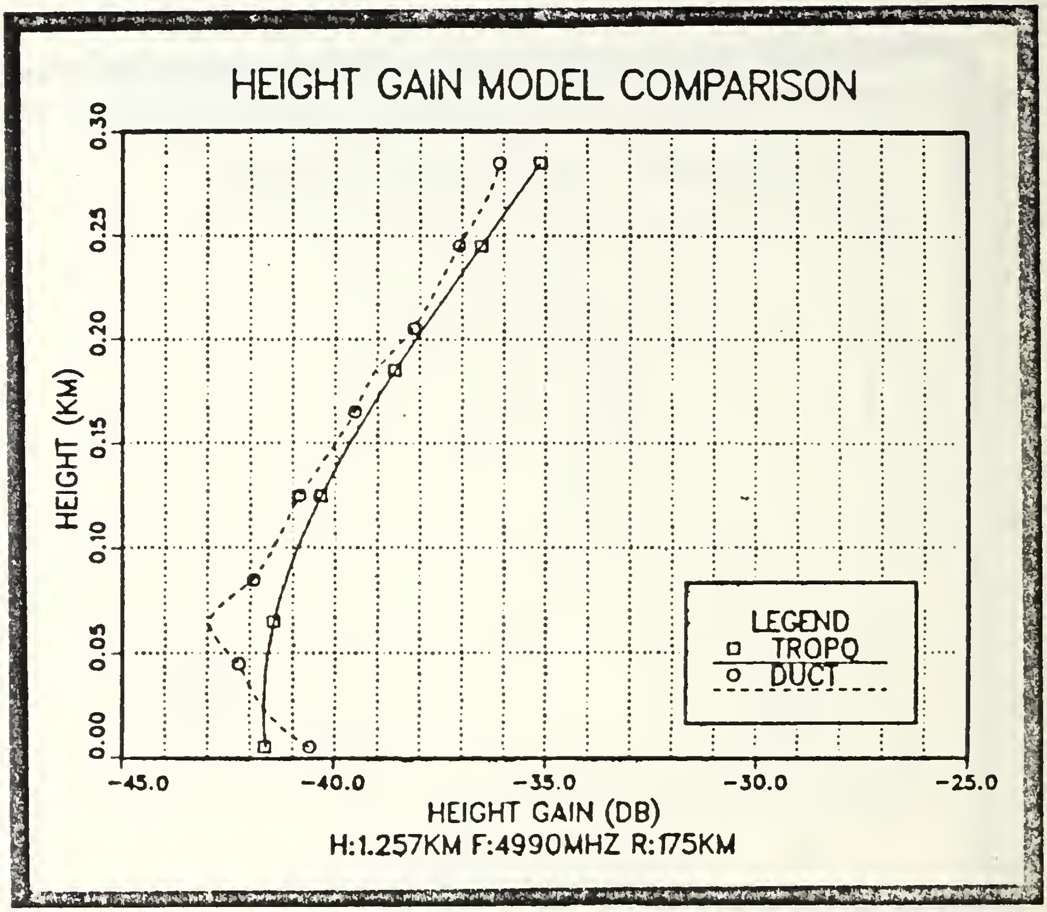


Figure 5-7b Height Gain Model Comparison

(Range: 175 Kilometers)

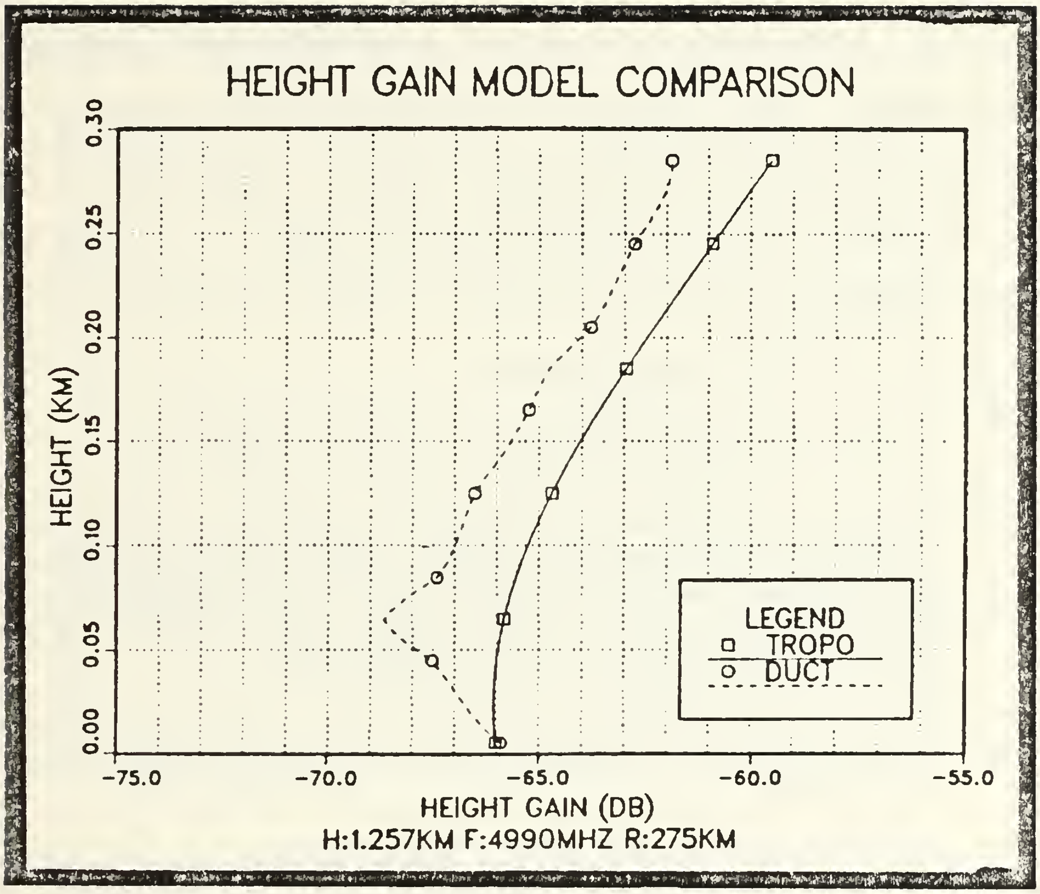


Figure 5-7c Height Gain Model Comparison

(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 acccurate 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 PDUCT 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 PDUCT computer model. The model did not compute the height gain for surface-based ducts.

B. RECOMMENDATIONS

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

1. The validation of the computer-derived system perfomance 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 included 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 transmisssion loss, L_{bsr}, [Ref. 12:p. 389] and [Ref. 18:pp. 8-8 thru 8-14].

1. Long-term Median Basic Transmission Loss

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

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(d):

For a surface refractivity:

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

$N_s = 301$ .... Refer to Figure A-2
$N_s = 350$ .... Refer to Figure A-3
$N_s = 401$ .... Refer to Figure A-4

3. Scattering-Efficency Term

The following equation can be used:

$$F_o = 1.086\left(\frac{\eta s}{h_o}\right)(h_o - h_1 - h_{1t} - h_{1r}) \qquad \text{(A-2)}$$

where h_o = height of transmitter/receiver antenna beam intersection (km)

h_1 = height from obstacle elevation baseline to the antenna beam intersection (km)

h_{1t} = transmitter obstacle elevation (m)
h_{1r} = receiver obstacle elevation (m)

4. Frequency-Gain Function

The frequency-gain function is expressed by as:

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

and $r_1 = 41.92\ \theta f h_{te}$
$r_2 = 41.92\ \theta f h_{re}$

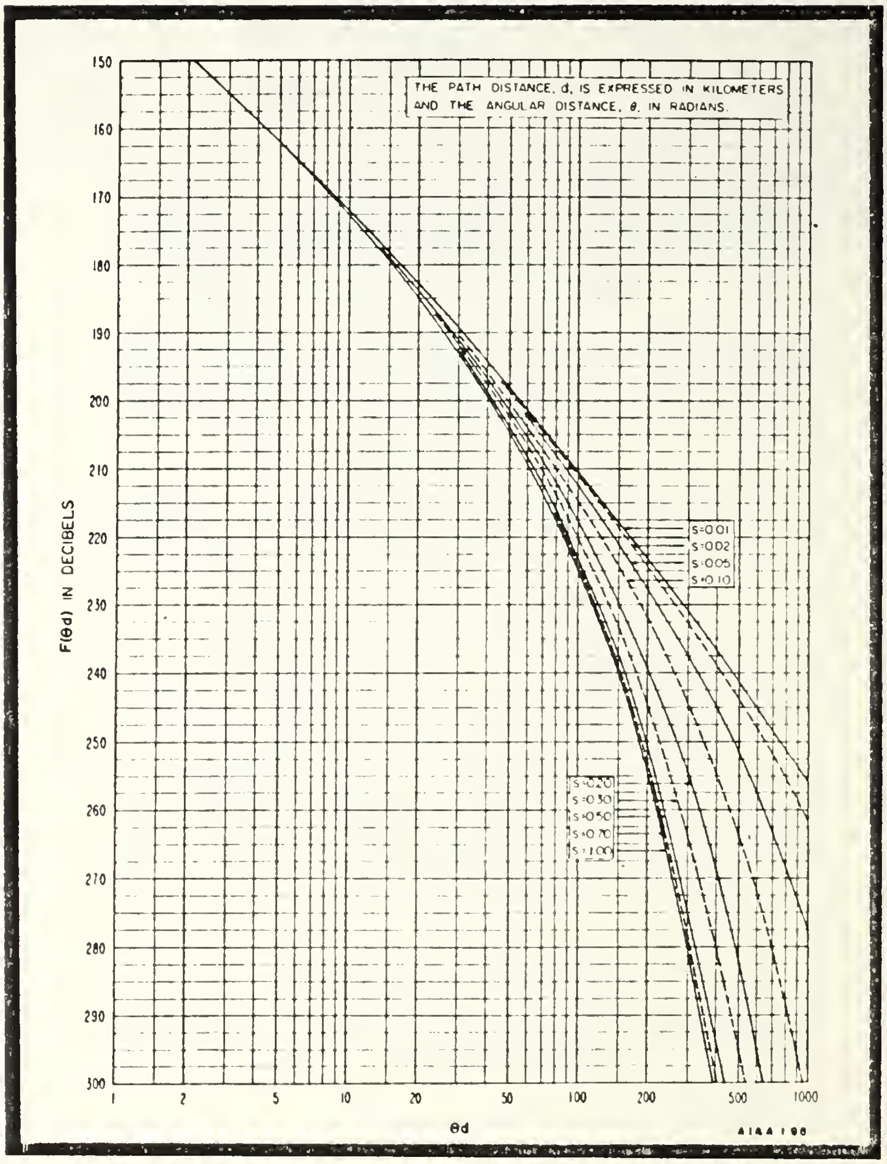


Figure A-1 Function $F(\theta d)$ for $N_s = 250$

(After Ref. 18:p. 8-9)

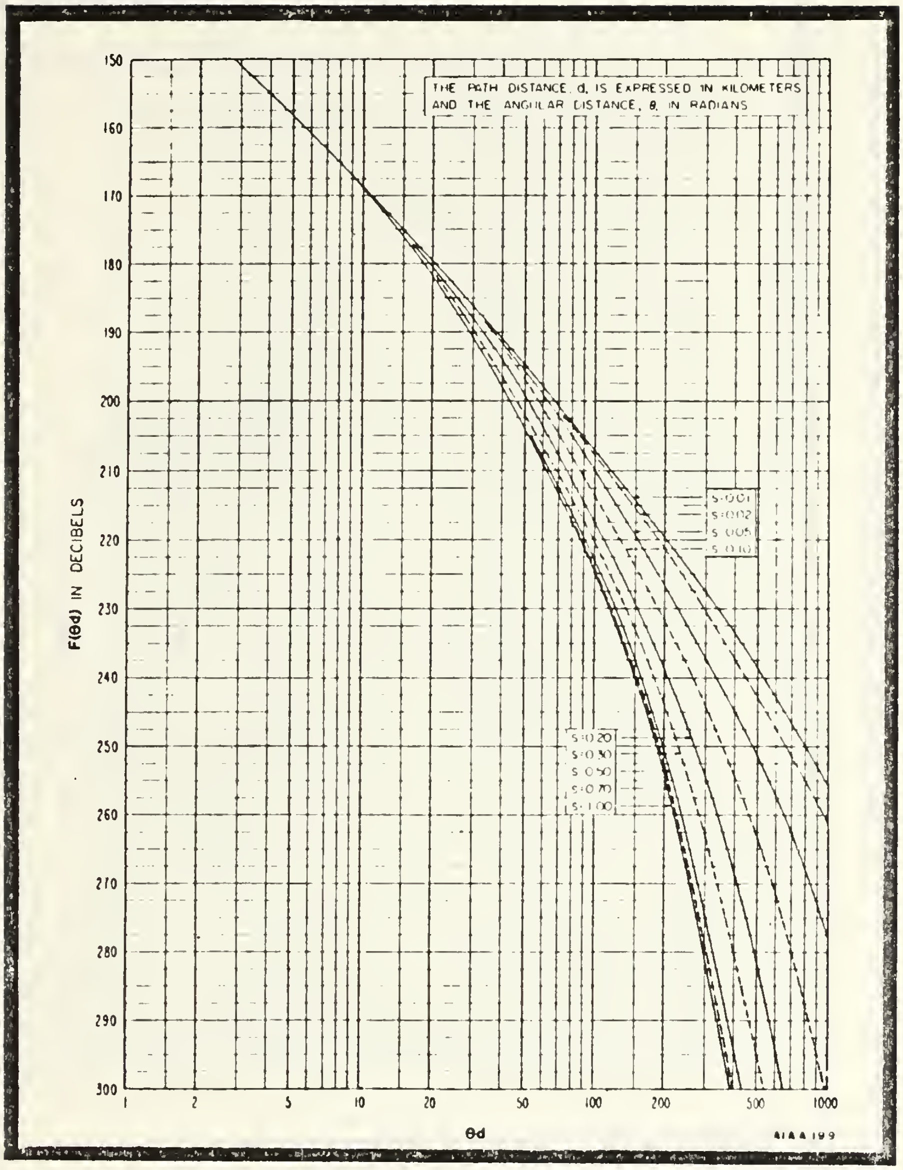


Figure A-2 Function F(θ d) for $N_s = 301$

(After Ref. 18:p. 8-10)

