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MILITARY HANDBOOK

FACILITY DESIGN FOR TROPOPHERIC SCATTER (TRANSHORIZON MICROWAVE SYSTEM DESIGN)

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

S L H C

DEPARTMENT OF DEFENSE
WASHINGTON DC

MIL-HDBK-417

FACILITY DESIGN TROWSPHERIC SCATTER (TRASHORIZON MICROWAVE SYSTEM DESIGN)

1. This standardization handbook was developed by the Department of Defense in accordance with established procedure.

2. This publication was approved on 25 NOVEMBER 1977 for Printing and inclusion in the military standardization handbook series.

3. This document provides basic and fundamental information on Facility Design Tropospheric Scatter (Transhorizon Microwave System Design). It will provide valuable information and guidance to personnel concerned with the preparation of specifications and the procurement of Tropo Scatter equipment for the Defense Communication System. The handbook is not intended to be referenced in purchase specifications except for informational purposes, nor shall it supersede any specification requirements.

4. Every effort has been made to reflect the latest information on Tropospheric Scatter Design It is the intent to review this handbook periodically to insure its completeness and currency. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Rome Air Development Center, ATTN: RADC/RBRD, Griffiss AFB NY 13441 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

This handbook has been prepared to provide communications engineers with the information and techniques needed in the design of wide-band transhorizon radio systems at frequencies generally between 200 MHz and 5 GHz. The material was compiled from many sources, including CCIR and CC ITT documents, military manuals and standards, and various technical books and journals. Many members of the ITS staff have contributed to this effort; those most directly involved were L.G. Hause (Project leader), A.P. Barsis, J.E. Farrow, F.G. Kimmett, A.G. Longley, P. L. Rice, C.A. Samson, and R.E. Skerjanec. The project was sponsored by the United States Air Force Communications Service, Richards-Gebaur AFB, with B. Heidgen of that organization providing technical liaison with ITS.

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CHAPTER 1

SCOPE

1.1 General

1.1.1 This handbook for transhorizon radio systems includes techniques and procedures necessary for communications engineers to design systems utilizing state-of-the-art principles existing now. Information in this handbook is applicable to systems operating at frequencies between approximately 0.2 to 5 GHz, and outlines the design methods to be employed in engineering of transhorizon facilities so that they will. operate in accordance with the required criteria. In order for an actual system to meet Defense Communications System (DCS) standards and objectives, the appropriate and current Military Standards (see section 2.1), Defense Communications Agency (DCA) circulars, CCIR Recommendations or service-wide publications (see section 2.2) must be consulted as source documents for performance criteria and specifications These referenced standards are updated as the state-of-the-art improves, and will not necessarily be reflected in this handbook. [77,78,79]

1.1.2 Information is provided first on how to start the design work with a preliminary selection of sites and routes based on stated performance requirements. Selection is aided by obtaining preliminary path profiles and calculating initial transmission loss values.

1.1.3 Procedures are then established for planning and making field surveys, and using the results obtained for further refinement of site and route selections.

1.1.4 Worksheets and procedures are given for the detailed evaluation of individual links after provision is made for adequate terrain clearance Various equipment alternatives are discussed and quantitative data for equipment planning are supplied.

1.1.5 The treatment of overall system planning includes system layout, frequency allocation, intra-system intererence allowable link noise quota, and system performance predictions.

1.2 Purpose

1.2.1 This handbook is intended to assist suitably qualified personnel in designing transhorizon systems to current state-of-art standards. It is not intended as a substitute for engineering educaticn or experience. Various aspects of problems are considered and several alternatives to their solutions are presented Wherever possible. The handbook draws information and ideas from many sources, but it is not meant to be an all-inclusive source of design information.

1.3 Application

1.3.1 The handbook applies to transhorizon radio systems which are used to provide point-to-point, multichannel communications, and usually transmit voice, teletype facsimile digital data, and visual displays. Such systems generally use a carrier frequency in the range of 0.2 to 5 GHz over individual paths which are typically 100 - 300 km in length, but range upward to 800 - 1000 km. Transmitter outputs of 1 kW are commonly used, but 10 kW to 50 kW may be used on particularly difficult paths. High-gain directional parabolic antennas 9 to 18 m in diameter are used on many paths, as w-en as "billboard” antennas up to a nominal 36 m.

1.4 Objectives

1.4.1 The main objective of this handbook is to provide methods for trans-horizon system design. The topics covered include: detailed path profiles, pathloss calculations, service probability and fading range estimates, radio interference investigations, adherence to DCA noise standards and link equipment requirements. Graphs, basic equations and tables are provided for optimizing the design through trade-off studies, arid to insure that the required functional, reliability, and safety requirements are met. The design procedures presented here require only slide rule calculations, and occasional reference to mathematical tables; however, the methods are readily adaptable to programming on electronic computers.

1.4.2 Certain studies must be made to insure the compatibility of the basic links with the total communication system objectives. These are mainly (1) system performance predictions based on the composite characteristics of the basic links, and (2) the specification of branch and terminal requirements so that the linking of branches at the sites is achieved properly.

1.5 General Instructions

1.5.1 The handbook provides: (1) a recommended order of procedures for designing a system, and (2) information of specific topics related to various design problems.

1.5.2 The organizational block diagrams (figures 1. 6-1 through 1.6-5) indicate the order of procedures, the functional relationships between the topics, and which tasks are prerequisite to others.

1.5.3 Many topics are considered from several points of view or at different stages in the design and, therefore, are discussed at more than one place in the handbook. For certain technical processes, either appendices or worksheets are provided. Examples of the worksheets appear in the text where appropriate. Additionally, a set of sample worksheets is included in the appendix, section 6.4.

1.6 Organization

1.6.1 The design portion of the handbook (Chapter 4) is organized as shown in figures 1. 6-1 through 1.6-5. The subject matter is discussed in the manual in the order in which it normally occurs in actual system design. Major topics are listed in the Table of Contents and are numbered using periods to separate sections and subsections.

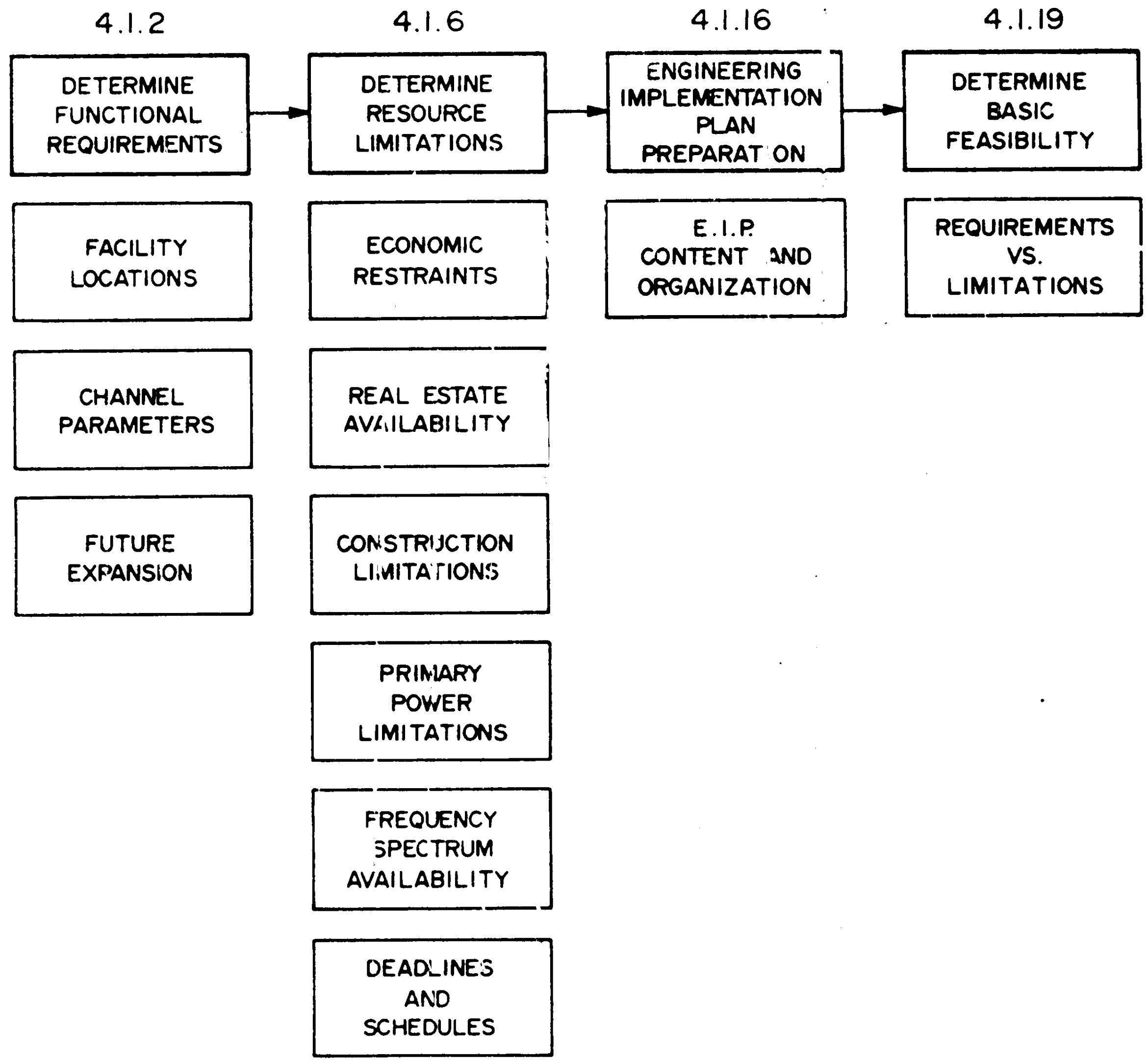


Figure 1.6-1 General Considerations in Starting Design.

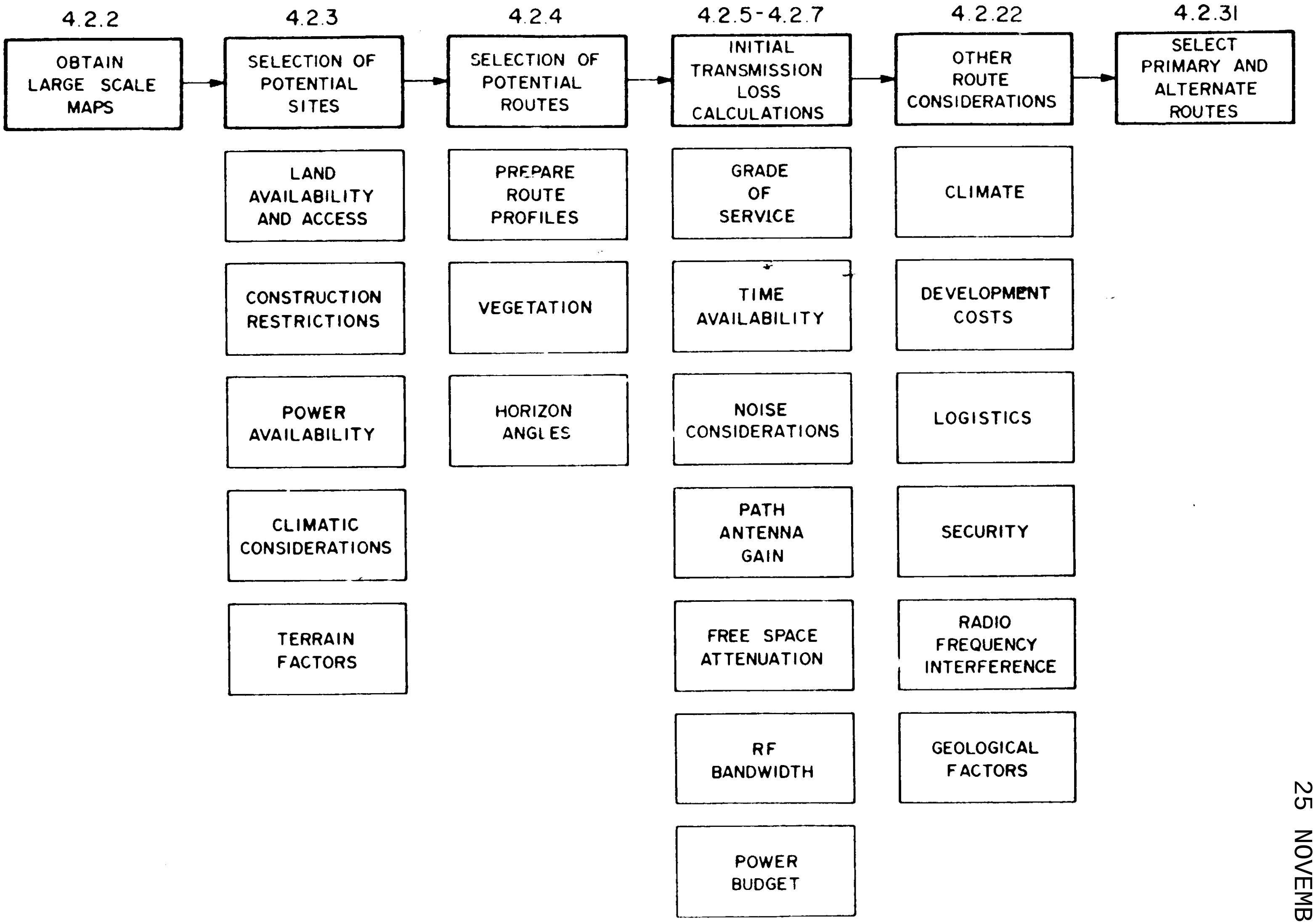
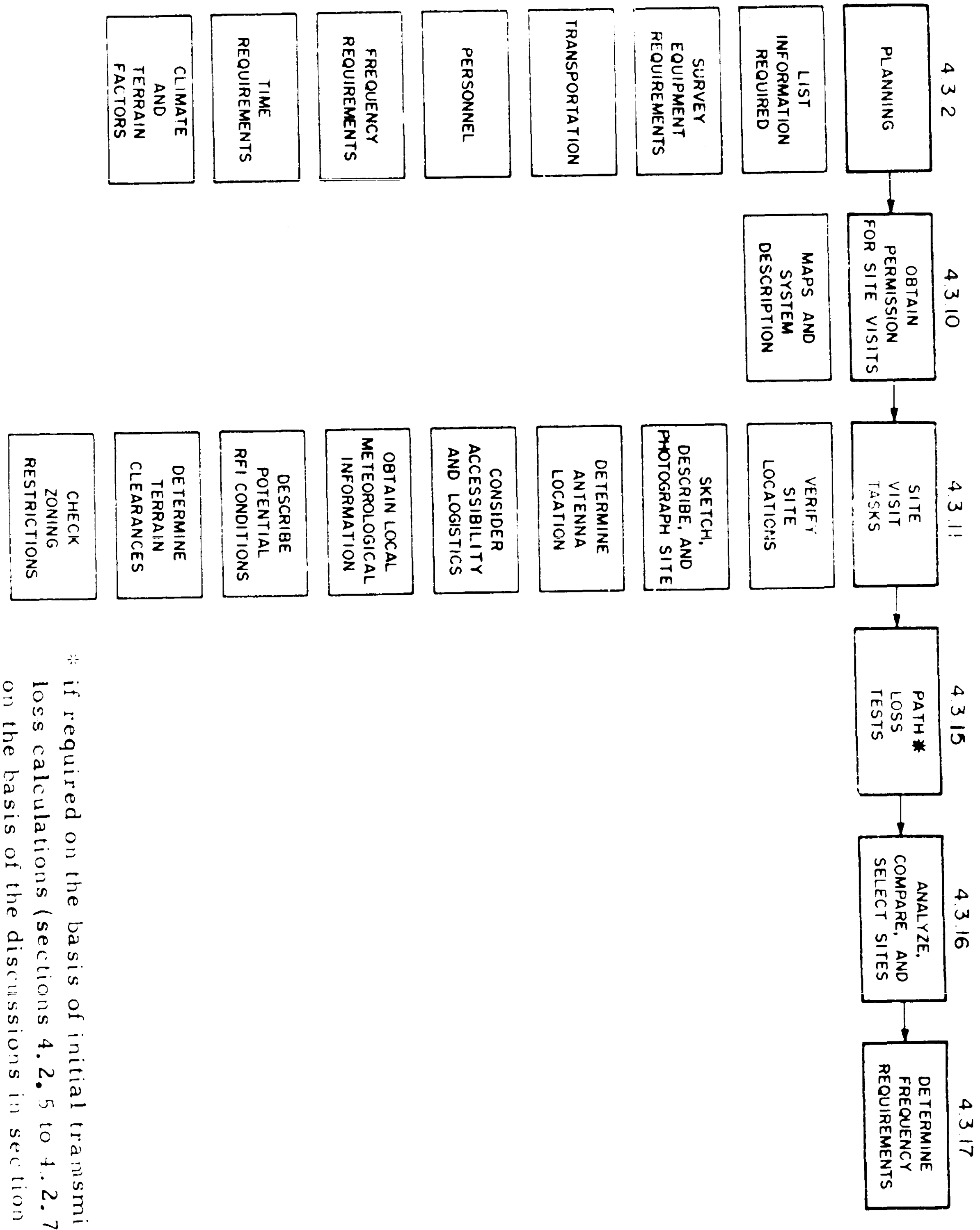


Figure 1.6-2 General Considerations in Study of Route Alternatives



* if required on the basis of initial transmission loss calculations (sections 4.2.5 to 4.2.7) and on the basis of the discussions in section 4.3.1

Figure 1.6-3 General Considerations for Field Survey

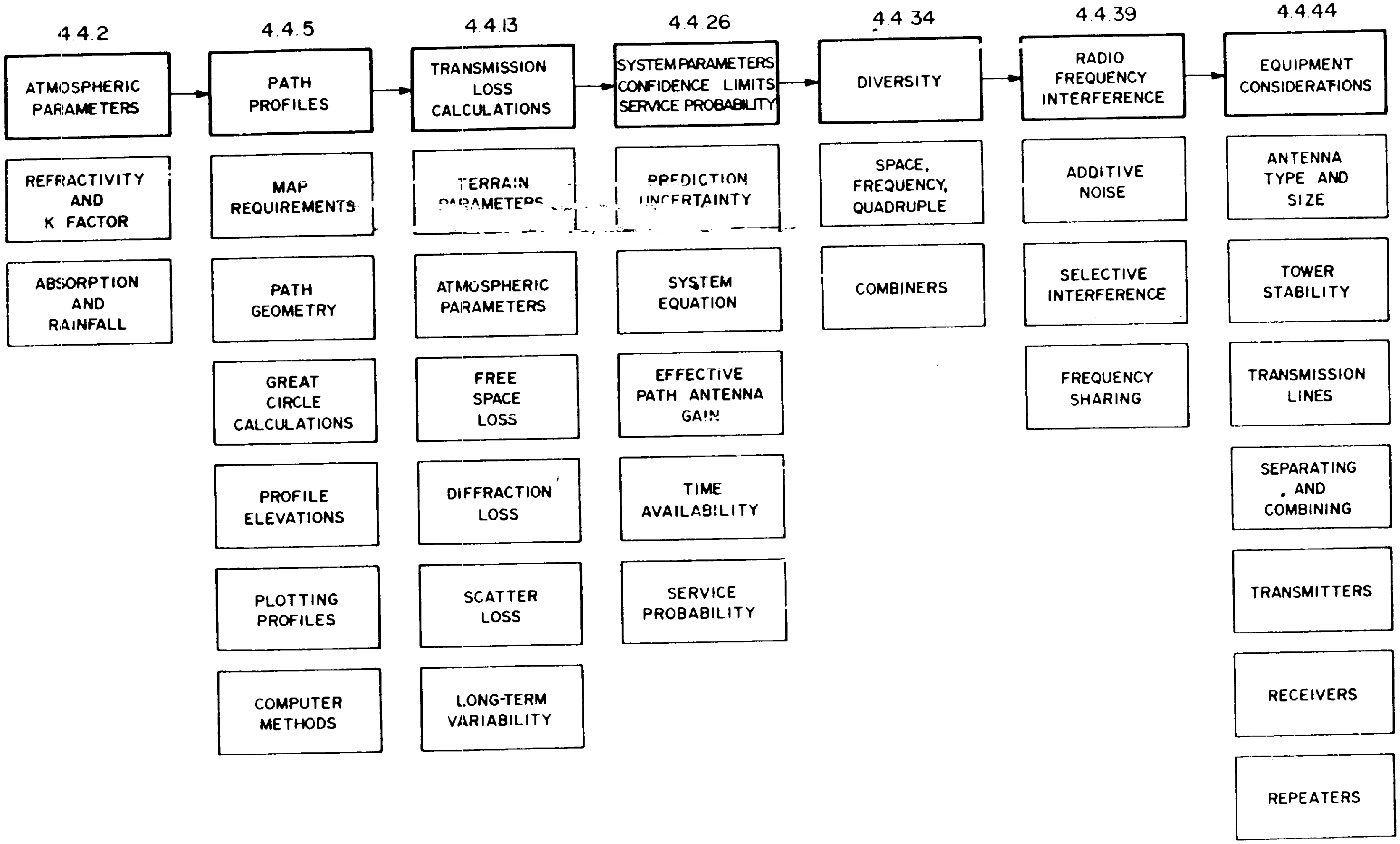


Figure 1.6-4 General Considerations for Link Design

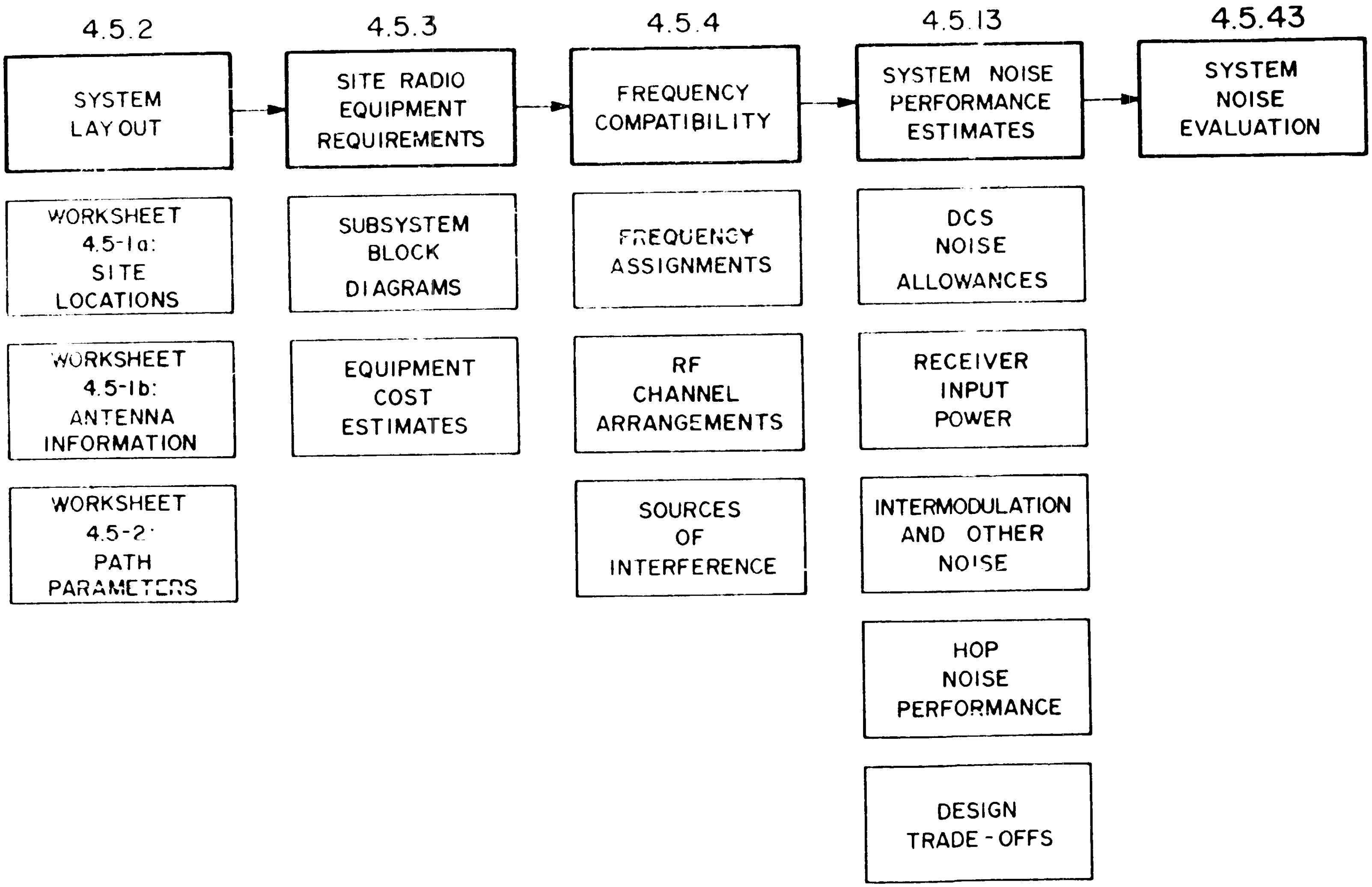


Figure 1.6-4 General Considerations for Integrating Link Design into System Design.

CHAPTER 2
REFERENCED DOCUMENTS

2.1 Military standards

a.	MIL-STD-188C	Military Communication System Technical Standards, 24 Nov 69 (to be replaced by MIL-STD-188-200 series) .
b.	MIL-STD-188-100	Common Long Haul and Tactical Communication System Technical Standards, 15 Nov 72.
C.	MIL-STD-188-310	Subsystem Design and Engineering Standards for Technical Control Facilities, 2 Aug 71.
d.	MIL-STD-188-311	Technical Design Standards for Frequency Division Multiplexer, 10 Dec 71.
e.	MIL-STD-188-313	Subsystem Design and Engineering Standards and Equipment Technical Design Standard for Long Haul Communication Transversing Microwave LOS. Radio and Tropospheric Scatter Radio, 15 Mar 73.
f.	MIL-STD-188-340	Equipment Technical Design Standards for Voice Order Wire Multiplex, 21 May 71.
g.	MIL-STD-188-342	Standards for Long Haul Communications Equipment Technical Design Standards for Voice Frequency Carrier Telegraph (Fsk), 29 Feb 72.
h.	MIL-STD-188-346	Standards for Long Haul Communications, Equipment Technical Design Standards for Analog End Instruments and Central Office Ancillary Devices, 30 Nov 73.

i.	MIL-STD-188-347	Equipment Technical Design Standards for Digital And Installments and Ancillary Devices, 29 Mar 3.
j.	MIL-STD-1327	Selection of Flange, Coaxial and Waveguide, and Coupling Assemblies, 15 Jan 68.
k.	MIL-STD-1328	Selection of Coupler, Directional (Coaxial and Waveguide), 15 Jan 68. Selection of Waveguides, Rectangular, Ridged and Circular, 16 May 70.
l.	MIL-STD-1381	Technical Electronic Terms and Definitions, 15 Aug 72.