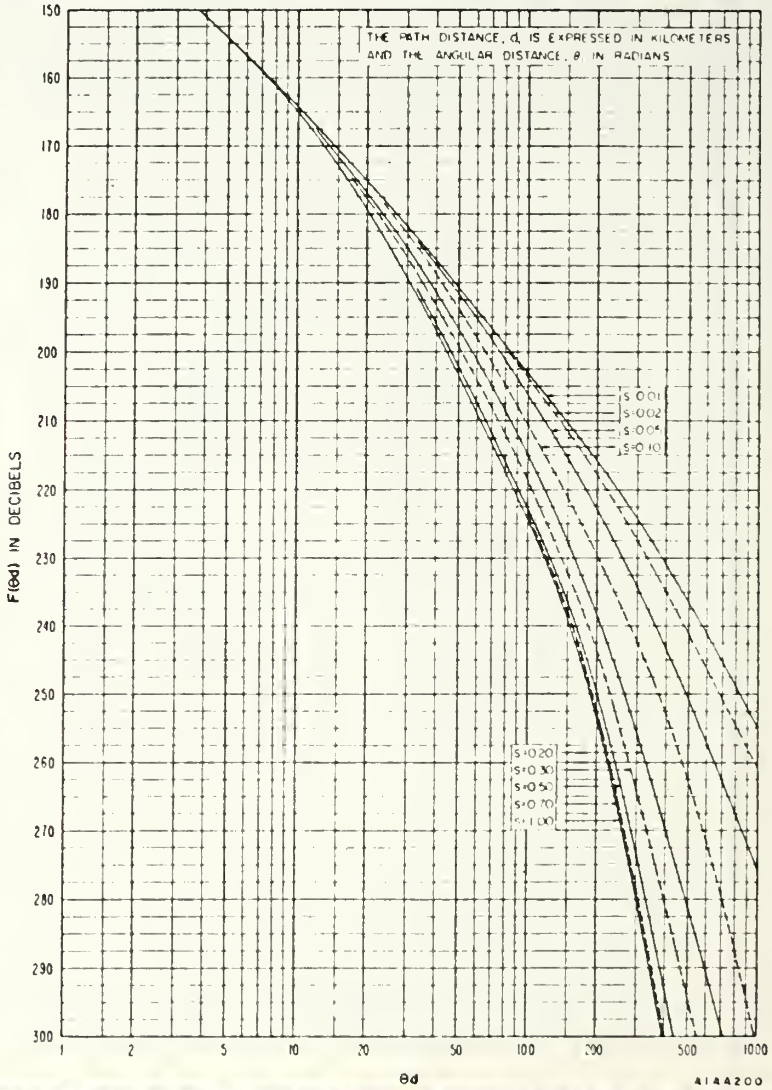


Figure A-3 Function F(θ d) for N_s = 350

(After Ref. 18:p. 8-11)

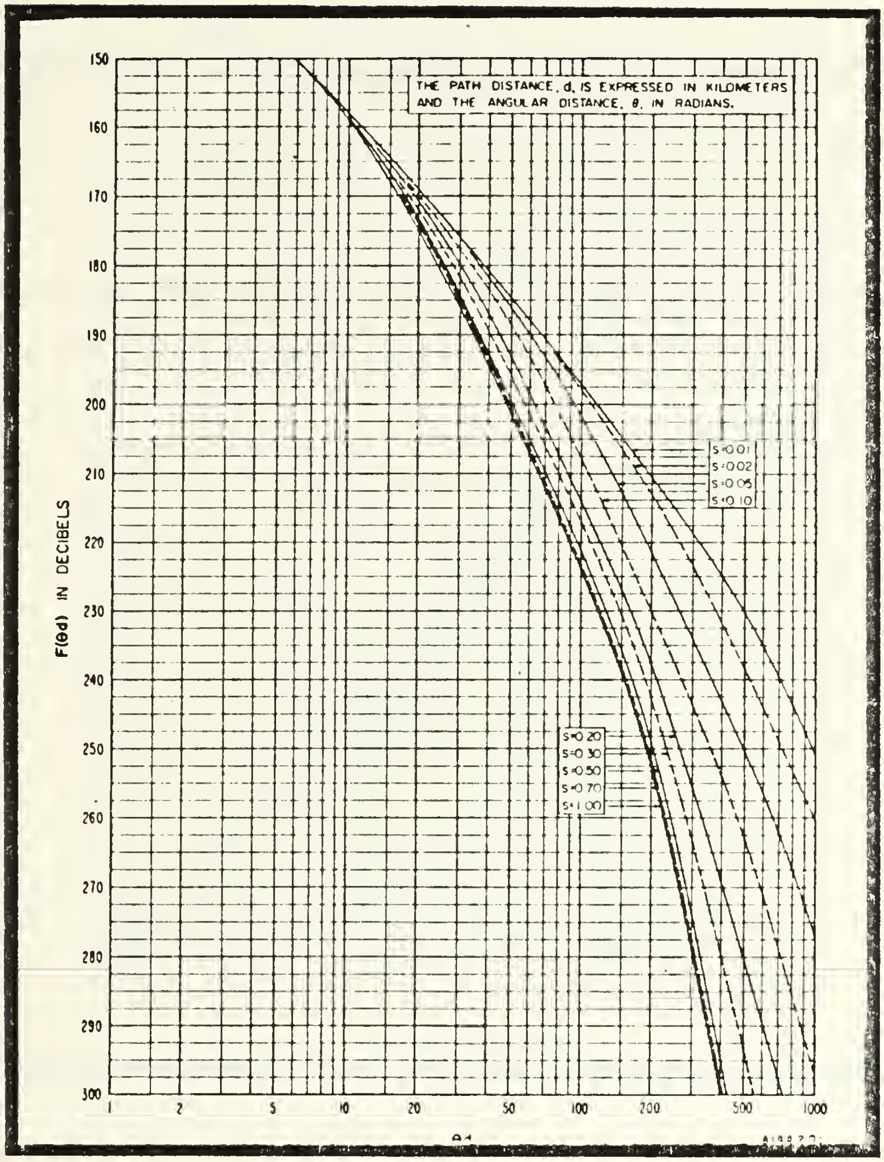


Figure A-4 Function F(θ d) for N_s = 401

(After Ref. 18:p. 8-12)

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

where θ = scatter angle (angular distance) (mrad)

f = frequency (MHz)

h_{te} = transmitter elevation (km)

h_{re} = receiver elevation (km)

$S = \alpha_o / \beta_o$ (symmetry factor)

$q = r_2 / (s)(r_1)$

$H_o(r_1)$ and $H_o(r_2)$ are graphically derived using Figure A-6, with η_s obtained from Figure A-5

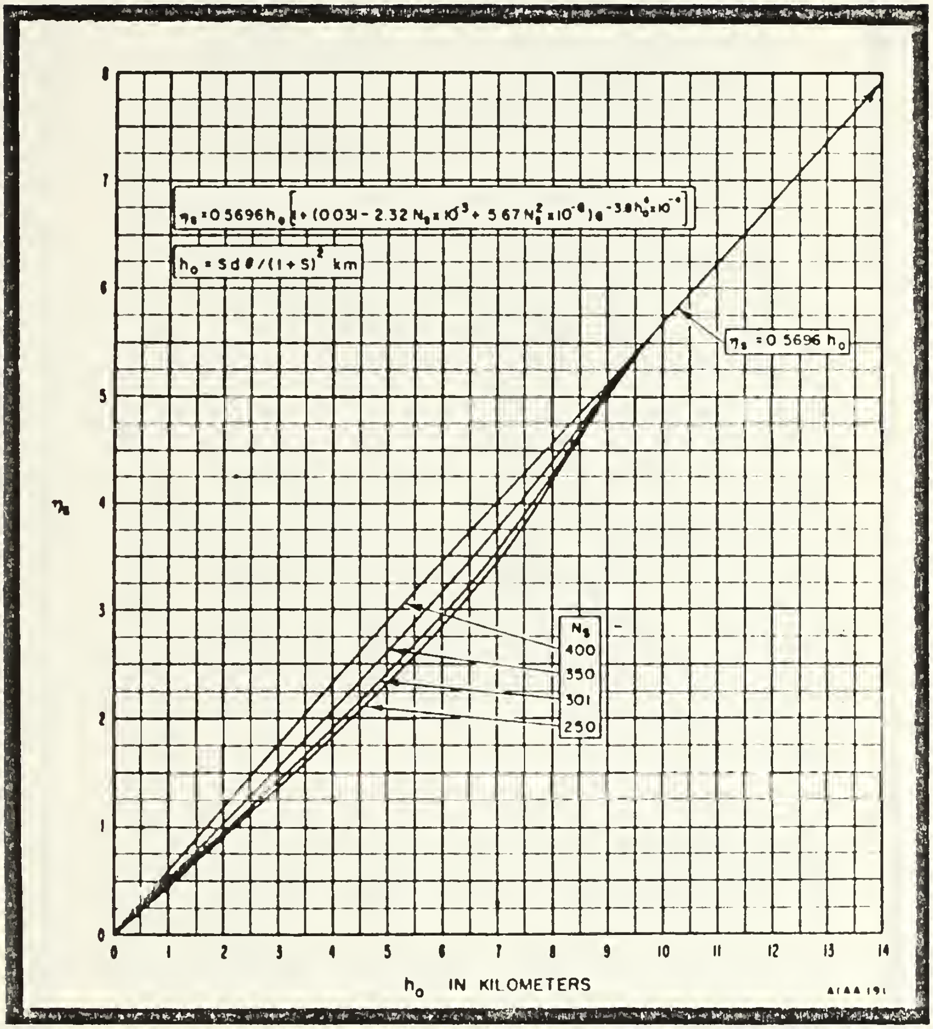


Figure A-5 Parameter N_s [h_o] Used to Compute Ho
(After Ref. 18:p.6-32)

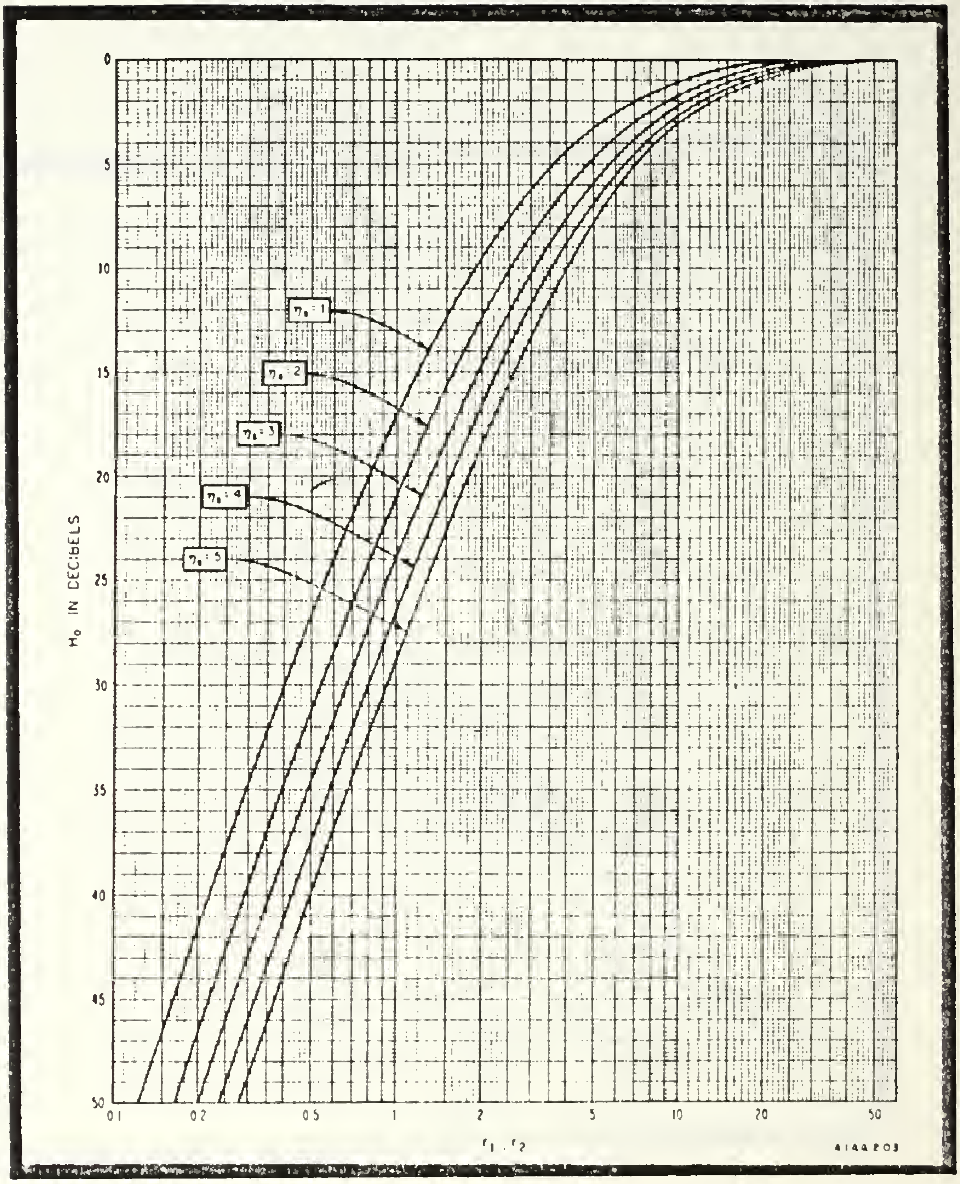


Figure A-6 Frequency Gain Function

(After Ref. 18:p. 8-13)

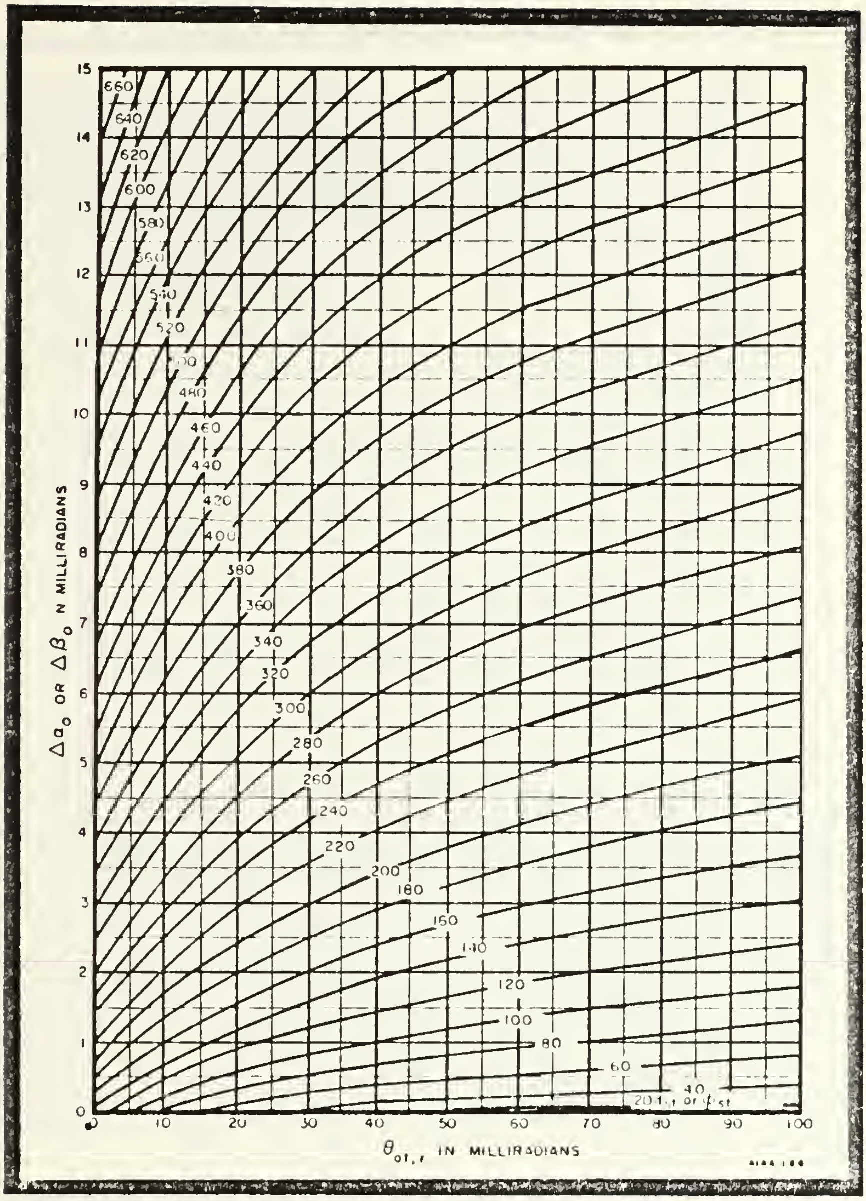


Figure A-7 Correction Terms for N_s = 301

(After Ref. 18:p. 6-28)

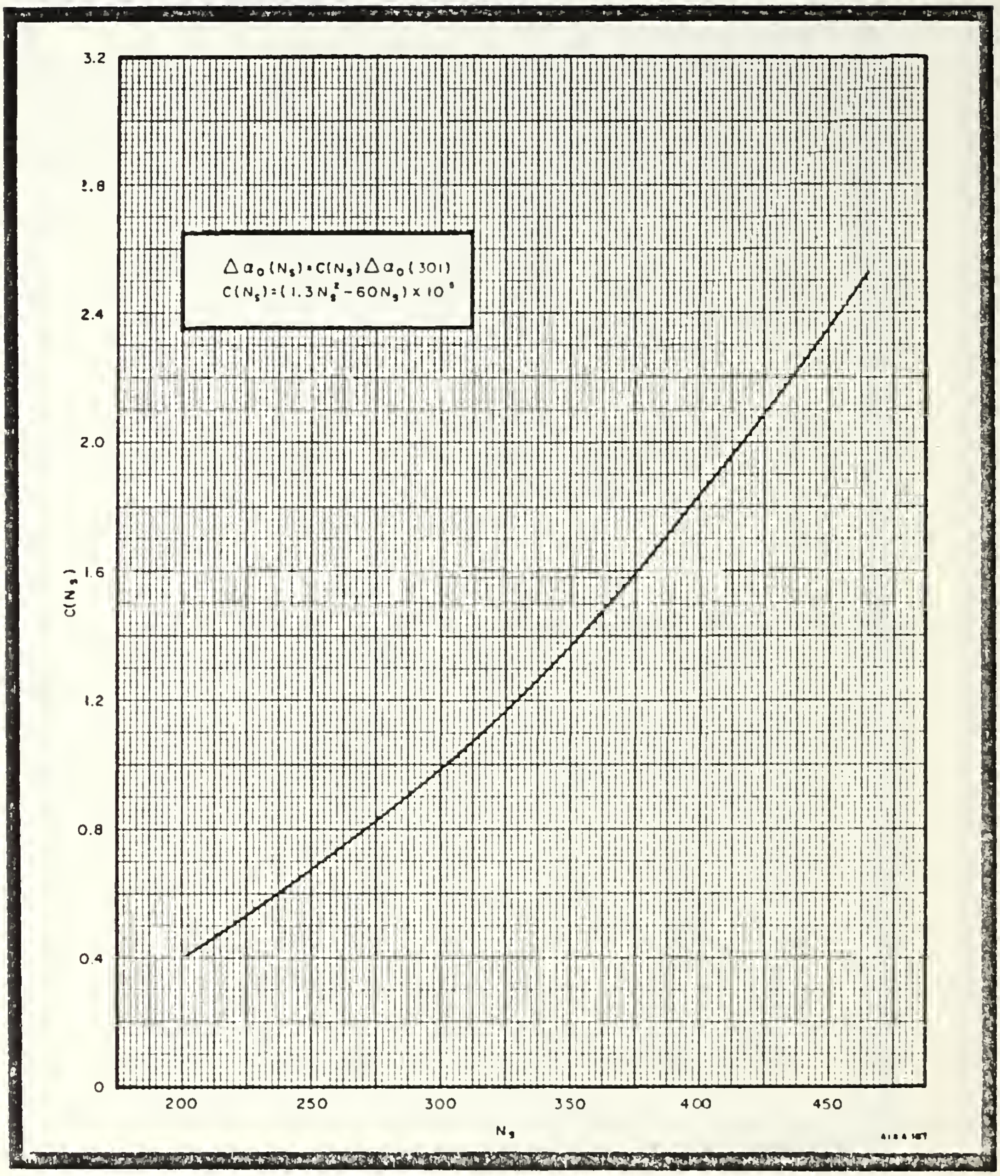


Figure A-8 Adjustment Factor for Figure A-7

(After Ref. 18:p. 6-29)