2.2 Military Handbooks

m.	MIL-HDBK-232	Red/Black Engineering-Installation Guidelines, 14 Nov 72.
n.	MIL-HDBK-411	Facility Design Handbook for Long Haul (DCS) Power and Environmental Control for Physical Plant, 21 May 71.
o.	MIL-HDBK-416	Facility Design Handbook for Line-of-Sight Microwave Communications {Proposed).

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[1] Copies of these reports are available from the National Technical Information Service, Operations Division, Springfield, Va. 22151. Order by indicated accession number.

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CHAPTER3

TERMS AND DEFINITIONS

3.1 Term and Definitions are located in MIL-Std. 188-120.

3.2 SYMBOLS

In the following list the English alphabet precedes the Greek alphabet, and lower-case letters precede upper-case letters. As far as possible (without contradicting established asage, upper-case letters have. been used for quantities expressed in decibels. When the upper-case symbol is the decibel equivalent of a lower-case symbol, they may be listed together.

a	Effective earth radius (km)
$a_1, 2..$	Effective earth radius used in irregular terrain diffraction calculations (km)
a_o	Actual earth radius (6370 km)
a_a	Effective radius used in diffraction calculations
a_r	Effective radius used in two-horizon diffraction calculations (km)
a_t	Effective radius used in two-horizon diffraction calculations (km)
A	Attenuation relative of free space(dB);or excess propagation attenuation (4,2.12); antenna area; true area of reflector (4.4. 57); parameter in feeder echo noise calculations
A_a	Median atmospheric attenuation (dB)
A_C	Circulator /Duplexes loss, dB
A_{cr}	Calculated attenuation relative to free space (d B); reference attenuation
A_{ds}	Mixed mode attenuation (scatter and diffraction) (dB)
$A_d(0.9999)$	Diffraction attenuation for worst hour (dB)
A_{diffr}	Diffraction attenuation (4. 4. 24)
A_i	Isolator loss (dB)
A_{id}	Diffraction attenuation (irregular terrain) (dB)
A_f	Forward feeder attenuation (dB)

A_k	Diffraction attenuation (single obstacle) (dB)
A	Maximum tolerable attenuation (dB)
A_r	Worst-hour median attenuation (dB) ; reverse feeder attenuation (dB)
A_{rd}	Diffraction attenuation (smooth terrain) (dB)
$A_s(0.9999)$	Scatter attenuation for worst hour (dB)
A_{tl}	Transmit transmission line attenuation (dB)
$A(\theta, \rho)$	Single-obstacle diffraction function (dB)
$A(v, 0)$	Single-obstacle diffraction loss (dB)
$A(v, \rho)$	Single-obstacle diffraction loss (dB)
b	Parameter used in residual height gain and diffraction calculations (in degrees) ; also bandwidth in Hz, kHz, or .MHz
b_b	Highest baseband frequency in MHz (fig. 4. 2-8)
b_c	Voice channel bandwidth in kHz
b_{if}	Intermediate frequency bandwidth in kHz
b_{rf}	RF bandwidth (MHz) ; baseband width (kHz)
B, B_{rf}	Bandwidth; intermediate frequency predetection bandwidth in dB. ($B = 10 \log b$; $B_{if} = 10 \log b_{if}$)
B_b	Baseband bandwidth (kHz)
B_{0s}	Parameter used in irregular terrain diffraction calculations
B_{IF}	Receiver IF bandwidth
B_{rf}	Predetection RF bandwidth (dB)
B_t	Parameter used in two-horizon diffraction calculations

B_r	Parameter used in two-horizon diffraction calculations
B_o	Paramerter used in two-horizon diffraction calculations
$B(K, b)$	Parameter used in two-horizon diffraction calculations
C	Factor used in time availability estimates; also carrier power (ususally) in milliwatts)
$C_{o1,2}$	Parameter related to residual height gain function and diffraction calculations
c	Difference in longitude of the terminals (4.4.9); carrier level (4.5.20)
C_{ot}	Irregular terrain diffraction parameter
C	Irregular terrain diffraction parameter
$C_1(K_{1,2}b)$	Parameter used in two-horizon diffraction calculations
d	Great circle path distance (km); also used in statute and nautical miles (4.4.9)
d_e	Effective distance (km)
$d_{L1,2}$	Distance to horizon (km)
d_{sr}	Distance used in irregular terrain diffraction calculations (km)
d_{st}	Distance used in irregular terrain diffraction calculations (km)
d_{Lo}	Parameter used in estimating variability
d_{sl}	Parameter used in variability calculations
D	Antenna (meters)
D_o	Antenna diameter (feet)

D_s	Distance between radio horizons (km); width of diffracting obstacle
D_{Lo}	Parameter used in variability calculations
e, e_{max}	Field strength (dB) (4.4.48)
$e_{s1,2}$	Antenna site elevation above mean sea level (km)
e_s	Saturation vapor pressure of the atmosphere, in millibars
E	Field strength (dBu); secondary field (dB) (4.4.57)
ERP	Effective radiated power
f	Frequency in MHz; carrier frequency; effective noise factor
f_1	Lowest frequency in baseband
f_m	Highest baseband or maximum modulation frequency
F, F_r	Receiver noise figure (dB); noise factor (4. 5. 20)
$F(x_{1,2})$	Function used in diffraction calculations
$F(\theta d)$	Scatter attenuation function (dB)
F_{am}	Median of hourly values of F_a within a time block (dB)
g	Power gain of an antenna (4. 4. 47); also a <u>qualitative</u> symbol denoting grade of source (4. 2. 13. 5)
$g(q,f)$	Frequency correction factor, variability estimates
G	Antenna gain in dB (4.4. 47)
$G_{1,2}$	Free-space antenna gain above isotropic (dB)

G_P	Path antenna gain (db)
$G(h_{1,2})$	Residual height gain function
$G(x)$	Function used in diffraction calculations
h	Parameter used in diffraction calculations (4. 4. 20)
h_0	Parameter used in scatter calculations
$h_{el, 2}$	Effective antenna heights (meters)
h_g	Elevation of antenna feed point above surface (4.4. 21)
$h_{gl, 2}$	Antenna height above ground (in meters - 4. 2; km - 4,4)
$h_{L1,2}$	Horizon elevation above mean sea level (km)
h_s	Common horizon elevation above mean sea level (4. 4.3. 9)
$h_{sl,2}$	Antenna height above mean. sea level (km)
$\bar{h}_{1,2}$	Residual height gain function
H	Horizontal polarization
H_0	Frequency gain functior (db)
I_d	Median diversity improvement in dB
I_P	Pre-emphasis improvement in dB
I_{te}	Threshold antenna improvement in dB
IF	Intermediate frequency
k	Effective earth’s radius factor (a/a_o)

k	Boltzman's constant = 1.3806 x 10^{-23} joules/° kelvin
k	$2\pi/\lambda$ (4.4.20)
kTb	Thermal noise power; Johnson noise
K	Parameter related to residual height gain function and diffraction calculations
$K(a_t)$	Irregular terrain diffraction parameter
$K(a_r)$	Irregular terrain diffraction parameter
$K(a_{1,2})$	Parameter used in single obstacle diffraction calculations
$K(a)_{1,2}$	Parameter used in two-horizon diffraction calculations
K_s	Parameter used in two-horizon diffraction calculations
$\log_{10}$	Logarithm to the base 10
L	Transmission loss (dB); transmission loss in free space (4.4.59)
L_b	Basic transmission loss (dB)
L_{bf}	Basic free-space transmission loss (dB)
$L_b(q)$	Hourly median basic transmission loss not exceeded during q% of all hours of an average year (dB)
L_{bcr}	Reference value of basic transmission loss (dB)
L_{bsr}	Basic transmission loss (forward scatter)
L_c	Antenna circuit losses in dB
L_{gP}	Loss in path antenna gain, or multipath coupling loss (dB)
L_ℓ	Sum of all transmission line losses in dB between antenna and transmitter and receiver
L_i	Transmission line length, receiver

L_T	Transmission line length, transmitter
M_O	Auxiliary constant for all time-invariant or specified terms in the system equation
n	Radio refractive index; number of voice channels; noise power (usually in picowatts)
n_e	Equipment inter modulation noise in pWO
n_f	Total feeder echo noise in pWO
$n_{f(rec)}$	Receiver feeder echo noise in pWO
$n_{f(trans)}$	Transmitter feeder echo noise in pWO
n_P	Median path intermodulation noise in pWO
$n_t, n_t(0.5,0.5)$	Thermal noise (usually in picowatts)
n_T	Total median noise in pWO
$n_y(0.5)$	DCA noise allowance
nlr	Numerical RMS noise loading ratio; NLR = 20 log nlr
NLR	RMS noise loading ratio in dB
N	Number of voice channels; noise; refractivity
N_O	Minimum monthly mean surface refractivity referred to sea level
$\bar{N}_o$	Average minimum monthly mean surface refractivity referred to sea level
N_S	Surface refractivity (N-units)
$\bar{N}_s$	Average monthly mean surface refractivity
NPR	Noise Power Ratio

P	Height of irregularity on reflector surface (4. 4. 58)
$P_{mr}(g)$	Operating noise threshold (4.2.9)
pf	Numerical peak factor; PF = 20 log pf
PF	Baseband peak-to-RMS voltage ratio in dB; generally assumed to be 13.5 dB
P	Pressure in millibars (4. 4. 3)
Pa	Power available at terminals of a loss-free antenna (dBW)
P_t	Power radiated, after allowance for line lasses, etc.; transmitter power (dBW)
P_{ta}	Power supplied to input terminals of a loss-free transmitting antenna
P_{ra}	Power available at the output terminals of a loss-free receiving antenna
P_m	Operating noise threshold; minimum required hourly median wanted carrier level (dBW)
P_r, $P_r(0.5, 0.5)$	Power available at the receiver input in dBW.
P_o	Specified transmitter power (dBW)
P_{tcr}	Power corresponding to the reference value of basic transmission loss (dBW)
q	Time availability; time fraction
Q(z)	Service probability
r	Radius of curvature of an obstacle (km) ; echo amplitude
$r_{1, 2}$	Parameters used in scatter calculations

R	Hourly median single-receiver carrier-o-thermal noise ratio; grade of service
R_r	Specified hourly median predetection RMS carrier-to-RMS noise ratio; grade of service
R_{ro}	Worst-hour carrier-to-noise ratio (dB)
R(0.5)	Function used in combining scatter and diffraction losses (dB)
R(0.9999)	Hourly median wanted pre-detection carrier-to-noise ratio exceeded for 99.99% of all hours in an average year (4.2.13.5)
$R_r(g)$	Predetection hourly median carrier-to-thermal noise ratio (dB) required to provide a grade of service characterized by g.
RH	Relative humidity expressed as a fraction (4.4.3.1)
RL_i	Receive return loss, dB
RL_t	Transmit return loss, dB
RMS	Root-mean-square
s	= Co/Bo path asymmetry factor
S/D	Siganal-to-distortion ratio in dB (feeder echo noise calculations)
S/N_f	Signal-to-feeder echo noise ratio in dB
s/N_P	Signal-to-path inter modulation noise ratio in dB
S/N_t, $S/N_t(0.5,0.5)$	Signal-to-thermal noise ratio expressed in dB

T, T_o	Temperature (°K); ambient temperature (°K)
U(vp)	Diffraction parameter (dB)
v	Diffraction parameter; percent velocity of propagation
V	Velocity of propagation
V(q)	Long-term variability function (dB)
V(0.5)	A function of climate type used in variability calculations
X	Parameter related to the resudual height gain function and diffraction calculations
$X_{0, 1, 2}$	Parameters used in irregular terrain diffraction calculations
$\Delta x_{1,2}$	Parameters used in diffraction calculations
	Component of the variability function
z	Standard normal deviate
Z, Z′	Great circle angular distance
$Z\acute{O}_{rc}$	Service probability term
$\propto$	Reduction in gain caused by irregularities in reflector surface (4. 4. 58); inside width of broad wall of a waveguide (4.4. 65)

α_o	Angle between transmitted radio ray and the line connecting the radio terminals (at terminal A) (radians)
β_o	Angle between transmitted radio ray and the line connecting the radio terminals (at terminal B) (radians)
δ	Per-channel RMS frequency deviation (kHz)
δf	RMS per-channel deviation (kHz)
δF	RMS carrier deviation (kHz)
Δ	Path delay (intermodulation noise calculations)
ΔF	Peak carrier frequency deviation (kHz)
$\Delta N/\Delta h$	Refractivity gradient in the first km above the earth (N-units/km)
$\overline{\Delta N}/\Delta h$	Average monthly mean refractivity gradient (4. 4.3. 7)
ϵ	Dialectic constant
η	Efficiency of antenna aperture; nominally 0. 55. (4.4. 47)
η_s	Parameter used in scatter calculations
θ	Scatter or diffraction angle; angular distance (radians) ; angle between incident and reflected rays on flat reflector. (4.4.59)
$\theta_{e1,2}$	Takeoff angle; horizon elevation angle (radians)
θ_n	Beamwidth between first null points (4. 4, 53)
θ_u	Antenna beamwidth (4. 4. 48)
λ	Wavelength
λ_c	Wavelength of cutoff frequency in a rectangular guide (4.4.64)
ρ	Rounding coefficient; index of curvature
σ	Ground conductivity
$\sigma_c(q)$	Standard deviation of transmission loss estimates

ϕ	Horizontal angle between main beam and overreach path; latitude (4. 4. 9) ; component of phase lag due to diffraction over an ideal knife edge
ϕ_j	The phase lag of the diffracted field for the j^{TH} ray over an isolated perfectly conducting rounded obstacle
τ	Echo delay time in seconds
Ω	Antenna half-power beam width
ω	Angular velocity
ω_τ	Radian delay

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CHAPTER 4

SYSTEM DESIGN

4.0 Introduction

4.0.1 Chapter 4 contains the essential information for designing transhorizon radio systems, with the exception of facility design criteria (such as detailed information on physical plant layout, primary power, tower and antenna structure, safety, etc.) which are presented in Chapter 5.