APPENDIX B

```
C
C
C
C
C
C
C
C
C     ************************************************************
C     *                                                          *
C     *               PROGRAM INTRODUCTORY REMARKS               *
C     *                                                          *
C     ************************************************************
C
C     THESIS PROGRAM FOR TROPOSCATTER COMMUNICATIONS SYSTEM DESIGN
C
C     CPT(P) EDWARD M. SIOMACCO, US ARMY
C
C     NAVAL POSTGRADUATE SCHOOL MONTEREY, CALIFORNIA 93943
C
C     27 SEPTEMBER 1985
C     ************************************************************
C     *                                                          *
C     *          PROGRAM ENTRANCE/COMPILE INSTRUCTIONS           *
C     *                                                          *
C     ************************************************************
C     THE SOURCE PROGRAM, "TROPO.FOR" (72 KBYTES), WAS WRITTEN IN
C     FORTRAN77. IT WAS COMPILED USING MICROSOFT FORTRAN77V3.20
C     02/84. A "TROPO.EXE" (129 KBYTES) PROGRAM WAS CREATEL FOR
C     THE IBM-XT (3270) PERSONAL COMPUTER ANI A DISKETTE COPY CAN
C     BE OBTAINED THRU:
C
C               PROFESSOR JEFFEREY KNORR, CODE 62K0
C               DEPARTMENT OF ELECTRICAL ENGINEERING
C               NAVAL POSTGRADUATE SCHOOL
C               MONTEREY, CALIFORNIA  93943
C               AUTOVON 878-2032/2955
C
      PROGRAM TROPC
C     ************************************************************
C     *                                                          *
C     *                   VARIABLE DEFINTIONS                    *
C     *                                                          *
C     ************************************************************
```

```
C
      DIMENSION DIST(10),ELEV(10),MELEV(10),DIST1(40),ELEV1(40),
     *MELEV1(40),DIST2(40),MELEV2(40),DIST3(40),PRES(40),TEMP(40),
     *WVP(40),ALT(40),RM(40),RN(40),NGRAD(40),COND(40),DRN(40),
     *DALT(40),MALT(40),TYPE(10)
      INTEGER  Z,I,K,J,RESPON,LEV,DELTAM,DUCT,SET,
     *FLAG,L,SYS,PROFILE,DIFF
      REAL*4 ALAT,ALONG,BLAT,BLONG,P,SP,SLA,CIA,CIB,SLB,CP,LP,
     *DA,SM,KM,DM,DEG,RADIAN,PI,CONV,LP1,LP2,R,KR,SNP,SNA,SNB,
     *DB,DEGA,DC,DEGB,CSA,CSB,AZA,AZB,DEGC,DEGC1,DEGD,DEGD1,DA1,
     *THI,RTH,R1,RAD,DIST,ELEV,MELEV,HTS,HRS,TANTH,RANTH,HS,NS,
     *DIST1,ELEV1,MELEV1,DIST2,MELEV2,DIST3,THETA,THETA1,THETA2,
     *RH,TH,DLT,DLR,HLT,HLR,FREQ,TAND,RAND,TAGN,RAGN,PRES,TEMP,
     *WVP,ALT,RN,RM,NGRAD,DALT,DRN,MALT,HOPT,DTHK,VC,DIM,FMI,
     *PTDBM,PT,BIF,BW,RATE,CNR,EBN,RSDBM,RS,NPDBM,PIM,DELTAH
      REAL*4 DELTAV,DELTAF,LT,LC,LA,CL,LS,FIM,ANTG,HG,LW,TAKE1,
     *TAKE2,RR,ALPHA,BETA,LAMDA,CON,LL,HO,H,S,HCG,WGL,WAIT,
     *RYR,RMM,AA,BB,YY,ZZ,KK,REL,E1,E2,U,UNDP,PP,Q,PB,PM,X,
     *FADE,DD,CCN,NBAO,PNDBM,LDF,SNR,LD,TG,PN,WGD,THETAD,FIT,
     *TAMR,TBMR,TMR,DS,M1,M2,SLOPE,SUMX,SUMY,SUMXY,SUMX2,SUMYS,
     *YINT,XMEAN,YMEAN,DBOT,DTOP,NF
C
      CHARACTER*4  ID1
      CHARACTER*6  TYPE
      CHARACTER*35 PATH
      CHARACTER*20 TYPE1,TYPE2,TYPED
      CHARACTER*4  Y,N,STOP,ANS
      CHARACTER*3  A11,A12,B11,B12
C
      OPEN (7,FILE='LPT1:',STATUS='NEW')
      DATA RAD/6.378E6/, N/'N   '/,STOP/'STOP'/, Y/'Y   '/
      TYPE1='ELEVATED   '
      TYPE2='SURFACE    '
      LD1 = 'NA  '
      PI=4*(ATAN(1.))
      CONV=2*PI/360.
C     ****************************************************************
C     *                       IDENTIFY VARIABLES                     *
C     ****************************************************************
C
C     BIF    = IF BANDWIDTH (HZ)
C     BW     = TRANSMISSION BANDWIDTH (HZ)
C     CCN    = PRECICTED CHANNEL NOISE (DBAO)
C     CL     = WAVEGUIDE CONNECTOR/JOINT LOSS
C     CNR    = CARRIER-TO-NCISE RATIO (DB)
C     DELTA  = COMMON TERRAIN OBSTACLE DEVIATION (METERS)
C     DIM    = DIVERSITY IMPROVEMENT FACTOR
C     DIST   = INCREMENTAL TERRAIN DISTANCE POINT ARRAY
C     DIST1  = TERRAIN POINT SORTING ARRAY
C     DIST2  = TERRAIN DISTANCE PLOTTING DATA ARRAY
```

```
C       DIST3   = TEMPORARY TERRAIN POINT ARRAY
C       DLR     = RECVR OBSTACLE DISTANCE
C       DLT     = TRANS OBSTACLEDISTANCE
C       DS      = DISTANCE BETWEEN HORIZON OBSTACLES
C       EBN     = BIT ENERGY/SPECTRAL NOISE DENSITY (DB)
C       ELEV    = INCREMENTAL TERRAIN ELEVATION POINT ARRAY
C       ELEV1   = ELEVATION POINT SORTING ARRAY
C       ELEV2   = TERRAIN ELEVATION PLOTTINGDATA ARRAY
C       FADE    = FADE MARGIN
C       FIT     = FM IMPROVEMENT THRESHOLD
C       FREQ    = OPERATING FREQUENCY (MHZ)
C       HLR     = RECVR OBSTACLE ELEVATION
C       HLT     = TRANS OBSTACLE ELEVATION
C       HO      = ESTIMATED SCATTER VOLUME BASE ALTITUDE
C       HTS     = TOTAL TRANS ANT ELEVATION
C       HRS     = TOTAL RECVR ANT ELEVATION
C       HS      = AVERAGE ANTENNA HEIGHT
C       LA      = RAINFALL ATMOSPHERIC ABSORPTION LOSE
C       LC      = APERTURE-TO-MEDIUM COUPLING LOSS
C       LD      = KNIFE-EDGE DIFFRACTION LOSS
C       LDF     = CHANNEL LOADING FACTOR
C       LS      = FREE-SPACE/SCATTER LOSS
C       LT      = BASIC MEDIAN TRANSMISSION LOSS
C       LW      = WAVEGUIDE LOSS
C       NBAO    = MINIMUM STANDARD CHANNEL NOISE (DBAO)
C       NF      = RECEIVER NOISE FIGURE (DB)
C       NS      = SURFACE REFRACTIVITY (N-UNITS) AT ELEVATION
C       PB      = PROBABILITY OF BIT ERROR
C       PM      = PROBABILITY OF SYMBOL ERROR
C       PIM     = PREEMPHASIS IMPROVEMENT FACTOR
C       PN      = RECEIVED NOISE THRESHOLD (DBW)
C       PT      = TRANSMIT POWER (DBW)
C       RATE    = TRANSMISSION DATA RATE (BITS/SEC)
C       RAGN    = RECVR ANT GAIN (DB)
C       RAND    = RECVR ANT DIAMETER (M)
C       RANTH   = RECVR ANTENNA HEIGHT
C       RH      = DISTANCE TO RECEIVER RADIO HORIZON
C       RS      = RECEIVED SIGNAL LEVEL (DBW)
C       RSDBM   = RECEIVED SIGNAL LEVEL (DBM)
C       RTH     = RECVR TERMINAL ELEVATION
C       R1      = SURFACE REFRACTIVITY (N-UNITS) MEAN SEA LEVEL
C       SNR     = SIGNAL-TO-NOISE RATIO (DB)
C       TAND    = TRANS ANT DIAMETER (M)
C       TAGN    = TRANS ANT GAIN (DB)
C       TANTH   = TRANS ANTENNA HEIGHT
C       TH      = DISTANCE TO TRANSMITTER RADIO HORIZON
C       THETA   = SCATTER ANGLE (RADIANS)
C       THETA1  = TRANSMITTER TAKE-OFF ANGLE (RAD)
C       THETA2  = RECVR TAKE-OFF ANGLE (RAD)
C       THT     = TRANS TERMINAL ELEVATION(M)
```

```
C     WGD     = WAVEGUIDE LENGTH(METERS)
C     WGL     = WAVEGUIDE LOSS PER UNIT LENGTH (DB/100 METER)
C
      CALL CLEAR
      WRITE(*,101)
  101 FORMAT(//
     $13X,'PROGRAM "TROPO": A TROPOSPHERIC SCATTER COMMUNICATIONS'/
     $13X,'               SYSTEM DESIGN PROGRAM                    '//
     $13X,'          ****************************************      '/
     $13X,'               VERSION 1.0 - 1985                     . '/
     $13X,'          ****************************************      '//
     $13X,'DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING       '/
     $13X,'NAVAL PCSTGRADUATE SCHOOL  MONTEREY, CALIFORNIA 93943 '/
     $13X,'SEPTEMBER 1985'//
     $13X,/
     $1X,'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
      WRITE(*,103)
  103 FORMAT(//
     $13X,'           ******** INSTRUCTIONS ********              '//
     $13X,'    THE PROGRAM WILL SEQUENCE THROUGH SEVERAL SCREEN '/
     $13X,'MENUS. SELECTION MENUS WILL REQUIRE A SINGLE INTEGER '/
     $13X,'RESPONSE. ALL NUMERICAL INPUT DATA ARE CONSIDERED    '/
     $13X,'REAL VALUES, HENCE A DECIMAL POINT IS REQUIRED. ALL  '/
     $13X,'INTEGER RESPONSES WILL BE SPECIFIED. PROGRAM RESULTS '/
     $13X,'WILL BE PROVIDED AS PRINTED OUTPUT AND CANNOT BE     '/
     $13X,'STORED FOR A REPEATED RUN. TERRAIN DATA POINTS '/
     $13X,'CAN BE STORED IN AN EXTERNAL DATA FILE.'//
     $13X,'    THE PROGRAM WAS DESIGNED TO COMPUTE PERFORMANCE  '/
     $13X,'PREDICTIONS FOR NUMEROUS TROPOSCATTER TERMINAL EQUIP-'/
     $13X,'MENT, INCLUDING THE DIGITAL RADIO, AN/TRC-170.'///
     $1X,'ENTER (1) TO CONTINUE...........')
      READ(*,590) RESPON
      IF(RESPON.NE.999) CONTINUE
      CALL CLEAR
      WRITE(*,104)
  104 FORMAT(//
     $13X,'    TERRAIN PROFILE PLOT:  THE PRINTER PLOT WILL'/
     $13X,'PROVIDE A LINEAR TERRAIN PROFILE WITH RESPECT TO A'/
     $13X,'SELECTED TRANSMITTER SITE. EXTERNAL TERRAIN PLOTTING'/
     $13X,'METHODS CAN BE USED AND NEAR OBSTACLE DATA CAN BE '/
     $13X,'ENTERED INDEPENDENTLY.'//
     $13X,'    RADIOSONDE DATA ANALYSIS:  IF REAL-TIME RADIOSONDE'/
     $13X,'WEATHER DATA CANNOT BE OBTAINED, STATISTICAL INFORMA- '/
```

```
     $13X,'TION ON ELEVATED TROPOSPHERIC DUCTS CAN BE USED.       '/
     $13X,'IF THE SELECTED ELEVATED DUCT PARAMETERS DO NOT MEET   '/
     $13X,'THE HEIGHT GAIN 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)
      READ  (*,510) ALONG
      WRITE (*,530)
      READ  (*,510) BLAT
      WRITE (*,540)
      READ  (*,510) 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))))
      RADIAN=360/(2*PI)
      DA1=(PI/2.)-DA
      DEG=DA1*RADIAN
      SM=(DEG*60.0)*1.1516
      KM=(DEG*60.0)*1.85325
      SND=SIN(DEG*CONV)
      SNP=SP/SND
      SNA=SNP*CLB
      SNB=SNP*CLA
      DEGA=RADIAN*(ATAN(SNA/(SQRT(1-(SNA**2)))))
      DEGA=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
```

```
          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 (//1X,'ANY COORDINATE CHANGES? YES(1)/NO(2)')
  590 FORMAT (I1)
  500 FORMAT (/1X,'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 POSTIVE REAL. ALL DEGREES SOUTH AND EAST ARE'/
     $13X,'ARE NEGITIVE REAL VALUES.'//
     $13X,'EXAMPLE: LATITUDE 35 DEGREES/38 MINUTES SOUTH'/
     $13X,'          ENTER AS:   - 35.633 DEGREES')
  510 FORMAT (F8.2)
  520 FORMAT (/1X,'ENTER TRANS SITE LONGITUDE (DEG).')
  530 FORMAT (/1X,'ENTER RECVR SITE LATITUDE  (DEG).')
  540 FORMAT (/1X,'ENTER RECVR SITE LONGITUDE (DEG).')
C
C
      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
      READ  (*,704) Z
      FLAG = 0
      GOTO 1150
C
C INPUT PATH TERRAIN ELEVATION AND DISTANCE TO DETERMINE
C TERRAIN PROFILE.
C
C     WRITE(*,620)
C 620 FORMAT(//
C    $13X,'DO YOU WISH TO ENTER TERRAIN DATA FROM AN   '/
C    $13X,'EXTERNAL DATA FILE. THIS FILE SHOULD BE     '/
C    $13X,'NAMED: TERRAIN.TXT AND FORMATTED AS 1E10.3  '/
C    $13X,'COLUMN 1: DISTANCE (KILOMETERS) TO ELEVATION'/
C    $13X,'COLUMN 2: ELEVATION (METERS)                '/
C    $13X,'              YES(1) OR NO(2)')
C     READ(*,590) RESPON
C     IF(RESPON.EQ.1) THEN
```

```
C         REWIND(2)
C         DO 51 I = 1,Z
C           READ(2,603)DIST(I),ELEV(I)
C  51     CONTINUE
C         RESPON =  3
C        ELSE
C          CONTINUE
C       ENDIF
C       IF(RESPON.EQ.3) THEN
C          GOTO
C       ELSE
C          GOTO 1105
C       ENDIF
 1120 CALL CLEAR
      WRITE(*,1104)
 1104 FORMAT(/
     $13X,'ENTER THE FOLLOWING RADIO HORIZON INFORMATION.')
      WRITE(*,1110)
 1110 FORMAT(//13X,'DISTANCE (KM) TO RADIO HORIZON/OBSTACLE ',
     $'FROM TRANSMITTER SITE')
      READ(*,1111)DLT
      DLT = DLT*1.0E3
 1111 FORMAT(F6.2)
      WRITE(*,1112)
 1112 FORMAT(/13X,'TRANSMITTER RADIO HORIZON TERRAIN ',
     $'ELEVATION (METERS)')
      READ(*,1111)HLT
      WRITE(*,1113)
 1113 FORMAT(//13X,'DISTANCE (KM) TO RADIO HORIZON/OBSTACLE ',
     $'FROM RECEIVER SITE')
      READ(*,1111)DLR
      DLR = DLR*1.0E3
      WRITE(*,1114)
 1114 FORMAT(/13X,'RECEIVER RADIO HORIZON TERRAIN ',
     $'ELEVATION (METERS)')
      READ(*,1111)HLR
      GOTO 1151
 1105 FLAG =1
 1150 CALL CLEAR
      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
```

```
      WRITE(*,693)
  693 FORMAT(/1X,'ENTER RECEIVER ANTENNA HEIGHT (METERS)')
      READ(*,700)  RANTH
      ELEV(Z)=RTH+RANTH
      DIST(Z)=KM*1.0E3
      IF(FLAG.EQ. 1) GOTO  1120
C ************    AVERAGE ANTENNA HEIGHT*********************
 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
            READ  (*,700)  DIST1(I)
            DIST1 (I)=DIST1(I)*1.0E3
            WRITE  (*,707) L
            READ  (*,700)  ELEV1(I)
    3    CONTINUE
      ELSE
         CONTINUE
      ENDIF
      WRITE(*,701)
      READ  (*,590)  RESPON
      GOTO(750,751,752),RESPON
  750 R1=289.0
      GOTO 803
  751 R1=315.0
      GOTO 803
  752 WRITE(*,710)
      READ(*,700)  R1
C *************    EFFECTIVE EARTH'S RADIUS EQUATION:  ***********
  803 WRITE(7,*)'HS=',HS
      NS=EXP((-3.222E-2*HS))*R1
      KR=RAD/(1-(EXP((NS*5.577E-3))*0.04665))
      WRITE(7,*)  R1,NS,KR
      IF(FLAG.EQ.0) THEN
         WRITE(*,*)'DO YOU WANT TO SAVE TERRAIN DATA? YES(1)/NO(2) '
         READ  (*,590) RESPON
         IF(RESPON.EQ.1)  THEN
            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(1)=ELEV(1)-((DIST(1)**2)/(KR*2.0))
         DO 4  I=1,Z-2
            MELEV1(I)=ELEV1(I)-((DIST1(I)**2)/(KR*2.0))
    4    CONTINUE
```

```
            MELEV(Z)=ELEV(Z)-((DIST(Z)**2)/(KR*2.0))
            WRITE(7,901) CHAR(27),CHAR(15)
            WRITE(7,753)
   753      FORMAT(/'1',15X,'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,DIST1(I),ELEV1(I), MELEV1(I)
     6      CONTINUE
            WRITE(7,706)Z,DIST(Z),ELEV(Z),MELEV(Z)
            WRITE(7,917) CHAR(27),CHAR(18)
            WRITE(7,*)' '
            WRITE(7,754)
   754      FORMAT('1')
C *******    CREATE PLOTTING DATA ARRAY (DIST2/MELEV2) ***********
            DIST2(1)=DIST(1)
            MELEV2(1)=MELEV(1)
            DO 13 I=1,Z-2
               L=I+1
               DIST2(L)=DIST1(I)
               MELEV2(L)=MELEV1(I)
    13      CONTINUE
            DIST2(Z)=DIST(Z)
            MELEV2(Z)=MELEV(Z)
   700      FORMAT(F10.3)
   701      FORMAT(/13X,'SURFACE REFRACTIVITY (SELECT)',
       *        /15X,'(1)......289 N-UNITS (STANDARD)',
       *        /15X,'(2)......315 N-UNITS (W. GERMANY)',
       *        /15X,'(3)......OTHER')
   703      FORMAT(/
       $    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')
   704      FORMAT(I2)
   705      FORMAT(//1X,'ENTER POINT(',I2,') DISTANCE (KM)')
   706      FORMAT(//3X,'POINT(',I2,')',2X,F10.3,3X,F10.3,3X,F10.3)
   707      FORMAT(//1X,'ENTER POINT(',I2,') TERRAIN HEIGHT (METERS)')
   710      FORMAT(/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    8      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(1)=ELEV(Z)
         ELEV(Z)=HOLD
CDEBUG   WRITE(7,*)DIST(1),ELEV(1)
         DO 15 I=2,Z-1
            DIST3(I)=DIST2(I)
   15    CONTINUE
         DO 9 I=1,Z-2
            DIST1(I)=(KM*1.0E3)-DIST3(Z-I)
            MELEV1(I)=ELEV1(I)-((DIST1(I)**2)/(KR*2.))
CDEBUG      WRITE(7,*) DIST1(I),ELEV1(I),MELEV1(I)
    9    CONTINUE
CDEBUG   WRITE(7,*)DIST(Z),ELEV(Z)
         CALL SORT2(MELEV1,DIST1,Z-2)
         MELEV(1)=ELEV(1)
CDEBUG   WRITE(7,*)DIST(1),ELEV(1),MELEV(1)
C        DO 11 I=1,Z-2
C           WRITE(7,*) DIST1(I),ELEV1(I),MELEV1(I)
C  11    CONTINUE
         MELEV(Z)=ELEV(Z)-((DIST(Z)**2)/(KR*2.0))
CDEBUG   WRITE(7,*)DIST(Z),ELEV(Z),MELEV(Z)
         DLR=DIST1(Z-2)
         HLR=MELEV1(Z-2)
CDEBUG   WRITE(7,*)'MAXBDIST=',DIST1(Z-2),'MAXBELEV=',MELEV1(Z-2)
CDEBUG   WRITE(7,*) 'DIST2/MELEV2'
C        DO 14 I=1,Z
C           WRITE(7,*)DIST2(I),MELEV2(1)
C  14    CONTINUE
      ELSE
         CONTINUE
      ENDIF
C
C     ****** DELTA REPRESENTS THE SINGLE KNIFE-EDGE *******
C                 OBSTACLE TOLERANCE INTERVAL
C
      DELTA = 100.0
      HTS = TANTH+THT
      HRS = RANTH+RTH
      RH = SQRT(2*KR*HRS)
      TH = SQRT(2*KR*HTS)
C **********   SINGLE KNIFE-EDGE DIFFRACTION MODE  ***********
      IF((DLT.LE.DLR+DELTA).AND.(DLR.LE.DLT+DELTA)) GOTO 1000
C **********    BOTH TERMINALS AT NEAR OBSTACLES  ************
      IF((DLT.LT.TH).AND.(DLR.LT.RH)) GOTO 1100
C **********    DOUBLE SMOOTH EARTH DIFFRACTION  *************
      IF((DLT.EQ.TH).AND.(DLR.EQ.RH)) GOTO 1200
C ** NEAR OBSTACLE AT TRANSMITTER AND SMOOTH EARTH AT RECVR **
      IF((DLT.LT.TH).AND.(DLR.EQ.RH)) GOTO 1300
C ** NEAR OBSTACLE AT RECVR AND SMOOTH EARTH AT TRANSMITTER **
```

```
      IF((DLT.EQ.TH).AND.(DLR.LT.RH)) GOTO 1400
 1000 THETA1 = (((HLT-HTS)/DLT)-(DLT/(2*KR)))
      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*KR)))
      PATH = 'SMOOTH EARTH/NEAR OBSTACLE PATH     '
 1800 ALPHA = (KM*1.0E3)/(2*KR) + (HTS-HRS)/(KM*1.0E3)
     &  + THETA1
      BETA = (KM*1.0E3)/(2*KR)+(HRS-HTS)/(KM*1.0E3)
     &  + THETA2
      THETA = ALPHA + BETA
      S = ALPHA/BETA
      DS = (KM*1.0E3) - DLT - DLR
      HO = (S*DS*THETA)/((1+S)**2)
  600 FORMAT(2X,F10.3,2X,F10.3,2X,F10.3)
  603 FORMAT(2X,1E15.3,2X,1E15.3)
      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(Z,DIST2,MELEV2)
C
C    ******* LONG-TERM MEDIAN BASIC TRANSMISSION LOSS ***********
C                 INPUT PARAMETERS AND CALCULATION
C
 1500 CALL CLEAR
      WRITE(*,*)  'ENTER THE OPERATING FREQUENCY (MHZ)'
      WRITE(*,*)  'RANGE:  4500.0 MHZ  -  5000.0 MHZ'
      READ (*,1501) FREQ
 1501 FORMAT(F10.3)
      WRITE(*,*)  'ENTER TRANSMIT ANTENNA DISH DIAMETER (FEET)'
      READ(*,1502)  TAND
 1502 FORMAT(F7.2)
      WRITE(*,*)  'ENTER RECEIVER ANTENNA DISH DIAMETER (FEET)'
      READ(*,1503)  RAND
```

```
1503 FORMAT(F7.2)
     TAGN =(20*LOG10(FREQ)) + (20*LOG10(TAND)) - 52.6
     RAGN =(20*LOG10(FREQ)) + (20*LOG10(RAND)) - 52.6
     ANTG = TAGN + RAGN
     GOTO 300
C
C *************     DIFFRACTION LOSS      ******************
C
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
     THETAD = THETA*57.2958
     LD = 0.0
     IF(PROFILE.EQ.99) THEN
        LD = 20*LOG10(2*PI*THETAD*(SQRT(DLT/LAMDA)))
     ELSE
        DIFF = 0
        LD = LD1
     ENDIF
C
C ********    APERTURE-TO-MEDIUM COUPLING LOSS    **********
C
     DD = (KM + 50.0)/50.0
     LC = -0.8929+(0.8655*DD)-(0.0131*(DD**2))
C
C ************      FREE-SPACE/SCATTER LOSS    **************
C
     LS = 30*LOG10(FREQ)+20*LOG10(SM)+0.2*(NS-310.0)+10*THETAD+57.0
C
C
     CALL CLEAR
     WRITE(*,400)
 400 FORMAT(//
    *13X,'************ WAVEGUIDE ATTENUATION ************',//
    *13X,'SELECT THE APPROPRIATE WAVEGUIDE TYPE:          ',//
    *13X,'(1) ................WR229 (R40) RIGID           ',/
    *13X,'(2) ................WR18  (R48)  RIGID          ',/
    *13X,'(3) ................EW44  (FLEXIBLE)            ',/
    *13X,'(4) ....................... OTHER                ')
     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
```

```
  402 FORMAT(F5.2)
      WGD = (WGD*3.281)/100.0
      GOTO(403,404,405,406),RESPON
  403 WGL = 2.4
      GOTO 410
  404 WGL = 4.0
      GOTO 410
  405 WGL =4.5
      GOTO 410
  406 GOTO 1458
 1451 WRITE(*,*)'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
 1458 WRITE(*,407)
  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      ************
C
      GOTO 1457
 1452 WRITE(*,*)'INCORRECT DATA ENTRY. PLEASE TRY AGAIN.'
 1457 WRITE(*,1460)
 1460 FORMAT(/
     $13X,'ENTER THE TOTAL NUMBER OF WAVEGUIDE CONNECTIONS.'/
     $13X,'ENTER DATA AS A REAL NUMBER')
      READ(*,491,ERR=1452)CCN
  491 FORMAT(F3.0)
      CL = CON*0.06
C
C *****    RAINFALL ATMOSPHERIC ABSORPTION LOSS (DB)******
C
      CALL CLEAR
      WRITE(*,420)
  420 FORMAT(//
     *13X,'****** RAINFALL ATMOSPHERIC ABSORPTION ******  '//
     *13X,'ENTER CURRENT RAINFALL RATE:                   '//
     *13X,' (1)..................CLOUDBURST (100 MM/HR)    '/
     *13X,' (2)..................HEAVYRAIN  ( 15 MM/HR)    '/
     *13X,' (3)..............MODERATE RAIN  (  4 MM/HR)    '/
     *13X,' (4).................LIGHT RAIN  (  1 MM/HR)    '/
     *13X,' (5)........ NEGLECT RAINFALL                   ')
      READ(*,590) RESPON
      GOTO(421,422,423,424,425),RESPON
  421 RR = 0.5
      GOTO 430
  422 RR = 0.07
      GOTO 430
  423 RR = 0.02
      GOTO 430
```

```
  424 RR = 0.005
      GOTO 430
  425 RR = 0.0
  430 LA = RR*(KM*0.62137)
C
      LT = LS+LD+LC+CL+LA+LW-ANTG-HG
      TG = ANTG + HG
      CALL CLEAR
      WRITE(*,1430)
 1430 FORMAT(//
     $13X,'  ***************** 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(*,432,ERR=1453)WATT
  432 FORMAT(F7.2)
      PT = 10*LOG10(WATT)
      PTDBM = PT + 30.0
      RS = PT - LT
      GOTO 1455
 1454 WRITE(*,*)'DATA ENTRY ERROR. PLEASE TRY AGAIN.'
 1455 CALL CLEAR
      WRITE(*,433)
  433 FORMAT(//
     $13X,'************ RECEIVER PARAMETER INPUT ***********'//
     $13X,' '//
     $13X,' '//
     $13X,'ENTER RECEIVER NOISE FIGURE (DECIBELS):'//
     $13X,'REMARK ........'//
     $13X,'* AN/GRC-143/144 RECIEVER NOISE FIGURE:  5.5'/
     $13X,'* AN/TRC-170     DIGITAL RADIO TERMINAL: 4.0')
      READ(*,434,ERR=1454)NF
  434 FORMAT(F4.1)
      WRITE(*,435)
  435 FORMAT(//
     *13X,'ENTER THE RECEIVER IF BANDWIDTH (MHZ):'//
     *13X,'REMARK ........'//
     *13X,'* AN/GRC-143/144 IF BANDWIDTH: 70  MHZ'/
     *13X,'* AN/TRC-170     IF BANDWIDTH: 70  MHZ'/