4.0.2 Section 4.1 outlines the information needed on functional requirements and resource limitations; it also discusses the content of the engineering implementation plan which must be prepared as the design effort proceeds. Section 4.2 describes a systematic approach to the selection of sites and routes, based largely on simplified methods for estimating path performance. This provides information for grading of paths so that usable alternatives will not be overlooked. On the basis of this grading, certain paths and sites are selected for additional investigation by a field survey. The field survey techniques and requirements are outlined in section 4. 3. Section 4.4 describes the design of individual links, based on the detailed information on path profiles, site conditions, and other information obtained by the survey party. The considerations include path geometry, propagation mechanisms, local meteorological conditions, potential interference sources, and available equipment. Section 4.5 takes up the problem of integrating the links into a compatible system. This task involves system layout, frequency allocation, intra-system interference and the preparation of system performance predictions.

4.0.3 Chapter 4 is organized as shown in the flow diagrams in section 1.6. Quantitative information necessary for link design is included, primarily in the form of graphs, tables, and worksheets for ease of of application. The necessary calculations involve only simple mathematics, and units and definitions of terms are supplied in the immediate context of the equations. Cross-referencing has been used in cases where descriptive material relative to the same topic appears in more than one place in the text.

4.1 STARTING DESIGN

4.1.1 General

4.1.1.1 The first step in the design of a transhorizon radio system is to obtain several copies of an outline map of the general area to be served by the new system. One or more of these maps can be used to record information relevant to the system as it becomes available. These outline maps can also be made to serve as an index to more detailed information about the system. For example, a grid of larger scale map coverage can be drawn on the outline map; site names and numbers can be shown at their approximate location with more detailed information about the sites provided in tabular form.

4.1.1.2 Functional information about the system must be obtained, such as numbers and types of channels, quality requirements, terminal locations, direction of information flow, compatibility with existing equipment and services, and flexibility for expansion. Uncertainty in functional requirements often translates into additional system costs because increased ranges of flexibility must be designed into the system. Flexibility is very desirable, especially where it can be obtained at very little cost, but often it must be obtained at the expense of other valuable features if resources are limited.

4.1.2 Functional Requirements

4.1.3 Facility Locations

4.1.3.1 Communication centers that are to be connected through the main route should be located as precisely as possible, and the radio terminals along the route that are to be serviced by spur links off the Main route should also be located as accurately as possible. The positions of the radio terminals are a major consideration in determining the optimum routing of the main route

4.1.4 Future Expansion

4.1.4.1 Plans or possibilities regarding future system expansion should be examined. Appropriate planning for the iritial system should include provisions for later expansion or upgrading so that reconfiguration or . new construction can be minimized. Upgrading of the system may necessitate enlargement of buildings, greater air conditioning capacity, increased logistic capabilities (such as primary power), enlargement of terminal sites, and possibly relocation of existing stations or addition of new terminal or repeater sites.

4.1.5 Channel Parameters

4.1.5.1 Information on numbers and quality of channels, bandwidths, and direction of traffic flow is needed to determine frequency spectrum and supportive requirements. The format provided by Worksheet 4. 1-1 can be used to list such information, along with estimates of RF spectrum requirements which are provided by figure 4.2-7 (in section 4.2.16) as a function of the number of voice channels. The necessary spectrum space may be twice that for the RF path since frequency diversity may be required to meet design objectives for transhorizon links. Channels needed to carry traffic over the link will usually be assumed equal in either direction.

4.1.6 Resource Limitations

4.1.6.1 Limitations imposed by available resouces must be studied to determine feasibility. These limitations include economic restraints, real estate availability, construction limitations and operational deadlines, primary power limitations, and spectrum reliability. Some of these items will be treated in more detail in subsequent sections.

4.1.7 Economic Restraints

4.1.7.1 The initial system cost estimates are important because requests for final project funding may be based on these estimates.

Channel requirements for traffic

from site__________ to site__________

(a) Current Requirements

Type of Channel	Number of Channels	Baseband per Channel	Quality	Equivalent voice channels per information channel	Number of equivalent voice channels	Baseband Spectrum
Voice (Telephone)						
Voice (Facsimile)						
Voice (VFTG Tone Pack)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						
High Quality Audio						

Totals ________ ________

Link channel requirements rounded to the next higher nominal value[1] ________

Transmitter RF bandwidth[2] ________

(b) Requirements for Future Expansion

Voice (Telephone)						
Voice (Facsimile)						
Voice (VFTG Tone Pack)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						
High Quality Audio						

Totals ________ ________

Link channel requirements rounded to the next higher nominal value[1] ________

Transmitter RF bandwidth[2] ________

[1] Nominal values are 24, 48, 60, 72, 120, 180, 300 and 600.

[2] Estimate using figure 4.2.7.

WORKSHEET 4.1-1 FORMAT FOR RECORDING CHANNEL REQUIREMENTS FOR FDM-FM SYSTEMS

The design engineer should keep cost estimates updated as the design proceeds, so that fiscal planners have sufficient time to modify funding requests, if need be. Multiplexlng equipment costs are nearly proportional to the number of channels over the path, whereas the price for increased effective radiated power increases in an exponential manner. The cost for diversity equipment, waveguide, dehydrators, heating and air conditioning etc., are relatively fixed and will be similar at each site. Building costs may vary widely over the area covered by one transhorizon system, and if construction must be speeded up to meet an operational deadline the costs may escalate rapidly because of premium pay for overtime work.

4.1.8 Real Estate Availability

4.1.8.1 There are usually many factors limiting the number of suitable transhorizon sites. Some of these factors are blockage by terrain or terrain clutter (without using unacceptably high antennas supporting structures), prior use of suitable sites, political boundaries, potential interference with other radio systems, local zoning regulations, ease of access, and environmental aspects. Site availability investigations should include a check into possible site security problems. Although the possibility of theft, vandalism, or other damage exists at all sites, some may be particularly vulnerable and require special and substantial considerations. Site development costs will generally be substantially lower if a site can be found on government-owned lands, rather than on private property.

4.1.9 Construction Limitations

4.1.9.1 The most common and important construction limitation is that of tower height and antenna size. Structures exceeding a given height may violate local ordinances for a number of reasons. If a link will be near an airport, or in established air corridors, the site proposed may not be approved if it requires the use of high towers or other large structures. Similar restrictions may be encountered in or near residential areas, or in certain scenic areas. A very remote site may involve special construction restrictions if access roads will not permit heavy equipment (e. g., cranes) to reach the site. Certain types of construction materials may be unavailable or undly expensive in some areas, and special types of construction may be necessary because of local climatic conditions, as in the arctic or extremely wet regions, or in regions subject to earthquakes.

4.1.10 Primary Power Limitations

4.1.10.1 Definite information on the availability of commercial electric power will probably not become available until the first site survey is completed. At this stage of the design, it will be sufficient to determine from available reference sources or contacts in the area of the proposed system whether or not such power is likely to be available. If power for a site must be provided by engine-generator sets, the problem of hauling fuel to the site must be considered, as well as the additional expense involved for buildings, equipment, fuel storages and operating personnel. In some cases, this may place a limitation on the maximum usable transmitter power.

4.1.11 Frequency Spectrum Availability

4.1.11.1 The designer should work through the applicable Frequency Management Office to determine what blocks of frequencies can be made available for the proposed system. Despite the lack of specific information on system parameters and routing, it is important that early contact be made with this office, since at least a preliminary commitment must be available prior to the feasibility study. The designer should assemble as much information on the proposed system as possible prior to this initial contact, e. g., the geographical area involved, approximate locations of terminals or installations to be served, and probable RF power and bandwidth requirements., At least general information on the size of antennas and type of terminal equipment will probably also be available at this time. Further information on the type of information generally required for frequency allocations is given in section 4. 1.14 but the exact format for a particular case should be obtained from the Frequency Management Office. Because of the high radiated power and distances involved in transhorizon systems, in many cases more than one nation may be involved in the frequency allocation negotiations. This can result in considerable delay in obtaining the desired assignment, so it is very important that the system designer work closely with the Frequency Management Office from the beginning of the design effort.

4.1.12 Radio Frequency Assignment

4.1.13 General

4.1.13.1 Frequency assignments are made through negotiations with the frequency-controlling agencies of the countries where the system is to be intalled. These negotiations are conducted by the Military Communications-Electronics Board (MCEB) of the Department of Defense. In carrying out these negotiations, the MCEB utilizes the services of portions of certain agencies established for this purpose: the Frequency Allocation Panel, U.S.(FAPUS); the Frequency Division of the Defense Communications System Directorate; the Communications-Electronics Directorate of the Joint Chiefs of Staff (J-6); and the Frequency Branches of the Communications-Electronics Divisions of the Unified Commands. The system engineering function in this process is to provide the necessary technical inputs for the negotiations. For transhorizon radio systems, the inputs are dictated by the Military Standards 188 Series [59] and are contained large part in MIL-STD 188-313.

4.1.14 Application for Frequency Allocation

4.1.14.1 Table 4.1-1 (adapted from table 4-40 of [67] contains a list of items usually specified in applications for a frequency allocation. Each item of the list that is pertinent to transhorizon radio frequency requirements should be included in the application.

4.1.15 Deadlines and Schedules

4.1.15.1 Guidelines for the design of a transhorizon system will usually include one or more deadlines for the completion of various tasks. Such deadlines are planning for procurement of construction materials, scheduling employment of personnel, and establishing lead time necessary for sub-contracting, equipment procurement, and related efforts. To insure that planning objectives are realistic, a table of events for the project should be prepared and made available for early review. This scheduling may be prepared using a flow chart or a simple scheduling chart such as the one shown as worksheet 4. 1-2, which is based on one calendar year. As the design progresses scheduling in more detail will be required along with timely modifications.

4.1.16 Engineering Project File

4.1.16.1 The Engineering Project File is a compiled report of all factors that contribute to the development of the transhorizon radio system, from the initial proposal to the final system acceptance. It should be started with the initial survey of functional requirements and resource limitations. It will primarily be an organization of information (notes, letters, maps, tables, profiles, sketches, etc.) necessary for the determinations that must be made during the feasibility study. It should be as complete as possible, since it will be referred to frequently in later stages of the design as a basis for decision and implementation. This file will also be used as the basis for preparing the documentation normally required to obtain approval and funding of the project by higher headquarters.

Table 4.1-1 Procedure for Frequency-Allocation Application [67]

No.	Item	Comments
	Proposed Allocation	
1	Frequency band	Enter the frequency limits between which it is technically feasible to operate the equipment in performance of its required function.
2	Function	Describe the function to be performed by the equipment as specifically as possible; i.e., multi-channel communications.
3	Purpose and method of operation	Describe the purpose and method of operation; i.e., to provide transhorizon transmission by tropospheric scatter or diffraction.
4	Geographical area	State geographical area or points of use actually required under joint and service plans: Give geographical coordinates or terminal locations.
5	Extent of use	A narrative statement describing the number of equipments and/or systems normally utilized in a given area of operation. The number is the number of terminals and relay stations in the system. They are to be operated continuously.
6	Degree of protection required	List any special considerations with respect to interference vulnerability, special features incorporated, or techniques employed which make the equipment less susceptible to interference from other equipments. Give receiver tuned cavity filter characteristics.
7	Target date for operations	Indicate the date on which it is expected that operational use of the equipment or system will occur.
8	Previous allocation and/or equipment to be changed or superseded	Identify the allocation and/or equipment affected and describe the change or supersession.

Table 4.1-1 Continued

	Transmitter	
9	Nomenclature of transmitter of system	List joint nomenclature if available, i.e., AN/GRC-66, or manufacturer's identification. If no nomenclature has been assigned state "NONE".
10	Installation	Indicate type of ship, vehicle, weapon, aircraft, missile, or place where installed and whether fixed or transportable; e.g., Air Force Base, ground installation, fixed.
11	Actual tuning range and/or operating frequencies	Indicate maximum tuning range for satisfactory operation and/or specific stop frequencies which can be employed, and optimum operating frequencies: All optimum operating frequencies should be stated.
12	Type emission	List type of emission. For transhorizon FM systems, this is F3.
13	Bandwidth	List the necessary bandwidth for communication. For DCS transhorizon systems, the modulation type will be frequency modulation and the necessary bandwidth is given as a function of top modulating frequency, f_m (highest baseband frequency) and peak carrier-frequency deviation, ΔF: $b = 2(\Delta F + f_m)$ Hz (or kHz).
14	Pulse repetition	Applicable only to pulse modulation systems.
15	Pulse width	Applicable only to pulse modulation systems.
16	Modulation and coding	Indicate type of modulation, if any, and give general description of any coding system. For DCS transhorizon systems FDM-FM, list "FM with single-sideband suppressed carrier, frequency-division multiplexing."
17	Power output	State power output to the antenna in watts and whether it is average, peak, or root mean square.
18	Frequency control	Indicate means for obtaining frequency control.