     *13X,'* AN/GRC-201     IF BANDWIDTH:  2  MHZ')
      READ(*,436)BIF
  436 FORMAT(F6.3)
      BIF = BIF*1.0E6
C
C     ***************** FREQUENCY AND SPACE DIVERSITY ***************
C                        SEPARATION REQUIREMENT
C
```

```
      TAMR = THETA1*1.0E3
      TBMR = THETA2*1.0E3
      TMR =  THETA*1.0E3
      TAND = TAND*0.3048
      DELTAH = 0.36*SQRT(TAND**2+1600)
      DELTAV = 0.36*SQRT(TAND**2+225)
      DELTAF = (1.44*FREQ/(KM*TMR))*SQRT(TAND**2+225)
C
      PN = -204.0 + NF + 10*LOG10(BIF)
      NPDBM = -174.0 + NF + 10*LOG10(BIF) + 10.0
      CNR = RS - PN
      RSDBM = RS + 30.0
      PNDBM = PN + 30.0
      FIT = PNDBM + 10.0
      FADE = RSDBM - FIT
C
C *********     SYSTEM PATH RELIABILITY CALCULATION   ***********
C
      CALL CLEAR
      WRITE(*,470)
  470 FORMAT(//
     $13X,'SELECT THE APPROPRIATE TERRAIN DESCRIPTION.      '//
     $13X,'      (1) ....... SMOOTH EARTH, OVER WATER,DESERT'/
     $13X,'      (2) ....... ROLLING HILLS, ROUGH TERRAIN    '/
     $13X,'      (3) ....... MOUNTAINOUS TERRAIN')
      READ(*,590) RESPON
      GOTO(471,472,473),RESPON
  471 AA = 4.0
      GOTO 480
  472 AA = 1.0
      GOTO 480
  473 AA = 0.25
  480 RMM = AA*1.0E-5*((FREQ/1.0E3)/4)*(SM**3)
      WRITE(*,481)
  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
  482 BB = 0.5
      GOTO 490
  483 BB = 0.25
      GOTO 490
  484 BB = 0.125
  490 RYR = BB*RMM
      UNDP = RYR*10**(-FADE/10)
      REL = 100*(1 - UNDP)
      IF(REL.LT.0.0) REL = 0.0
```

```
      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/FDM (ANALOG)'/
     $13X,'(2) ..................... DIGITAL')
      READ(*,590) RESPON
      GOTO (499,493),RESPON
C     *****************************************************
C     *           PROBABILITY OF BIT ERROR                *
C     *              DIGITAL MODULATION                   *
C     *****************************************************
  493 CALL CLEAR
      WRITE(*,437)
  437 FORMAT(//
     $13X,'******  DIGITAL MODULATION PARAMETERS  ******'//
     $13X,' '//
     $13X,' '//
     *13X,'ENTER THE TRANSMISSION DATA RATE (KBITS/SEC):   ')
      READ(*,439) RATE
      RATE = RATE*1.0E3
  439 FORMAT(F10.3)
      EBN = RS - 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)...NONCOHERENT PCM/FM FSK         '/
     *13X,'         (7)...M-ARY FSK (RAYLEIGH CHANNEL)   '/
     *13X,'         (8)...AN/TRC-112/121     (RADIO SET) '/
     *13X,'         (9)...AN/TRC-170V(1-3)  (RADIO SET)  ')
      READ(*,590) RESPON
      IF(RESPON.EQ.1)  GOTO 451
      IF(RESPON.EQ.2)  GOTO 452
```

```
      IF(RESPON.EQ.3) GOTO 453
      IF(RESPON.EQ.4) GOTO 454
      IF(RESPON.EQ.5) GOTO 455
      IF(RESPON.EQ.6) GOTO 456
      IF(RESPON.EQ.7) GOTO 457
      IF(RESPON.EQ.8) GOTC 443
      IF(RESPON.EQ.9) GOTO 459
  452 KK = 1.0
      EBN = (EBN/L)*KK
      U = EBN/(1+EBN)
      GOTO 460
  451 KK = 1.0
      EBN = (EBN/L)*KK
      U = SQRT(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 = SQRT(EBN/(1+EBN))
      GOTO 460
  455 DD = SQRT(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
  465 E2 = ERFC(X)
      PB = 0.5*E2
      GOTO 900
  456 PB = 0.5*EXP(-EBN*0.5)
      GOTO 900
  460 PP = U/(SQRT(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*ZZ)+20*(ZZ*ZZ*ZZ)))
      GOTO 900
C
  457 CALL CLEAR
      WRITE(*,442)
  442 FORMAT(//
     *13X,'SELECT THE APPROPRIATE M-ARY SIGNALING          '//
     *13X,'     (1)......BINARY FSK (M = 2)                '/
     *13X,'     (2)......QUADRATURE FSK (M = 4)            ')
      READ(*,590) 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
  444 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)*PM
      GOTO 900
  459 CALL CLEAR
      WRITE(*,1409)
 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(RESPON.EQ.1) BW = 3.5E6
      IF(RESPON.EQ.2) BW = 7.0E6
      EBN = CNR + 10*LOG10(BW) - 10*LOG10(RATE)
C
C     *******   CALCULATE MULTIPATH DELAY (SEC)    **********
C
      DELAY =  (3*KM*1.0E3*(THETA**2))/(16*3.0E8)
C     ***********************************************************
C     *         AN/TRC-170 DIGITAL TROPOSCATTER TERMINAL        *
C     *   DUAL-PULSE DAR BER CURVE FIT EQNS. FIG(S) 3-12/13     *
C     ***********************************************************
      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.
     &(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
```

```
         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
  499 CALL CLEAR
      SET = 1
      WRITE (*,1481)
 1481 FORMAT(//
     $13X,'  ****  FM/FDM SYSTEM DESIGN MODULE  ********')
      SYS = 1
      WRITE(*,498)
  498 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
      WRITE(*,1482)
 1482 FORMAT(//
     $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)
 1491 FORMAT(//
     $13X,'ENTER THE NUMBER OF ANALOG VOICE CHANNELS: ')
      READ(*,1492,ERR=1493) VC
 1492 FORMAT(F3.0)
      IF(VC.LE.60.0) THEN
         PIM = 3.0
      ELSE
         PIM = 4.0
      ENDIF
      LDF = -10.0 + 10*LOG10(VC)
```

```
      FMI = 10.0
      SNR = CNR + LIM + FMI - LDF + PIM
C     ********* MINIMUM CHANNEL NOISE (DBAO) ************
      NBAO = 10*LOG10((KM/1.852)*2.0E4/6.0E3) - 6.0
C
C     ********* CALCULATED CHANNEL NOISE ****************
C
      CCN = 82.0 - SNR
C
      GOTO 900
C
C     ***************************************************************
C     *                  RADIOSONDE DATA MODULE                     *
C     *                     PROGRAM MODULE                          *
C     ***************************************************************
  300 CALL CLEAR
      WRITE(*,299)
  299 FORMAT(13X,'IF CURRENT RADIOSONDE DATA IS AVAILABLE,    '/
     *    13X,'IT CAN BE ENTERED AND A MODIFIED REFRACTIVITY  '/
     *    13X,'LISTING AND/OR PLOT WILL BE CALCULATED. SELECT:'//
     *    13X,' (1)  ..... ENTER CURRENT RADIOSONDE DATA     '/
     *    13X,' (2)  ..... ENTER AVAILABLE DUCT INFORMATION '/
     *    13X,' (3)  ..... ENTER KNOWN DUCT HEIGHT GAIN      '/
     *    13X,' (4)  ..... NEGLECT DUCTING EFFECTS           ')
      READ(*,590) RESPON
      GOTO(301,350,360,1620),RESPON
  301 CALL CLEAR
      WRITE(*,335)
  335 FORMAT(13X,'**********************************************'/
     *         13X,'*              RADIOSONDE DATA MODULE         *'/
     *         13X,'**********************************************')
      WRITE(*,302)
  302 FORMAT(//1X,'ENTER NO. OF RADIOSONDE READING LEVELS')
      READ(*,303) LEV
  303 FORMAT(I2)
      DO 21 I=1,LEV
  311    WRITE(*,304) I
  304    FORMAT(/3X,'***********   RADIOSONDE LEVEL (',I2,')',
     *   ' DATA INPUT    ***********')
         WRITE(*,331)
  331    FORMAT(//1X,'ENTER LEVEL ALTITUDE (FEET ABOVE MSL)')
         READ(*,305) ALT(I)
  305    FORMAT(F8.1)
         WRITE(*,*)'ENTER ATMOSPHERIC PRESSURE (MILLIBARS)'
         READ(*,306) PRES(I)
  306    FORMAT(F7.2)
         WRITE(*,*)'ENTER LEVEL TEMPERATURE (C)'
         READ(*,307) TEMP(I)
  307    FORMAT(F5.1)
         WRITE(*,*)'ENTER WATER VAPOR PRESSURE (MILLIBARS)'
```

```
        READ(*,306) WVP(I)
        WRITE(*,308)
 308    FORMAT(//3X,'ALT (FT)',2X,'PRESS (MB)',5X,'TEMP (C)',5X,
   *    'VAPOR PRESS (MB)')
        WRITE(*,309)ALT(I),PRES(I),TEMP(I),WVP(I)
 309    FORMAT(3X,F8.1,6X,F6.1,6X,F4.1,14X,F6.1)
        WRITE(*,316)
 316    FORMAT(//
   $1X,'ANY DATA CORRECTIONS?  ("Y" OR "N") '/
   $1X,'RESPOND WITH UPPERCASE IN SINGLE QUOTATIONS')
        GOTO 317
 310    WRITE(*,334)
 317    READ(*,*,ERR=310) ANS
        IF(ANS.EQ.Y) GOTO 311
        IF(ANS.EQ.N) CONTINUE
        TEMP(I) = TEMP(I) + 273.15
        PT = PRES(I)/TEMP(I)
        WT = WVP(I)/TEMP(I)
        WWT= WVP(I)/(TEMP(I))**2
        RN(I) =(77.6*PT)-(5.6*WT)+(3.75E5*WWT)
        RM(I) = RN(I) + ALT(I)*4.8E-2
        TEMP(I) = TEMP(I) - 273.15
  21 CONTINUE
     DO 22 I=1,LEV
        DALT(I)=ALT(I+1)-ALT(I)
        DALT(I)=DALT(I)/1000.
        DRN(I) =RN(I+1)-RN(I)
        NGRAD(I)=DRN(I)/DALT(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
C    *************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)
            DELTAM = M2 - M1
            IF((M1.GT.RM(I-1)).AND.(M1.LT.RM(I))) THEN
C     **********    LEAST SQUARES LINE EQUATION    ***************
              SUMX =0.0
              SUMX2 = 0.0
              SUMY = 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)
              XMEAM = SUMX/2
              YMEAN = SUMY/2
              SLOPE = (SUMXY - SUMX*YMEAN)/(SUMX2 - SUMX*XMEAN)
              YINT = YMEAN - SLOPE*XMEAN
              DBOT = SLOPE*M1 + YINT
              DTHK = DTOP - DBOT
              TYPED = TYPE1
            ELSE IF(M1.LE.RM(1)) THEN
              DTHK = DTOP
              TYPED = TYPE2
            ENDIF
         ENDIF
         IF((COND(I).EQ.4.0).AND.(COND(I+1).EQ.4.0)) THEN
            WRITE(*,323)
 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
  25  CONTINUE
      WRITE(*,333)
 333  FORMAT(//1X,'DO YOU WANT AN ENVIRONMENTAL DATA LISTING?',
     *' ("Y" OR "N")')
      GOTO 318
 319  WRITE(*,334)
 334  FORMAT(//1X,'YOU HAVE ENTERED AN INCORRECT RESPONSE,',
     *' TRY AGAIN')
 318  READ(*,*,ERR=319) ANS
```

```
      IF(ANS.EQ. N ) GOTO 312
      IF(ANS.EQ. Y ) CONTINUE
      WRITE(7,901) CHAR(27),CHAR(15)
      WRITE(7,313)
  313 FORMAT('1',18X,'**** ENVIRONMENTAL DATA LIST ****')
      WRITE(7,314)
  314 FORMAT(//,7X,'PRESS',3X,'TEMP',3X,'VAPOR PRESS',3X,'ALT',
     *3X,'N UNITS',3X,'N/KFT',3X,'M UNITS',3X,'CONDITION')
      WRITE(7,315)
  315 FORMAT(1X,'LEVEL',2X,'(MB)',4X,'(C)',7X,'(MB)',4X,'(FEET)')
      DO 24 I=1,LEV
      WRITE(7,322) I,PRES(I),TEMP(I),WVP(I),ALT(I),RN(I),NGRAD(I),
     *RM(I),TYPE(I)
  322 FORMAT(/2X,I2,2X,F6.1,3X,F4.1,6X,F4.1,3X,F7.1,3X,F6.1,3X,F6.1,
     *3X,F6.1,5X,A6)
   24 CONTINUE
      WRITE(7,*)'  '
  312 DO 40 I=1,LEV
         IF(TYPE(I).EQ.'TRAP  ') THEN
            WRITE(7,324)  TYPED,HOPT,DTHK,DELTAM
            DUCT = 2
            CALL CLEAR
            WRITE(*,324)  TYPED,HOPT,DTHK,DELTAM
  324       FORMAT(//13X,'TROPOSPHERIC DUCT DETECTED, TYPE: ',A10,
     *         /13X,'OPTIMUM COUPLING HEIGHT............',F6.3,' KM',
     *         /13X,'DUCT THICKNESS.....................',F6.3,' KM',
     *         /13X,'DUCT INTENSITY (M-UNITS) .......... ',I3)
         ELSE
            CONTINUE
         ENDIF
   40 CONTINUE
      WRITE(7,917) CHAR(27),CHAR(18)