Table 4.1-1 Continued

No.	Item	Comments
19	Stability	Indicate frequency stability of transmitter under normal operating conditions. Minimum stability for DCS systems is given in Mil-Std 188-313 [a]
20	Antenna	a. Indicate type antenna, e.g. horn-feed with parabolic reflector. b. Indicate whether antenna is fixed, directional or scans horizontally or vertically and rate of scan. In transhorizon systems the antenna is fixed and directional. c. State the antenna gain, e.g. 49.0 dB relative to isotropic d. State the beamwidth, horizontal and vertical angles in degrees at half-power points, e.g. horizontal 0.7°, vertical 0.7°.
21	Status of development	Indicate present status of proposed equipment or system. For FDM-FM transhorizon systems, state, "Development complete. Ready for installation."
22	Target date for operational availability	Indicate the expected target date when the equipment will be available for operational use.
	Receiver	
23	Nomenclature	List joint, manufacturer's, or other applicable nomenclature, e.g. AN/GRC-66.
24	Installation	State whether installation is integral with transmitter, if not, give installation data as fixed or portable. In DCS transhorizon FDM-FM systems the receiver installation is integral with the transmitter installation.
25	Actual tuning range and/or operating freq.	Indicate actual frequency range or specific frequencies over which receiver can operate successfully.
26	IF frequency	Indicate frequency of "IF" amplifier. [a] states that the IF center frequency shall be 70 MHz.
27	Selectivity	List the overall bandwidths of the receiver at 3, 20, and 60 dB points on selectivity curve. Use $B_{IF} = 2(\Delta F + f_m)$ Hz (or kHz), where B_{IF} is the IF bandwidth, ΔF is the peak carrier-frequency deviation, and f_m is the highest modulating frequency, for the 3-dB points. Find the 20- and 60-dB points from manufacturer's data.

Table 4.1-1 Continued

28	Sensitivity	State the minimum signal level in dBm required for acceptable or standard receiver input signal. Indicate the noise figure of the receiver in dB. For operational allocation, state the minimum ratio of desired signal to undesired signal necessary for operation of the system. This ratio should be at least 60 dB.
29	Stability	Indicate receiver frequency stability under normal operating conditions.
30	RF Preselection	State whether RF preselection is employed, and type of preselection used, e.g. tuned cavities.
31	Frequency range of local oscillator	Where local oscillator is tunable, give frequency range. Since this will vary from manufacturer to manufacturer, this information will have to be obtained from the manufacturer's specification.
32	Antenna	(a) Indicate whether antenna is same as for transmitter. For transhorizon systems, it is. (b) State antenna gain in dB relative to isotropic. (c) Beamwidth in degrees for azimuth and vertical, e.g. horizontal 0.7°, vertical 0.7°. (d) State polarization to be used.
33	Status of development	Indicate present status of proposed equipment or system. This should be the same statement as for the transmitters, e.g., "Development complete. Ready for installation."
34	Target date for operational availability	Indicate the expected target date when the equipment will be available for operational use. This date should coincide with the target date for operational availability of the transmitters.
35	Remarks	Add any information believed to be of assistance in evaluating the circumstances under which the proposed system or equipment will be operated. As a minimum, this should include reference to current standards for frequency assignment [a].

Engineering Implementation Plan Schedule

SCHEDULE SUMMARY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Desk Study												
First Site Survey												
Route and Site Selection Review												
Link Design												
Final Site Survey												
System Analysis												
Equipment Specification Preparation												
Preparation of Final Cost Estimates												
EMC Site Survey and /or EMC Study												

Worksheet 4.1-2 Simple design schedule sample.

4.1.17 Determine Engineering Project File Content

4.1.17.1 All design data that are developed and used for system decisions should be included in the Engineering Project File.

4.1.18 Determine Basic Feasibility

4.1.18.1 A decision on the feasibility of the proposed system is usually made at two points in the design process. The first is after the completion of the initial survey of functional requirements and resource limitations (see section 4. 2). The final feasibility evaluation should be made prior to actual commencement of site and equipment procurement. At that time, detailed studies will have been completed (sections 4.3, 4.4, 4.5), expected performance of the system will be reasonably well-known, and an accurate cost estimate of preparing each site will have been made. Along the way, however, the design engineer must verify that the limitations previously investigated, with regard to resources, do not impose insurmountable barriers.

4.1.19 Review Requirements vs. Limitations

4.1.19.1 The design engineer should review the information gathered on requirements and limitations to insure its completeness, so that the appropriate authority may review it to determine the soundness of the system proposal. Alternatives, if they exist, should not be neglected, e. g. , if an existing link, or links, can be incorporated into the design through upgrading and fulfill the requirements of the proposed system, this possibility should be documented. Finally, a summary of the most essential EPF data should be duplicated for dissemination to persons involved in the design project at the management or command level.

4.1.20 Review Requirements vs. Limitations

4.1.20.1 The design engineer should review the information gathered on requirements and limitations to insure its completeness, so that the appropriate authority may review it to determine the soundness of the system proposal. Alternatives, if they exist, should not be neglected, e.g. if an existing link, or links, can be incorporated into the design through upgrading and fulfill the requirements of the proposed system, this possibility should be documented. Finally, a summary of the most essential EIP data should be duplicated for dissemination to persons involved in the design project at the management or command level.

4.2 STUDY OF ROUTE ALTERNATIVES

4.2.1 General Considerations

4.2.1.1 Transhorizon radio links are a practical method for connecting communication centers separated by certain types of barriers. These barriers may include areas forbidden for political or administrative reasons, broad expanses of water, marsh, desert, jungle, and high or inaccessible mountains. Relays on either side of such a barrier may involve radio line-of-sight links, beyond-the-horizon links, and non-radio links, with either passive or active repeaters. Unless relay sites are already developed or mandatory, they should be selected with these two considerations in view:

a. to provide a satisfactory communications link across the barrier, and

b. to minimize the total cost of developing and maintaining new sites.

4.2.1.2 The necessity for maps to describe the location of relay sites and terminals relative to coastlines, rivers, major roads, cities, and major landmarks (as well as with coordinates of latitude and longitude) was discussed in section 4. 1. 1. The boundaries of restricted or inaccessible areas should be shown also, and it is a good idea to use two sets of boundaries if the barrier is a natural, rather than a political, obstacle. The outer boundary should enclose portions of the area that are possible to reach and service, although with some difficulty or expense; the inner boundaries should enclose regions that are considered completely impractical for site development. Some areas may be eliminated from consideration because of political, administrative, or economic reasons.

4.2.2 Types and Sources of Maps

4.2.2.1 Accurate and detailed topographic maps are essential for selecting potential relay or terminal sites. These maps may be of two types: small-scale for preliminary office surveys, and large-scale for more detailed evaluation and preparation of path profiles. The small-scale maps should be of a scale 1: 250,000 or less; the large-scale maps should have scales on the order of 1: 25,000 to 1:63,000 000 with contour intervals of around 10 feet (3 meters).

Maps can be obtained from the followinq,U.S. agencies

Director
Defense Mapping Agency Topograpic Center
Washington, 20315

Sales Office
U.S. Geological Survey
Washington, D. C. 20305 (also Denver, Colorado 80225)

Map Information
U. S. Coast and Geodetic Survey
Washington, D. C. 20350

U.S. Navy Hydrographic Office
Washington, D. C. 20390.

Other map sources include foreign government services, such as the British Ordnance Survey; national agricultural, forest, and soil conservation departments; and state highway agencies. Recent aerial photographs of an area can be useful in checking for new building construction, changes in major highway routing, and other details that may not be shown on the latest available topographic maps.

4.2.3 Selection of Potential Sites

4.2.3.1 There are a number of practical factors that will influence the development and use of a site. While studying the maps to determine possible sites, the designer should bear in mind the-following:

a. Availability of land in some areas only government-owned lands can be used.

b. Ease of access.

c. Availability of commercial electric power.

d. Possibility of construction restrictions, as in areas near airports, on mountain tops, in resort areas, in or near national parks or wilderness areas, or due to zoning regulations.

e. Likelihood of sufficient level ground for buildings and towers.

f. Interference potential - nearby cities, industrial plants, etc.

g. Climate of the area - sites on high mountains may be snowbound for months at a time; lowland sites may be flooded by seasonal heavy rains.

h. Coastal sites are more likely to experience anomalous propagation than are inland locations.

The terminal stations of transhorizon radio systems should be located close to the users, but in most cases a microwave link or land line will be required between the communications center and the beyond-the-horizon station. Co-location of the terminal sites with the communications center would frequently result in severe restriction on the choice of a site, and preclude taking advantage of terrain features conducive to efficient radio propagation. Most communications centers will be in or near cities or town, which are usually in low-lying areas with respect to the surrounding countryside. Transhorizon terminals and relay stations should, if possible, be located to provide a negative or zero horizon angle in the direction of the desired path with large positive horizon angles (providing terrain shielding) in all other directions. In many cases the benefits of reduced interference from a site so located will outweigh the increase in path attenuation.

4.2.4 Selection of Potential Routes

4.2.4.1 After tentative site selections have been made, route selection becomes a matter of determining the best of the several routes available using various combinations of the selected sites. A route consists of several links in tandem. Generally, the shortest route should be considered first, but in many cases a logcr route may offer important advantages, such as bctter horizon angle. or lower site development and operating costs.

4.2.4.2 The horizon angle of the radio beam from each antenna is the angle between a horizontal line extending from the center of the antenna and a line extending from the same point to the radio horizon (see figure 4.2-1). It is an important parameter in the (estimation of transmission loss (see sec. 4.2.12). Generally, negative horizon angles are preferable because of the relationship of the scatter or diffraction angle (or angular distance), which is the angle between the transmitted and received horizon ray. Any increase in horizon angle will result in a corresponding increase in scatter or diffraction angle, and since path attenuation usually increases with this angle, it follows that large positive horizon angles (such as illustrated by θ_{e1} in figure 4.2-1) result in greater path attenuation than small positive horizon angles, or negative horizon angles (such as θ_{e2}), Horizon angles can be computed from large-scale topographic map data (see sec. 4.4.7), but can also be determined approximately by optical surveying methods during the field surveys.* The order of precedence in selection is as follows: Sites with the largest negative horizon angles are the first choice; sites with the largest positive angles are the last choice. Notc the. 6_{el} (in figure 4.2. 1) could be reduced by increasing the antenna tower height at teminal 1, and this would also result in a smaller scatter angle for this radio path.

In a well-mixed atmosphere, the refraction of light rays is somewhat less than the refraction of radio rays (k = 1. 18 compared to 1.33), but errors in determining radio, clearance from optical measurements should not exceed 3 meters if the distance is not over about 8 km [54, page 85].

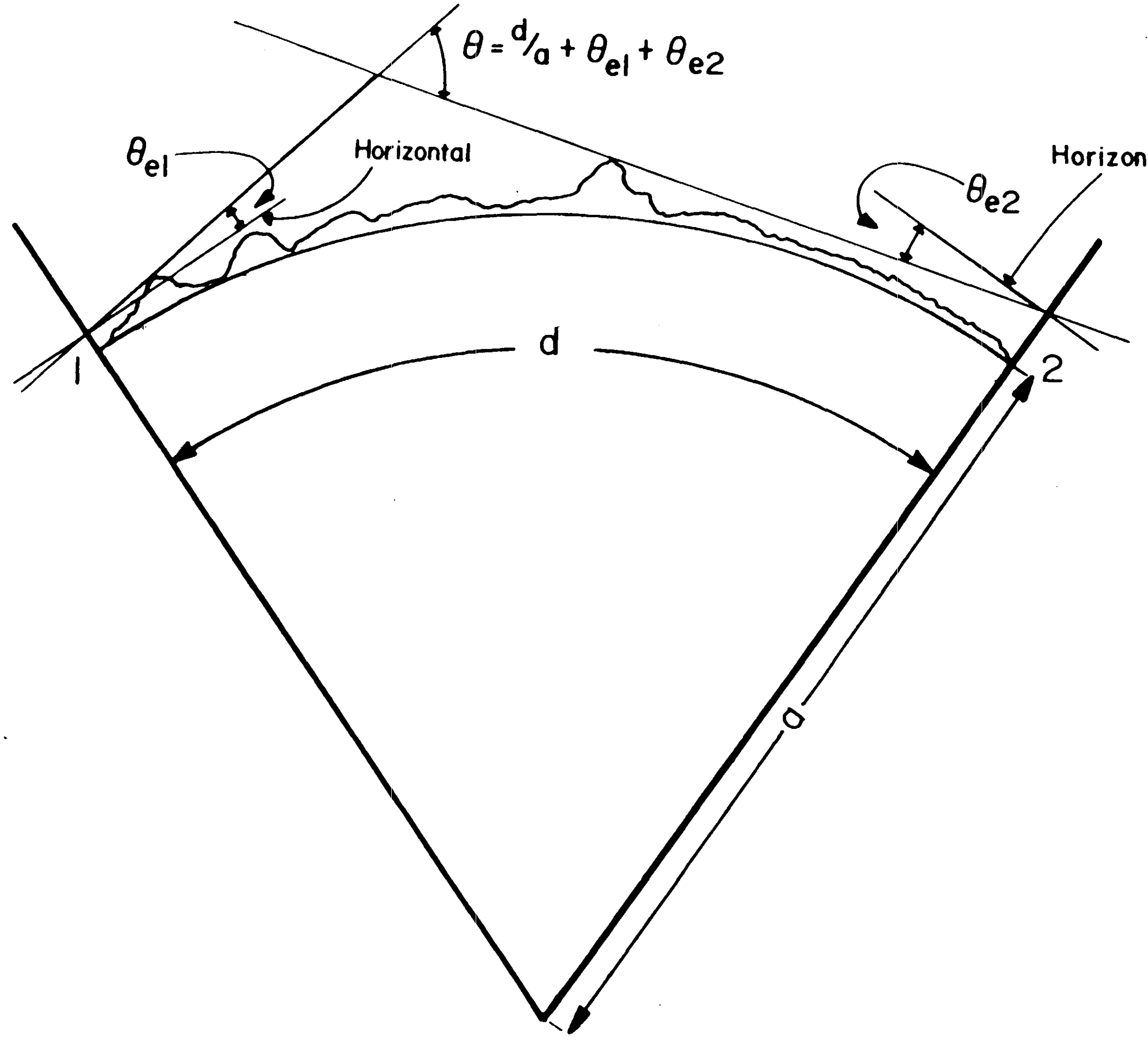

Figure 4.2-1 Positive ($_{el}$) and Negative ($_{e2}$) Horizon Angles, and their Relationships to the Scatter (or Diffraction) Angle ( ), where a = effective radius of the earth, d = great-circle distance between sites, and where all angles are in radians.

4.2.4.3 The effect of slight variations in path length is negligible for constant horizon angles; the transmission, loss on a transhorizon link will vary only slightly for changes in path length less than about 16 km (10 miles). In a given area, therefore, it is usually best to select the highest feasible site, which also provides adequate shielding from potential interference, even though this may result in a slightly longer path than some location at a lower elevation.

4.2.4.4 The effect of vegetation on radio propagation is very complex and Difficult to estimate precisely. Sparse growth or bare trees, for example, have less effect than dense woods or trees in full leaf. The safest procedure is to consider trees, shrubs, vines, and high grass or agricultural crops as being impenetrable to radio frequency energy, and consider the vegetation as though it were solid earth. The top of the vegetation, therefore, is used in determining the horizon angles. Most large-scale topographic maps indicate the approximate location of wooded areas; where these are shown on a radio path obstacle, the ground elevation of the obstacle should be increased by about 25 meters for calculations of the horizon angle. This arbitrary allowance for the heights of mature trees in the area should be verified by the field survey party.

4.2.4.5 For preliminary site selection and examination of a number of possible routes, maps at scales from 1:250, 000 to 1:1,000,000 are convenient. However, for the precise plotting of sites and routes and preparation of path profiles as shown in section 4.4.11, the greater details provided by larger scale maps are essential. Route comparison requires only approximate path profiles which can be obtained from the small-scale maps and need contain only the most important terrain features which are the locations and elevations of the potential radio horizons. The distance/elevation data obtained from the maps should be plotted on suitable graph paper which takes into account the earth's curvature (see sec. 4.4.11 for details). The location of the radio horizons can then be determined by use of a straightedge, having assumed a nominal height for the antenna at each site, and the distances from each antenna to its horizon can be estimated. For smooth terrain (or over water surfaces) the horizon angles $0_{el,2}$ in radians can be calculated as a function of the antenna heights $hg_{1,2}$ above the Surface in meters:*

$$0_{el} = -0.000686\sqrt{h_{g1}} \quad \text{radians} \qquad (4.2\text{-la})$$

and

$$0_{e2} = -0.000686\sqrt{h_{g2}} \quad \text{radians.} \qquad (4.2\text{-lb})$$

These formulas are based on an effective earth radius a = 4250 km, which may be considered to be representative of worst-hour conditions (see sec. 4.2.12). The utilization of the horizon angles for initial path loss calculations will also be shown in section 4.2.12.

4.2.4.6 For mountainous terrain, horizon angles are entirely dependent on site location in relation to terrain irregularities and should be estimated from maps and rough terrain profiles. Note again that in (la) and (lb) the heights and hg_1 are hg_2 are

4.2.4.7 On the basis of the horizon angle estimates and ether consi - dsrations available, a route or routes should be selected for more intensive analysis. The next step consists of performing initial trans - missionx loss calculations for these selected routes.

4.2.5 Initial Transmission Loss Calculations

4.2.6 General

4.2.6.1 Route selection is to a large degree based on a comparison of expected performance of various possible routes. This requires at least approximate estimates of transmission loss and performance parameters. In this section radio transmission loss and related terms will be defined, and it will be shown how values of maximum tolerable attenuation can be used as a basis for route evaluation and selection. Only simple calcula- - tions and use of a few graphs are necessary for these initial estimates;

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*Notations such as $\theta_{e1,2}$ will be used at times; they mean that the expressions apply equally to both path terminals or sites usually identified by the indices 1 and 2.

however, it should be realized that these results will be less precise than can be expected from the more complex methods given in section 4. 4. In particular, transmission line losses and related losses due to filters, duplexers, circulators and diplexers, or other coupling or isolating devices, will be neglected (these usually amount to no more than 3dB),

4.2.6.2 A step-by- step procedure for obtaining these initial transmission loss estimates is outlined on worksheet 4.2-1 at the end of this section.

4.2.7 Transmission Loss and Related Terms

4.2.7.1 A number of terms such as transmission loss, propagation loss, or path loss have been used to Characterize the loss between specific points in a radio system. In this handbook we will use only the terms "transmission loss" and "basic transmission loss". Transmission loss is the ratio of radio frequency power radiated from a transmitting antenna to the power available at the receiving antenna terminal . Detailed discussions of various related concepts and parameters may be found in CCIR documents [1], [24] For tropospheric transhorizon links at frequencies generally above 400 MHz, some simplifying assumptions can be made that are explained in the cited references. Basic transmission loss will be discussed in section 4.2.11.

4.2.7.2 Expressed in decibels, the transmission loss, L, over any single radio link is

$$L = P_t - P_a \quad \text{dB}, \qquad (4.2\text{-}2)$$

where

P_t = total power in dBW radiated from the transmitting antenna, after allowance for line losses, circuit losses, and any impedance mismatch.

and

P_a = available power in dBW at the terminals of a loss-free receiving antenna.

4.2.8 Grade of Service and Time Availability

4.2.8.1 A good grade of service and high operational reliability are required for the radio links and systems discussed in this handbook.

Grade of service may be defined by a minimum acceptable ratio of wanted-to-unwanted RF signal, and such a ratio must be available for a specified minimum percentage of all hours of the year. Thus, "satisfactory service" implies not only a certain grade of service free from distortion and interruption, but also a minimum acceptable time availability.

4.2.8.2 For point-to-point transhorizon systems, which are usually subject to rapid fading of the received signals, statistics of hourly median values are used in propagation and performance estimates . Such values are more readily available than statistics of instantaneous values; also, short-term (within-minutes or within-the-hour) fading can be largely compensated for by the use of diversity reception, and other effects are included in the definition of the grade of service in terms of an hourly median required wanted-to-unwanted signal ratio. Since, for the purposes of this handbook, internal receiver or set noise can be used to represent the "unwanted signal", the required ratio may be replaced by a minimum required hourly median wanted Carrier level , P_m.

4.2.9 The Operating Noise Threshold, P_m

4.2.9.1 It is assumed that the minimum required hourly median wanted carrier level, P_m dBW, corresponds to the operating noise threshold P_{mr} (g) dBW defined by the International Radio Consultative Consultative (CCIR) [2]. This threshold, P_m , is the minimum acceptable hourly median value of P_a in (4.2-2) and a method for determining Pm is given subsequently. The condition $P_a < P_m$ is called a threshold failure.

4.2.9.2 Some unwanted signal effects other than set noise can be allowed for with an "equivalent threshold" related to an established wanted-to-unwanted signal protection ratio. Other unwanted signals may be avoided by proper frequency allocations, and by careful design of signals, equipment, antennas, routing plans, and user schedules.

4.2.10 Total Percent Time Availablilty

4.2.10.1 As already noted in paragraph 4.2.8.1, the concept of satisfactory service implies, among other parameters, an evaluation of time availability, i. e., the time during which a given grade of service , is available. Usually, time availability is expressed as a percentage value (e. g., 99.99%), but occasionally it is expressed as a decimal number (e.g., 0.9999). The term "reliability" is also used. Strictly speaking, time availability is a conditional probability, and can be expressed by the product of two factors. One factor is the time fraction during which there is no distortion or other detriments to the grade of service when the available power Pa is greater than the minimum required power level such as P_m, and the other factor is the time fraction for which P_a is greater than P_m.

4.2.10.2 The above considerations apply to a single link. For several links in tandem, the time availability of a given performance parameter can be obtained by convoluting the cumulative distributions of this parameter for the individual links (see, as an example, [75]). The resulting distribution will also be a function of the correlation coefficient between instantaneous parameter values for the individual links, and exact computation can become quite cumbersome even if computers are available. In practice, the time availability of a given grade of service for a system of links in tandem (expressed as a fraction) will be a number between that for the poorest link (having the lowest time availability) and that obtained by multiplying the time fractions for all individual links. The latter method corresponds to the assumption that time variabilities of the individual links are uncorrelated.

4.2.11 Basic Transmission Loss, L_b. , and Path Antenna Gain, G_p

4.2.11.1 The transmission loss between hypothetical isotropic antennas, located where the real antennas are, is a normalized quantity convenient for calculations, and is called the "basic transmission loss",

L_b*. Basic transmission loss in free space, L_{bf} (i. e., in the absence of any terrain, atmospheric, or other effects) is calculated as:

$$L_{bf} = 32.45 + 20 \log_{10} f + 20 \log_{10} d \text{ dB},^{**} \qquad (4.2\text{-}3)$$

or $$L_{bf} = 20 \log (41.93\, fd)$$

where f is in MHz and d is in km. This is one component of the propagation losses that must be overcome in all circumstances. L_{bf} is plotted in figure 4.2-2 and may be determined by linear interpolation between the lines drawn for constant values (L_{bf} = 100 dB to L_{bf} = 165 dB).

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*Frequently, the term “path loss” has been used to mean “basic transmission loss”. If the term path loss is used in this handbook, it is intended to mean exactly basic transmission loss.

** In subsequent formulas it will be assumed that all logarithms are to the base 10, unless specifically stated otherwise. Thus the subscript "10" will be dropped.

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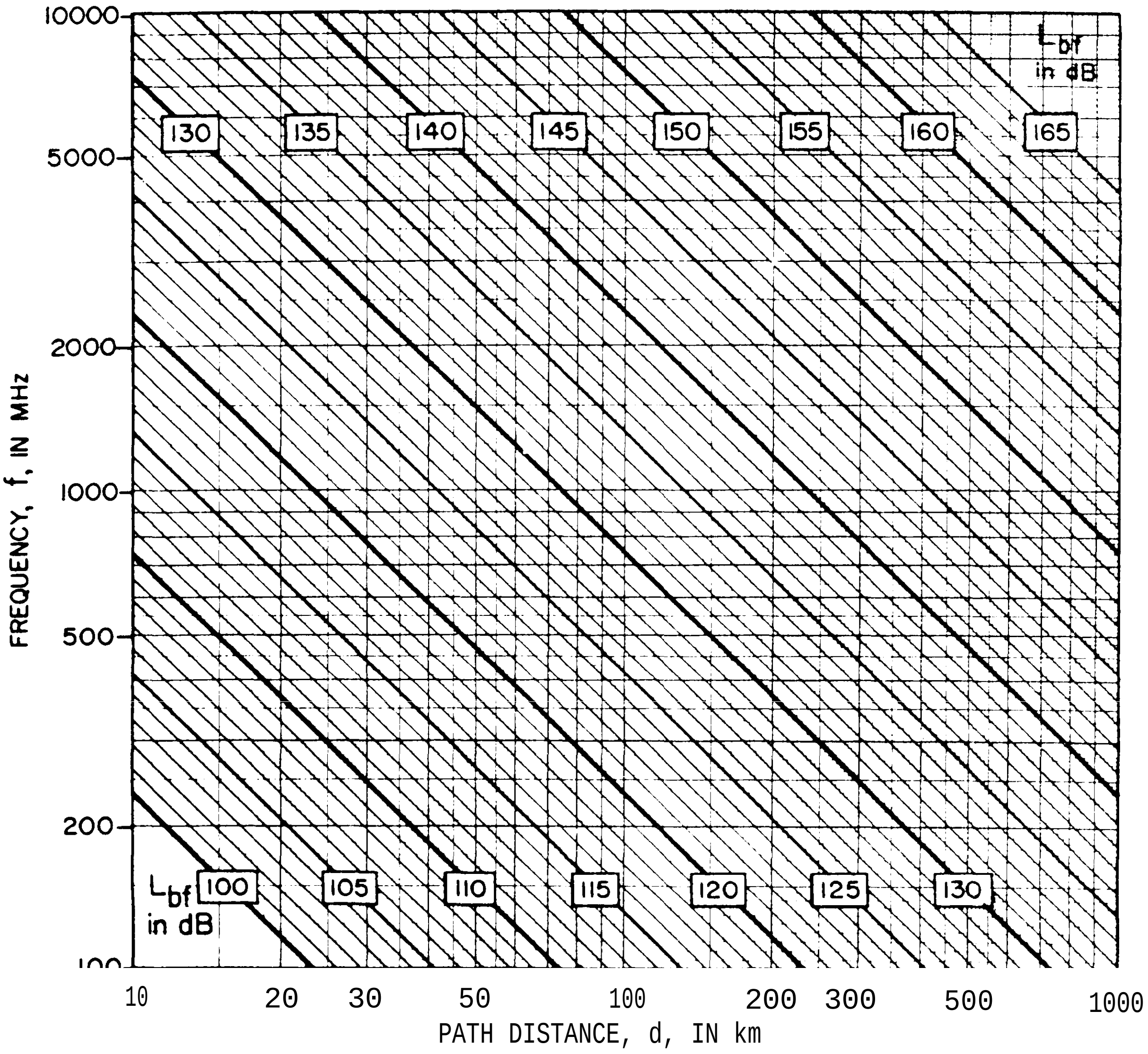

Figure 4.2-2 Basic Transmission Loss in Free Space, L_{bf}

4.2.11.2 The difference between trainsmission loss and basic transmission loss expressed in decibels is referred to as “path antenna gain since it reflects the total realized antenna gain over a radio link. Since theoretical or “free-space " antenna gains are not always obtained over an actual path, one needs to estimate the difference between the $G_1 + G_2$ of the maximum free-space gains, in decibels, and the <u>path antenna gain</u>, G_p. This is defined as the “multipath coupling loss” or “loss in path antenna gain”, L_{gp}. G_p and L_{gp} are defined as follows:

$$c_p = L_b - L = G_1 + G_2 - L_{gp} \text{ dB}, \qquad (4.2\text{-}4a)$$

$$L_{gp} = G_1 + G_2 - G_p \text{ dB}. \qquad (4.2\text{-}4b)$$

L_{gp} may be neglected for transhorizon links which have a single, well defined, common horizon. Formulas given by CCIR [1] to determine L_{gp} for transhorizon links as a function of the free-space antenna gains C_1 and G_2 tend to overestimate L_{gp} for large antennas. A recent analysis of available and applicable data* suggests the following approximate expressions for L_{gp}:

If $(G_1 + G_2) \leq 40$ dB, or if path is knife-edge or smooth-earth diffraction, then $L_{gp} = 0$ dB. (4.2-5a)

In other cases,

$$L_{gp} = 25.8 - 0.29\ (G_1+G_2) + 0.0036\ (G_1+G_2)2 \text{ dB}. \qquad (4.2\text{-}5b)$$

The path antenna gain, G_p, as a function of the sum of the free-space antenna gains $G_1 + G_2$, is plotted in figure 4.2-3 in accordance with (4.2 -5 b).