C
      WRITE(*,332)
  332 FORMAT(//1X,'DO YOU WANT A M-PROFILE PLOT?  YES(1)/NO(2)')
      GOTO 321
  320 WRITE(*,*)'YOU HAVE ENTERED AN INCORRECT RESPONSE, TRY AGAIN'
  321 READ(*,590,ERR=320) RESPON
      IF(RESPON.EQ.1) THEN
         WRITE(*,*)'PREPARE PRINTER ..........PLOTTING BEGINS......'
         CALL PLOT1(LEV,MALT,RM)
      ELSE
         CONTINUE
      ENDIF
      IF(DUCT.EQ.2) GOTO 1700
      GOTO 1600
  350 CALL CLEAR
      WRITE(*,*)'******** ENTER DUCT PARAMETER DATA ********'
      GOTO 1327
 1325 WRITE(*,*)'REAL DATA ENTRY ERROR. TRY AGAIN.'
```

```
 1327 WRITE(*,327)
  327 FORMAT(//1X,'   ENTER DUCT OPTIMUM COUPLING HEIGHT '/
     $          1X,'   (KILOMETERS ABOVE MEAN GROUND LEVEL)')
      READ(*,325,ERR=1325) HOPT
  325 FORMAT(F8.2)
      GOTO 1329
 1328 WRITE(*,*)'REAL DATA ENTERY ERROR. TRY AGAIN.'
 1329 WRITE(*,328)
  328 FORMAT(/1X,'ENTER DUCT THICKNESS (KILOMETERS)')
      READ(*,325,ERR=1328) DTHK
      GOTO 372
  371 WRITE(*,*)'INTEGER DATA ENTRY ERROR. PLEASE TRY AGAIN.'
  372 WRITE(*,329)
  329 FORMAT(/
     $1X,'ENTER DUCT INTENSITY (M-UNITS)                       '/
     $1X,' (AS TWO-DIGIT INTEGER VALUE)')
      READ(*,370,ERR=371) DELTAM
  370 FORMAT(I2)
      GOTO 1700
  360 CALL CLEAR
      WRITE(*,*)'   ********* HEIGHT GAIN INPUT *********'
      WRITE(*,330)
  330 FORMAT(/1X,'ENTER HEIGHT GAIN (DB)')
      READ(*,326) HG
  326 FORMAT(F7.2)
      GOTO 1600
C
C     ***************************************************************
C     *                                                             *
C     *        ELEVATED DUCT HEIGHT GAIN ESTIMATE MODULE            *
C     *                                                             *
C     ***************************************************************
C
C *** DETERMINE AVE. ANTENNA ELEV. FACTOR 'X'(0.005 KM = 1.0,
C     285 KM = 15.0, INCREMENT = 0.020 KM)
 1700 X = (HS + 0.015)/0.02
C *** DETERMINE RANGE FACTOR'RF' (75 KM = 1.0, 325 KM = 6.0,
C     INCREMENT = 50 KM)
      RF = ((KM - 25)/50.)-1
      IF(DELTAM.GT.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
```

```
      IF(HOPT.LT.0.8) CONTINUE
  880 CALL CLEAR
      WRITE(*,881)
  881 FORMAT(//13X,'HEIGHT GAIN (DB) CANNOT BE ESTIMATED       '/
     *         13X,'BECAUSE CURRENT ELEVATED DUCT PARAMETERS    '/
     *         13X,'EXCEED MODEL RELIABILITY. ENTER HEIGHT GAIN'/
     *         13X,'OBTAINED FROM AN ALTERNATIVE METHOD         '//
     *         13X,'    **** ELEVATED DUCT LIMITATION ****      '//
     *         13X,'                                            '/
     *         13X,'OPT. COUPLING HEIGHT:  0.800<KM<1.500   '/
     *         13X,'DUCT THICKNESS:        0.085<KM<0.120   '/
     *         13X,'DUCT INTENSITY:        0.0<M-UNITS<5.0  '//)
      WRITE(*,*)'ENTER (1) TO CONTINUE .........'
      READ(*,590) RESPON
      IF(RESPON.NE.999) CONTINUE
      GOTO 360
C     ****************************************************************
C     *  PA                ELEVATED DUCT DATA                        *
C     *  HOPT:    1.452 KM                      DTHK: 0.111 KM       *
C     *  DELTAM: 4.0 M-UNITS                                         *
C     ****************************************************************
  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
```

```
          HG1 = 0.1310 - 0.0015*X + 0.0007*(X**2)
          HG2 = 0.1511 - 0.0021*X + 0.0008*(X**2)
          FREQ1 = 4900.
          DELTR1 = -12.02
          DELTR2 = -11.78
      ENDIF
      IF(FREQ.NE.5000.) GOTC 890
      IF(FREQ.EQ.5000.) HGE = 0.1511 - 0.0021*X + 0.0008*(X**2)
      DELTR = -11.78
      HGE = DELTR*RF + (20*LOG10(HGE))
      GOTO 891
C     ****************************************************************
C     *  PG                  ELEVATED DUCT DATA                       *
C     *  HOPT:     1.412 KM                        DTHK: 0.0994 KM   *
C     *  DELTAM: 3.0 M-UNITS                                          *
C     ****************************************************************
  810 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 = 4500.
          DELTR1 = -10.7
          DELTR2 = -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.
          DELTR1 =-12.9
          DELTR2 =-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.
          DELTR1 = -12.87
          DELTR2 = -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.
          DELTR1 = -12.61
          DELTR2 = -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.
          DELTR1 = -13.53
          DELTR2 = -12.63
```

```
      ENDIF
      IF(FREQ.NE.5000.)  GOTO 890
      IF(FREQ.EQ.5000.)  THEN
         HGE = 0.1286 - 0.0010*X + 0.0008*(X**2)
         DELTR = -12.63
         HGE = DELTR*RF + (20*LOG10(HGE))
      ENDIF
      GOTO 891
C     ******************************************************************
C     *  PB                 ELEVATED DUCT DATA                         *
C     *  HOPT:    1.376 KM                           DTHK: 0.107  KM   *
C     *  DELTAM: 4.0 M-UNITS                                           *
C     ******************************************************************
 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.
         DELTR1 = -12.59
         DELTR2 = -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.
         DELTR1 =-12.5
         DELTR2 =-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.
         DELTR1 = -11.95
         DELTR2 = -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.
         DELTR1 = -12.43
         DELTR2 = -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.
         DELTR1 = -12.51
         DELTR2 = -11.67
      ENDIF
      IF(FREQ.NE.5000.)  GOTO 890
```

```
      IF(FREQ.EQ.5000.) THEN
         HGE = 0.1842 - 0.0039*X + 0.0010*(X**2)
         DELTR = -11.67
         HGE = DELTR*RF + (20*LOG10(HGE))
      ENDIF
      GOTO 891
C     ****************************************************************
C     *  PC                   ELEVATED DUCT DATA                     *
C     *  HOPT:    1.257 KM                        DTHK: 0.112  KM    *
C     *  DELTAM: 4.0 M-UNITS                                         *
C     ****************************************************************
  830 IF((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 + 0.0001*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.NE.5000.) GOTC 890
      IF(FREQ.EQ.5000.) THEN
         HGE = 0.1399 - 0.0035*X + 0.0009*(X**2)
         DELTR = -12.19
```

```
         HGE = DELTR*RF + (20*LOG10(HGE))
      ENDIF
      GOTO 891
C     ****************************************************************
C     *  PF                ELEVATED DUCT DATA                        *
C     *  HOPT:    1.151 KM                         DTHK: 0.089   KM  *
C     *  DELTAM:  3.0  M-UNITS                                       *
C     ****************************************************************
  840 IF((FREQ.GE.4500.).AND.(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.).AND.(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.).AND.(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.).AND.(FREQ.LT.4900.)) THEN
         HG1 = 0.1067 + 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.).AND.(FREQ.LT.5000.)) THEN
         HG1 = 0.1709 - 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
```

```
C     *************************************************************
C     *  PH                ELEVATED DUCT DATA                     *
C     *  HOPT:     1.077 KM                       DTHK: 0.116   KM *
C     *  DELTAM:  4.0  M-UNITS                                     *
C     *************************************************************
  850 IF((FREQ.GE.4500.).AND.(FREQ.LT.4600.)) THEN
         HG1 = 0.2049 - 0.0005*X + 0.0011*(X**2)
         HG2 = 0.1375 - 0.0021*X + 0.0009*(X**2)
         FREQ1 = 4500.
         DELTR1 = -12.25
         DELTR2 = -12.73
      ENDIF
      IF((FREQ.GE.4600.).AND.(FREQ.LT.4700.)) THEN
         HG1 = 0.1375 - 0.0021*X + 0.0009*(X**2)
         HG2 = 0.1581 - 0.0034*X + 0.0011*(X**2)
         FREQ1 = 4600.
         DELTR1 =-12.73
         DELTR2 =-12.27
      ENDIF
      IF((FREQ.GE.4700.).ANL.(FREQ.LT.4800.)) THEN
         HG1 = 0.1581 - 0.0034*X + 0.0011*(X**2)
         HG2 = 0.1298 + 0.0005*X + 0.0008*(X**2)
         FREQ1 = 4700.
         DELTR1 = -12.27
         DELTR2 = -12.64
      ENDIF
      IF((FREQ.GE.4800.).ANL.(FREQ.LT.4900.)) THEN
         HG1 = 0.1298 + 0.0005*X + 0.0008*(X**2)
         HG2 = 0.0986 + 0.0016*X + 0.0007*(X**2)
         FREQ1 = 4800.
         DELTR1 = -12.64
         DELTR2 = -13.50
      ENDIF
      IF((FREQ.GE.4900.).AND.(FREQ.LT.5000.)) THEN
         HG1 = 0.0986 + 0.0016*X + 0.0007*(X**2)
         HG2 = 0.1200 + 0.0000*X + 0.0008*(X**2)
         FREQ1 = 4900.
         DELTR1 = -13.50
         DELTR2 = -13.23
      ENDIF
      IF(FREQ.NE.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
C     *************************************************************
C     *  PD                ELEVATED DUCT DATA                     *
C     *  HOPT:     1.044 KM                       DTHK: 0.163   KM *
```

```
C      *  DELTAM: 6.0 M-UNITS                                          *
C      ****************************************************************
  860 IF((FREQ.GE.4500.).AND.(FREQ.LT.4600.)) THEN
          HG1 = 0.1524 - 0.0039*X + 0.0011*(X**2)
          HG2 = 0.0981 + 0.0017*X + 0.0007*(X**2)
          FREQ1 = 4500.
          DELTR1 = -12.80
          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 = 0.1008 + 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.NE.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
C      ****************************************************************
C      *  PE               ELEVATED DUCT DATA                          *
C      *  HOPT:    0.951 KM                         DTHK: 0.117   KM   *
C      *  DELTAM:  4.0 M-UNITS                                         *
C      ****************************************************************
  870 IF((FREQ.GE.4500.).AND.(FREQ.LT.4600.)) THEN
```

```
         HG1 = 0.1621 + 0.0022*X + 0.0011*(X**2)
         HG2 = 0.1001 + 0.0035*X + 0.0006*(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.NE.5000.) GOTO 890
      IF(FREQ.EQ.5000.) THEN
         HGE = 0.1347 + 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.