4. 2.11.3 The free-space gains G_1 and G_2 of the transmitting and receiving antennas may be determined using the following formula

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*Informal communication from Mrs. A.G. Longley of OT/ITS.

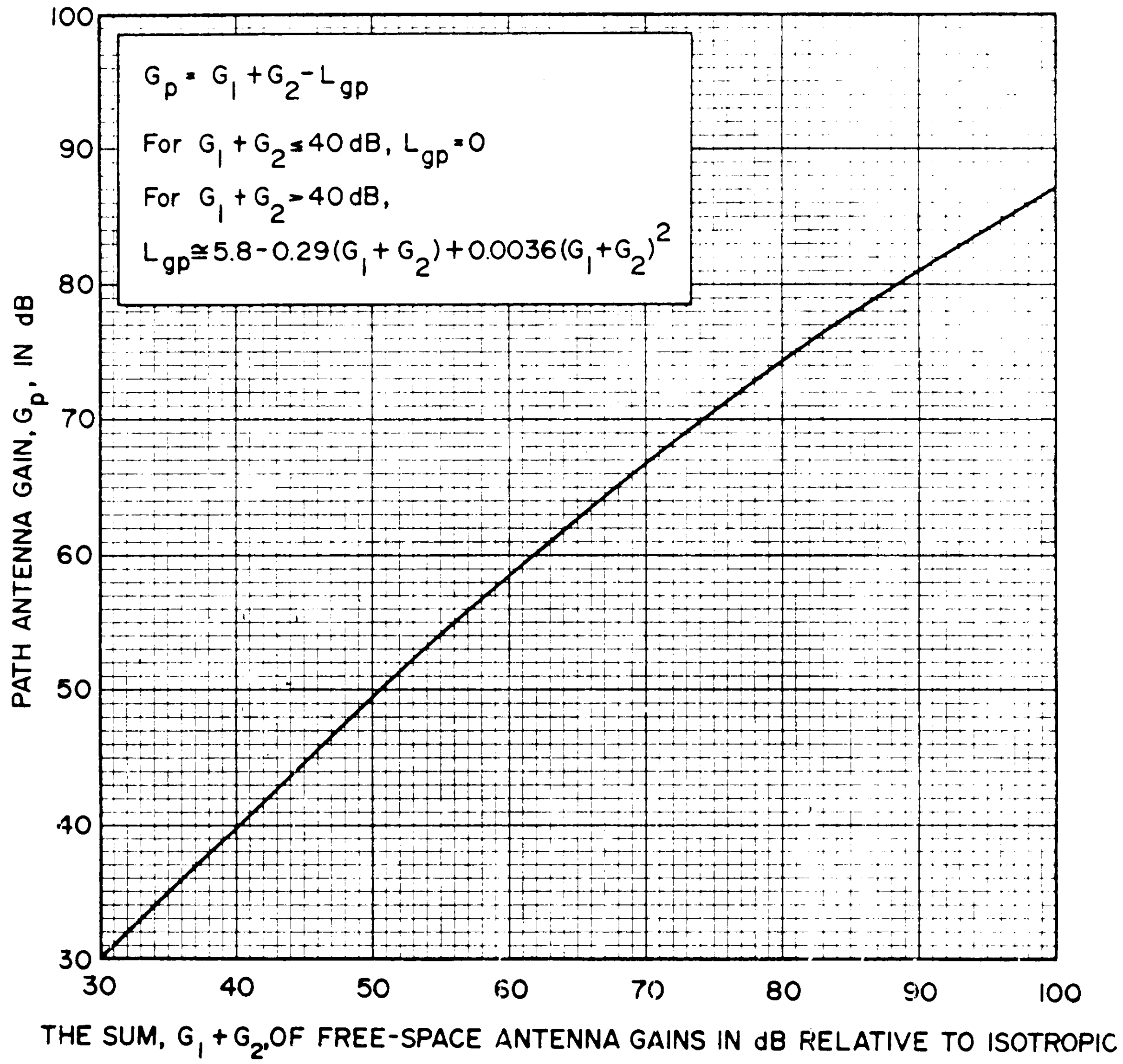

Figure 4.2-3 Path Antenna Gain, G_P For Transhorizon Links

(applicable to parabolic dishes with a 56% aperture efficiency and a diameter D in meters at a frequency f in MHz):

$$G=20 \log D+20 \log f-42.1 \text{ dB} \qquad (4.2\text{-}6a)$$

or

$$G = 20 \log (Df/127.4).$$

If the diameter D_o is given in feet,

$$G = 20 \log D_o + 20 \log f - 52.4 \text{ dB}. \qquad (4.2\text{-}6b)$$

The relationship for D in meters is plotted in figure 4.2-4.

4.2.12 Attenuation Relative to Free Space

4.2.12.1 It is useful to calculate the basic transmission loss (Lb) between two fixed stations as the sum of the free-space basic transmission loss, L_{bf} in decibels, and a term A, also in decibels, which may be defined as the excess propagation attenuation, or as the attenuation relative to free space. For the purposes of this handbook, basic transmission loss can be written as:

$$L_b = L_{bf} + A \text{ dB}. \qquad (4.2\text{-}7)$$

4.2.12.2 Similarly, from (4.2-4a) the transmission loss, L, in decibels, is the difference between the basic transmission loss and the path antenna gain, G_p (all in decibels):

$$L = L_b - G_p \text{ dB}. \qquad (4.2\text{-}8a)$$

Combining (4.2-7) and (4.2-8a), one may write:

$$L = L_{bf} + A - G_p \text{ dB}. \qquad (4.2\text{-}8b)$$

4.2.12.3 Of these quantities, L_{bf} is a function only of path length and carrier frequency, and therefore constant (not varying with time) for a fixed path and a fixed frequency. The path antenna gain, G_p, is also considered to be constant for a given path, frequency, and for fixed antenna parameters, since it is estimated as a long-term median value. Therefore all time variability in (4.2-8b) can be assigned to the attenuation relative to free space, A. This includes the concept of prediction

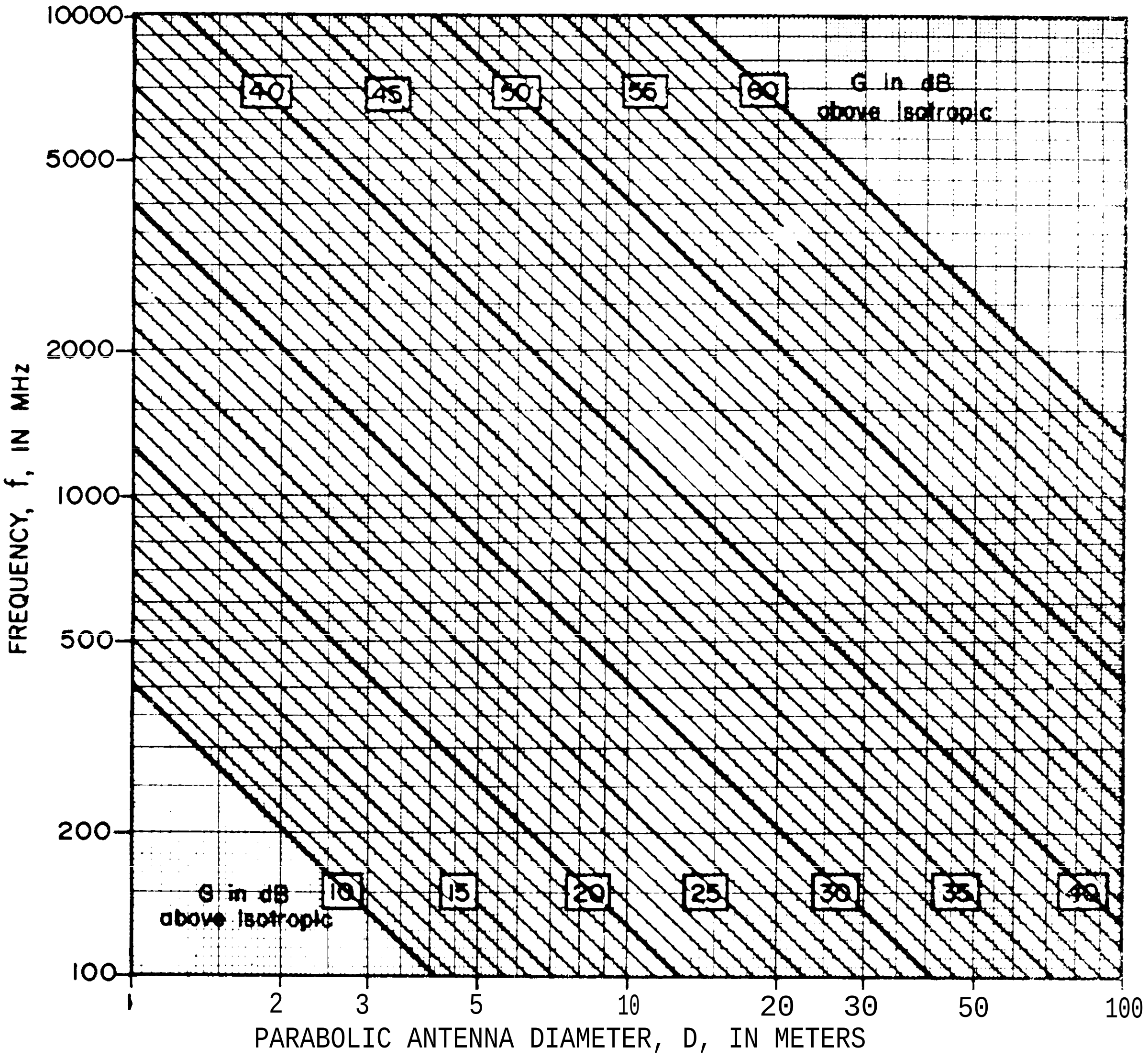

Figure 4.2-4 Free-Space Antenna Gain, G, as a Function of Antenna Diameter and Frequency

uncertainty, which will be further discussed in 4.4.27. For comparing potential routes, and for initial route and site select it it is usually sufficient to consider only one single appropriate value of A which corresponds to high time availability. The calculation of complete time distributions of A including estimates of prediction uncertainty is important for final performance estimates) and will be fully discussed in section 4.4.32.

4.2.12.4 Initial estimates for route and site comparison and selection are therefore based on the "worst hour" Of the year, which very approximately corresponds to one ten-thousandth (0.0001), or 0.01% of the year.* In terms of the notation in section 4.2.7, we will utilize the availability hourly median wanted signal power level $P_a(0.9999)$ which is exceeded during 99.99% of all hours of the year. The corresponding attenuation relative to free space, A (0.9999) which is <u>not</u> exceeded during 99.99% of all hours, will be designated A_r in this section for simplicity. For each radio link, sufficient power must be provided to overcome the propagation loss associated with A_r; thus, A_r is a measure of the <u>required</u> power. The use of A_r in comparison of the required and available power will be discussed further in section 4. 2. 13.

4.2.12.5 By definition, A_r = O dB in free space. For the purpose of route and site comparison and evaluation, a procedure for estimating A_r should be used which is described in the following steps:

1. As an approximation to "worst-hour" propagation conditions) use an effective earth radius a = 4250 km, which corresponds to an effective earth radius factor k = 2/ 3, and is also the basis for the horizon angle formula over smooth earth (4.2-1). Note that this approximation should <u>not</u> be used for the design procedures in section 4.4.

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*There are 8760 hours in a 365-day year.

2. Determine horizon distances d_{L1} and d_{L2}. in kilometers from maps and rough terrain profiles (see section 4. 2.4).

3. Estimate horizon angles θ_{e1} and θ_{e2} in radians, as described in section 4.2.4.2. These will always be negative over smooth terrain.

4. Calculate the angular distance, θ in radians using:

$$\theta = d/a + \theta_{e1} + \theta_{e2} \text{ radians} \qquad (4.2\text{-}9)$$

where d is in km, a = 4250 km, as noted above, and θ_{e1} and θ_{e2} are in radians (see fig. 4.2-1. Additional information on the calculation of angular distance and the horizon angles is given in 4.4.7).