```

```
      ENDIF
      IF((D.GE.0.667).AND.(D.LE.1.0)) THEN
          HG = HG2
          DIF = DEITR2
      ENDIF
      HG = (DIF*RF) + (20*LOG10(HG))
      GOTO 1600
  891 HG = HGE
      GOTO 1600
C
C DATA OUTPUT MODULE
C
  900 WRITE(7,901) CHAR(27),CHAR(15)
  901 FORMAT('+',A1,A1)
      CALL CLEAR
      WRITE(*,1900)
 1900 FORMAT(//
     $13X,'***************************************************'/
     $13X,'*                                                 *'/
     $13X,'*            PROBLEM PRINTER OUTPUT               *'/
     $13X,'*                                                 *'/
     $13X,'***************************************************')
      WRITE(7,924)
  924 FORMAT('1')
      WRITE(7,902)
  902 FORMAT(1X,'------------------------------------------'
     $,'----------------------------------')
      WRITE(7,903)
  903 FORMAT(17X,'TROPOSCATTER SYSTEM DESIGN SPECIFICATIONS')
      WRITE(7,902)
      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
```

```
      WRITE(7,905)ALAT,A11,BLAT,B11,ALONG,A12,BLONG,B12,THT,RTH
905   FORMAT(//15X,'SITE            TRANSMITTER      RECEIVER'/
     $15X,'LATITUDE: ',4X,F8.2,1X,A3,3X,F8.2,1X,A3/
     $15X,'LONGITUDE:',4X,F8.2,1X,A3,3X,F8.2,1X,A3/
     $15X,'ELEVATION:',2X,F10.2,' M',3X,F10.2,' M')
      WRITE(7,951) PATH
951   FORMAT(/15X,'TERRAIN PROFILE TYPE: ',A35)
      WRITE(7,935)TAMR,TBMR,TMR,TAKE1,TAKE2,THETAD
935   FORMAT(//15X,'TRANSMITTER TAKE-OFF ANGLE:     ',F7.2,' MRAD'/
     $            15X,'RECEIVER TAKE-OFF ANGLE:        ',F7.2,' MRAD'/
     $            15X,'SCATTER (ANGULAR DISTANCE):     ',F7.2,' MRAD'//
     $            15X,'TRANSMITTER TAKE-OFF ANGLE:',F10.2,' DEGREES'/
     $            15X,'RECEIVER TAKE-OFF ANGLE:   ',F10.2,' DEGREES'/
     $            15X,'SCATTER (ANGULAR DISTANCE):',F10.2,' DEGREES')
      WRITE(7,952) FREQ
952   FORMAT(/15X,'TRANSMIT FREQUENCY: ',F7.2,' MHZ')
      WRITE(7,953)DELTAF
953   FORMAT(/15X,'MINIMUM RECOMMENDED FREQUENCY SEPARATION ',
     $'FOR QUAD DIVERSITY: ',F7.2,' MHZ')
      WRITE(7,906)AZA
906   FORMAT(//15X,'AZIMUTH AT TRANSMITTER (TO RECVR): ',F6.2,
     $' (DEGREES N.)')
      WRITE(7,907)AZB
907   FORMAT(15X,'AZIMUTH AT RECEIVER (TO TRANS):    ',F6.2,
     $' (DEGREES N.)')
      WRITE(7,908)SM,KM
908   FORMAT(//15X,'GREAT CIRCLE PATH: ',F8.2,' STATUTE MILES',
     $' /',F8.2, ' KILOMETERS')
      DELTAV = DELTAV*3.2808
      WRITE(7,954) DELTAV
954   FORMAT(/15X,'MINIMUM RECOMMENDED ANTENNA VERTICAL ',
     $'SEPARATION FOR SPACE DIVERSITY: ',F5.1,' FEET')
      WRITE(7,955) HO
955   FORMAT(/
     $15X,'ESTIMATED SCATTER VOLUME BASE ALTITUDE: ',
     $F10.2,' METERS')
      WRITE(7,956)
956   FORMAT('1')
      WRITE(7,902)
      WRITE(7,911)
911   FORMAT(17X,'BASIC MEDIAN TRANSMISSION LOSS FACTORS')
      WRITE(7,902)
      WRITE(7,913)  LS
913   FORMAT(//
     $15X,'                 SYSTEM LOSS FACTORS'//
     $15X,'FREE-SPACE/SCATTER LOSS ...................',F7.1,' DB')
      WRITE(7,925)  LW
925   FORMAT(/
     $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,'RAINFFALL ABSORPTION LOSS ................',F7.1,' DB')
    WRITE(7,930) ANTG
930 FORMAT(//
   $15X,'                SYSTEM GAIN FACTORS'//
   $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) LT
933 FORMAT(//
   $15X,'NET PATH LOSS .............................',F7.1,' DB')
    WRITE(7,934) PTDBM
934 FORMAT(/
   $15X,'TRANSMITTER POWER .........................',F7.1,' DBM')
C
    WRITE(7,914) RSDBM,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,'THEORECTICAL RF CNR .......................',F7.1,' DB '//
   $15X,'SYSTEM FADE MARGIN ........................',F7.1,' DB ')
C
    WRITE(7,957)
957 FORMAT('1')
    WRITE(7,902)
    WRITE(7,*)'                             SYSTEM PERFORMANCE'
    WRITE(7,902)
    IF(SYS.EQ.1) THEN
       WRITE(7,950) REL
950    FORMAT(//
```

```
     $15X,'SYSTEM PATH RELIABILITY .........................',F8.2,
     $' PERCENT')
      ELSE
         WRITE(7,916)REL,EBN,PB
  916    FORMAT(//
     $15X,'SYSTEM PATH RELIABILITY ...............',F8.2,
     $' PERCENT'/
     $15X,'EB/NO (BIT ENERGY/NOISE DENSITY) ......  ',F6.2,' DB'/
     $15X,'PROBABILITY OF BIT ERROR ...............  ',1E10.4)
      ENDIF
C
      IF(SET.EQ.1) THEN
         WRITE(7,921) SNR,NBAO,CCN
  921    FORMAT(//
     $15X,'********** FM/FDM SYTEM PERFORMANCE DATA *********'//
     $15X,'SIGNAL-TC-NOISE RATIO .....................',F7.2,' DB   '/
     $15X,'MINIMUM STANDARD CHANNEL NOISE ..........',F7.2,' DBA0'/
     $15X,'PREDICTED CHANNEL NOISE ..................',F7.2,' DBA0')
      ELSE
         CONTINUE
      ENDIF
C     SET THE PRINTER TO NORMAL SPACING = 80 CHAR PER LINE
      WRITE(7,917) CHAR(27),CHAR(18)
  917 FORMAT(1X,A1,A1)
      WRITE(7,*)' '
C
      CALL CLEAR
      WRITE(*,920)
  920 FORMAT(/
     $13X,'DO YOU WANT TO START A NEW PROBLEM? YES(1)/NO(2)')
      READ(*,590) RESPON
      GOTO(100,999),RESPON
  999 CLOSE(2,STATUS='KEEP')
      CLOSE(7,STATUS='DELETE')
      STOP
      END
C
C     ****************************************************
C     *                                                  *
C     *               SUBROUTINE MODULE                  *
C     *                                                  *
C     ****************************************************
      SUBROUTINE CLEAR
C
C  THIS SUBROUTINE WILL CLEAR THE CURRENT SCREEN
C
      WRITE(*,10)
   10 FORMAT('0'/'0'/'0'/'0'/'0'/'0'/'0'/'0'/'0'/'0'/'0'/'0'/'0'/
     *'0')
      RETURN
```

```
      END
C
      SUBROUTINE PLOT (Z,X,Y)
C
C     THIS SUBROUTINE WILL PLOT A ONE PAGE TERRAIN PROFILE
C     GRAPH ON THE PRINTER.
C
      DIMENSION K(105),X(1),Y(1),XWRD(11),YWRD(11)
      INTEGER Z
      CHARACTER*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)
   50       IF (Y(I).GT.YMAX) YMAX = Y(I)
               YRNGE = YMAX - YMIN
               XWRD(1)= X(1)
               XWRD(11)  = X(Z)
               YWRD(1)  = YMIN
               YWRD(11)  = YMAX
               AY  = 0.1*YRNGE
               AX  = 0.1*XRNGE
               DO  60 I= 1,10
                   XI = I-1
                   XWRD(I)  = XWRD(1)  + XI*AX
   60              YWRD(I)  = YWRD(1)  + XI*AY
                   DO 65 I= 1,105
   65              K(I)  = BLANK
                   DO  70 I = 10,100,10
   70              K(I)  = ':'
C
C     SET THE PRINTER TO COMPRESS PRINT=132 CHAR PER LINE
      WRITE (7,75) CHAR(27),CHAR(15)
   75 FORMAT('+',A1,A1)
      WRITE (7,80)  (YWRD(I),I=2,10,2),(YWRD(I),I=1,11,2),
     &(K(I),I=1,100),IDOT
   80 FORMAT(1H1/19X,5(8X,E12.6)/9X,6(8X,E12.6)/14X,100A1,5X,A5)
      J=1
      J1=0
      JJ =1
      XL = 0.2*AX
   90 XJ = J1
      DO 100 I=1,104
  100 K(I)  = BLANK
      K(105)='-'
```

```
110 IF(J.GT.Z) GO 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) GO TO 190
    K(LOC)='+'
    GO TO 110
190 K(LOC)='*'
    GO TO 110
200 IF(J1.EQ.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(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(7,35)
 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)
330 FORMAT(1X,A1,A1)
    WRITE(7,*)' '
    RETURN
    END
C
    SUBROUTINE SORT2(A,B,Z)
C
C     THIS SUBROUTINE PERFORMS AN IN PLACE SORT OF A
C     ONE DIMENSIONAL ARRAY USING THE SHELL-METZNER
C     METHOD. THEN MATCHES THAT ORDER IN A SECOND ARRAY
C
C     A = THE ARRAY TO BE SORTED TO ASCENDING ORDER
```

```
C     B = THE SECOND ARRAY TO BE ORDERED AS THE FIRST
C     Z = THE NUMBER OF ELEMENTS IN THE ARRAY
C     T = TEMPORARY ELEMENT HCLDER FOR SWAP
C
      DIMENSION A(1),B(1)
      INTEGER I,J,K,Z
      REAL A,B,T
C
      K=Z
    5 IF(K.LE.1) GC TO 30
      K=K/2
        DO 20 J=1,Z-K
           DO 10 I=J,1,-K
              IF(A(I).LE.A(I+K)) GO TO 10
C     FIRST ARRAY CONTROLS CRDER
                 T=A(I)
                 A(I)=A(I+K)
                 A(I+K)=T
C     SECOND ARRAY
                 T=B(I)
                 B(I)=B(I+K)
                 B(I+K)=T
   10      CONTINUE
   20   CONTINUE
      GOTO 5
C
   30 RETURN
      END
C
      SUBROUTINE INVERT(A,N)
C
      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
C
      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
C
      SUBROUTINE PLOT1(Z,X,Y)
C
C     THIS SUBROUTINE WILL PLOT A ONE PAGE REFRACTIVITY
C     PROFILE ON THE PRINTER.
C
      DIMENSION K(105),X(1),Y(1),XWRD(11),YWRD(11)
      INTEGER Z
      CHARACTER*1 K,BLANK
      CHARACTER*5 IDOT,IDSH
      DATA BLANK /' '/,IDOT/'    :'/,IDSH/'    -'/
      CALL SORT2 (X,Y,Z)
      XRNGE = X(Z)-X(1)
      YMAX  = Y(1)
      YMIN  = Y(1)
      DO 50 I=2,Z
         IF(Y(I).LT.YMIN)  YMIN = Y(I)
   50       IF(Y(I).GT.YMAX) YMAX = Y(I)
               YRNGE = YMAX - YMIN
               XWRD(1)= X(1)
               XWRD(11)  = X(Z)
               YWRD(1)  = YMIN
               YWRD(11)  = YMAX
               AY  = 0.1*YRNGE
               AX  = 0.1*XRNGE
               DO 60 I= 1,10
                  XI = I-1
                  XWRD(I)  = XWRD(1)  + XI*AX
   60             YWRD(I)  = YWRD(1)  + XI*AY
                  DO 65 I= 1,105
   65             K(I)  = BLANK
                  DO 70 I = 10,100,10
   70             K(I)  = ':'
```

```
C
C     SET THE PRINTER TO COMPRESS PRINT=132 CHAR PER LINE
      WRITE (7,75) CHAR(27),CHAR(15)
 75   FORMAT('+',A1,A1)
      WRITE (7,80) (YWRD(I),I=2,10,2),(YWRD(I),I=1,11,2),
     &(K(I),I=1,100),IDOT
 80   FORMAT(1H1//19X,5(8X,E12.6)/9X,6(8X,E12.6)/14X,100A1,5X,A5)
      J=1
      J1=0
      JJ =1
      XL = 0.2*AX
 90   XJ = J1
      DO 100 I=1,104
100   K(I) = BLANK
      K(105)='-'
110   IF(J.GT.Z) GC TO 200
      IF((XWRD(1) + XJ*XL).IT.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   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(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 ',
     $'(M-UNITS)'/
     $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
      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
   10 I = I + 1
         SUM1 = SUM
         TERM = TERM*X2/(I + 0.5)
         SUM = TERM + SUM1
         IF(TERM.GE.TOL*SUM) GOTO 10
      ERF = 2 * SUM * EXP(-X2)/SQRTPI
   99 RETURN
      END
C
      FUNCTION ERFC(X)
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
      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
```

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