5. For single-horizon paths, calculate the parameter v using:

$$v = 2.583\ \theta \sqrt{f\, d_{L1}\, d_{L2}/d} \qquad (4.2\text{-}10)$$

where all distances are in kilometers, the angle θ is in radians, and the frequency f in MHz. Then the diffraction loss A_d(0. 9999) is determined from figure 4.2-5 as a function of v, and can be used as the initial estimate of A

6. For all other transhorizon links (two-horizon), determine first the product θd of the path distance d in km and the angle θ in radians, and determine the corresponding diffraction loss A(0. 9999) in dB from figure 4.2-6. Also, Calculate the scatter loss A_s (0.9999) from:

$$A_s(0.9999) = 73 + (d/16) \text{ dB} \qquad (4.2\text{-}11)$$

where d is the path distance in km. The initial estimate of A_r for such paths is then the <u>smaller</u> of A_d(0. 9999) and A_S(0. 9999) determined in this manner. Note that figure 4.2-6 requires interpolation between the curves given for nominal frequencies.

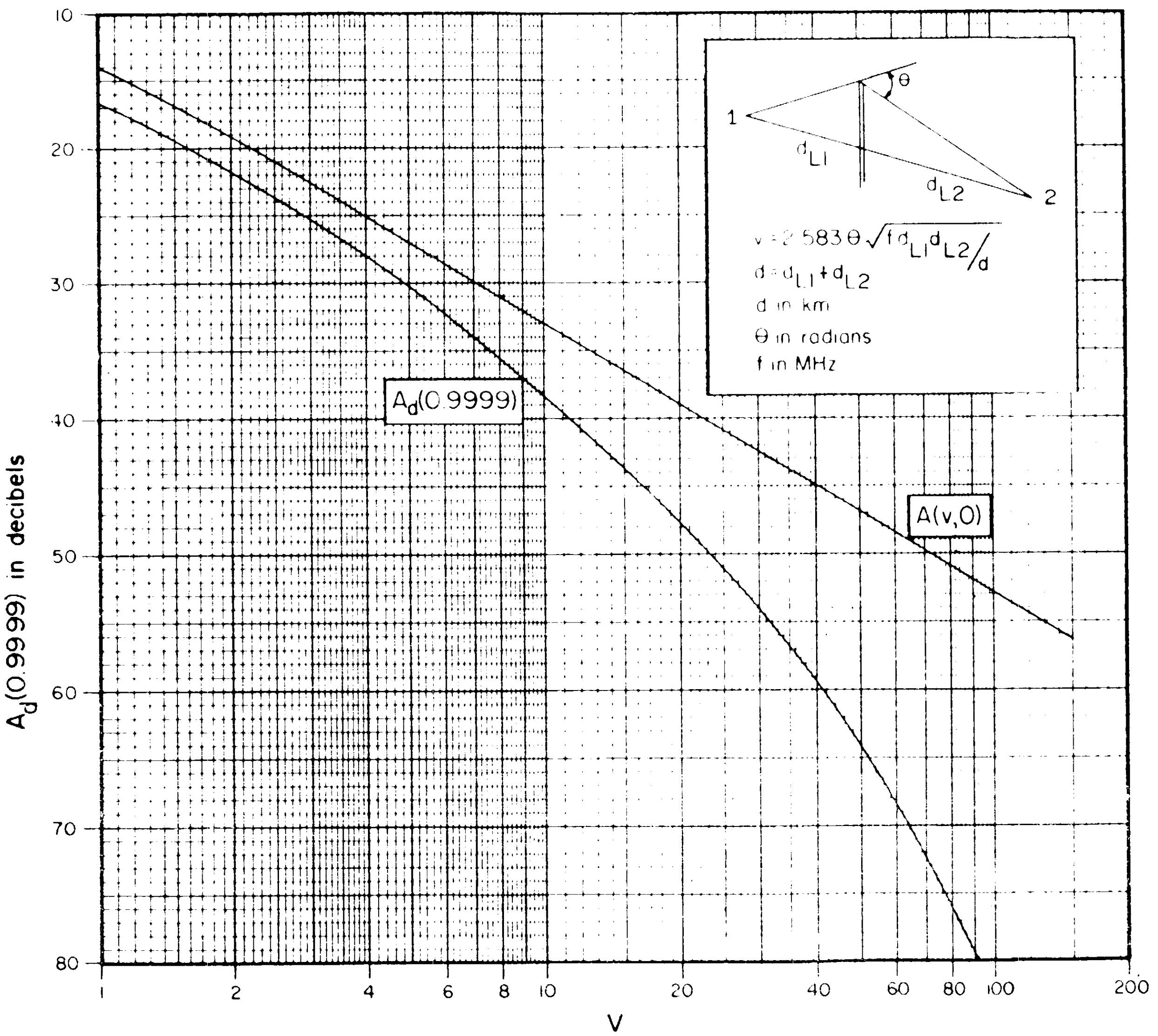

Figure 4.2-5 Diffraction Loss, A_d (0.9999), for Single-horizon Links

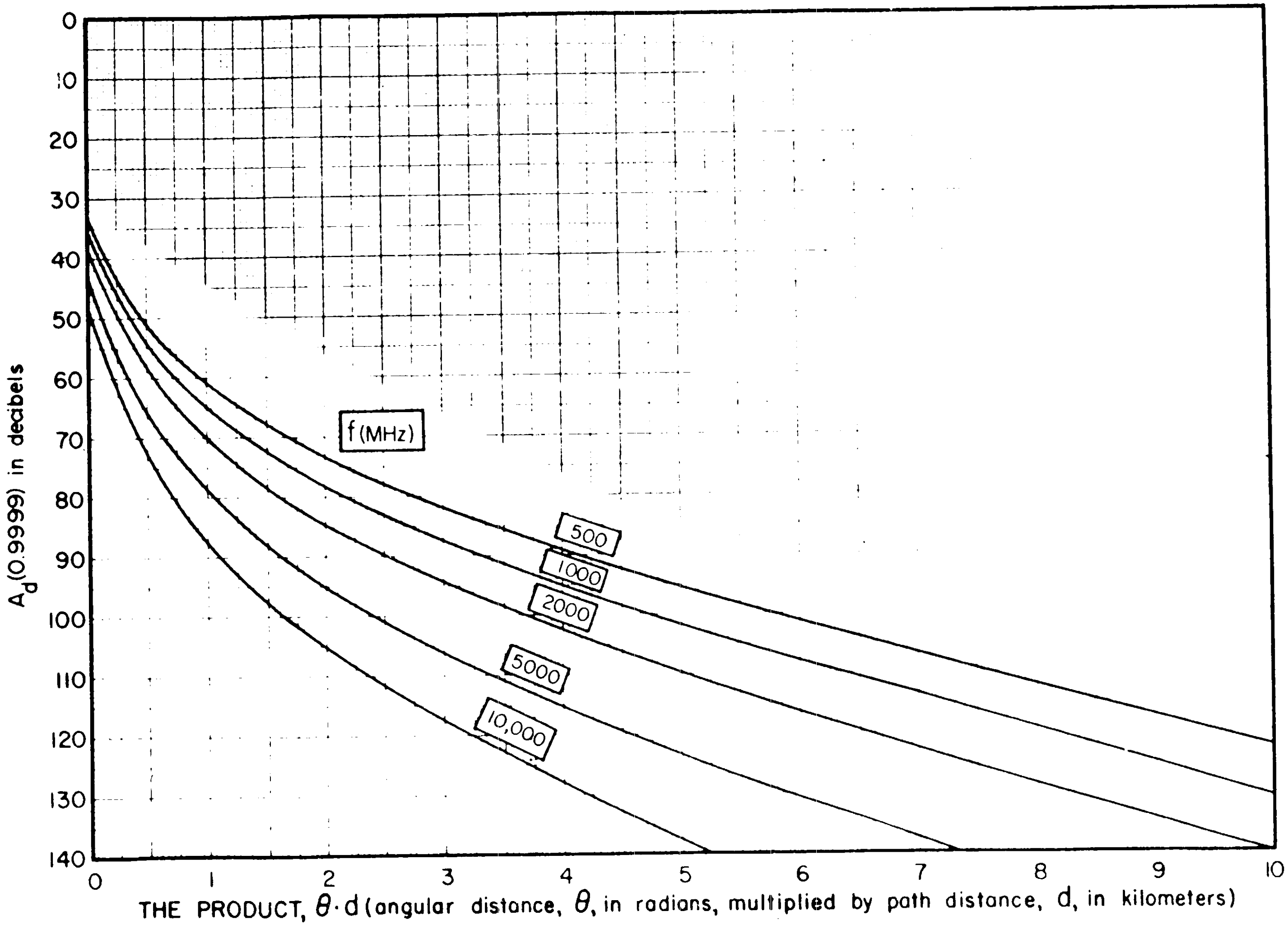

Figure 4.2-6 Diffraction Loss, A_d (0.9999), for Two-horizon Links

4.2.13 The Maximum Tolerable Attenuation, A_m, and the Power Budget.

4.2.13.1 In the previous section we have calculated the worst-hour median attenuation A_r expected over a particular link. In order to provide satisfactory service over the link, this attenuation must be overcome by proper choice of equipment and system parameters. For the purpose of this chapter, namely route comparison and site choice, we choose equipment parameters such as transmitter power, antenna size and the required hourly median predection carrier-to-inband-thermal - noise ratio, Rr(g), which will provide the desired grade of service. Transmission line losses and the effects of discrete unwanted signals can be neglected at this stage of the design. It is useful to include the free-space basic transmission loss L_{bf} into this procedure.

4.2.13.2 The power level, Pa, available at the receiving antenna terminals can be expressed as the algebraic sum of various system gains and losses in decibels [3]. Using the terminology of this section.

$$P_a = P_t + G_p - L_b \qquad (4.2\text{-}12)$$

where P_t is the transmitter power and G_p and Lb have been defined previously. P_a and p_t must be in the same units - either dBW(decibels relative to one watt) or dBm (decibels relative to one milliwatt), except that subsequent considerations make the use of dBW more practical. The maximum permissible (or tolerable) propagation attenuation, Am, relative to the free-space transmission loss L_{bf} is obtained by substituting into (4.2-12) the power level P corresponding to the receiver threshold for Pa and using $L_b = L_{bf} + A$ from (4.2-7). The receiver threshold determines the minimum acceptable power level which will result in satisfactory service.

4.2.13.3 Making these substitutions and solving (4.2-12) for A (which now becomes A_m) we obtain:

$$A_m = (P_t - P_m) - (L_{bf} - G_p) \text{ dB}. \qquad (4.2\text{-}13)$$

Here again, P_t and P must be in the same units (either dBW or dBm) .

4.2.13.4 Now the value of A may be compared with the calculated worst-hour attenuation A_r; if A_m is exceeded by A_r, the designer must determine the feasibility of obtaining either a larger value of A by suitable changes in the parameters (as an example, increasing the transmitter power P_t), or by changing the path, increasing antenna heights, etc. , so that A_r can be reduced. The comparison of A_r and A relates to establishing a "power budget", since it is equivalent to comparing required and available power.

4.2.13.5 As already noted, the condition for satisfactory service from a link in the absence of non-threshold or non-thermal noise problems can be expressed by the ability of obtaining a satisfactory grade of service (an adequate wanted-carrier -to-equivalent-noise ratio) for at least 99.99% of all hours within an average year. This may be given either in terms of received carrier level, of attenuation relative to free space, or of carrier-to-noise ratio:

$$P_a(0.9999) > P_m \text{ dBW}, \qquad (4.2\text{-}14a)$$

or

$$A(0.9999) = A_r < A_m \text{ dB}, \qquad (4.2\text{-}14b)$$

or

$$R(0.9999) > R_r(g) \text{ dB}, \qquad (4.2\text{-}14C)$$

where, in addition to the terms previously defined,

$R(0.9999)$ = the hourly median wanted predetection carrier-to-noise (in-band) ratio defined at the receiving antenna terminals and exceeded for 99.99 percent of all hours within an average year,

and

$R_r(g)$ = the predetection hourly median carrier-to-noise (inband) ratio at the antenna terminals that is required to provide a grade service* in the presence of noise plus unwanted signals whose effect depends only on their general type and power level.

The procedures discussed here are sufficiently general so that the unit dBW could be replaced by the units of a noise temperature or power spectra density (dBW/4kHz), for instance, where required.

4.2.14 Noise Considerations.

4.2.15 The Operating Noise Threshold, P_m.

4.2.15.1 The operating noise threshold, pm, has been defined in section 4.2.9 as the minimum required hourly median wanted carrier level, which can provide the required grade of service. It is used in (4.2-13) as one of the terms in the equation for the maximum allowable attenuation, and is a function of the required radio frequency bandwidth, b_{rf} at the receiver input (or at the input to the detector), of the receiver noise figure, F, and of the required hourly median predetection carrier-to-noise ratio, Rr(g), defined in the preceding section. The equation for P_m is:

$$P_m = (B_{rf} -204) + F\ R_r(g)\ \text{dBW}$$

4.2.15.2 The terms on the right-hand side of (4.2.15) are in decibels, and will be discussed in the following subsections.**

4.2.16 Pre-Detection Radio Frequency Bandwidth, b_{rf}.

4.2.16.1 The radio frequency bandwidth is a function of the number of voice channels, N, for an FDM-FM system (or the bit rate for a digital

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* The symbol"g" IS used here only in a qualitative sense, and has no numerical value attached to it.

**For the purpose of route and site selection, transmission line losses may be neglected.

system) and the per-channel root-mean-square (RMS) frequency deviation, Ó, for the system used. For initial estimates to compare potential sites and routes, the baseband width in kHz may be obtained from table 4.2-1 as a function of the number of voice channels, N. The information in this table is taken from CCIR Recommendation 380-2 [4]. The upper limit of the baseband, as shown in the second column of the table, is also used as the maximum modulating frequency, f_m, to determine the radio frequency channel bandwidth.

Table 4.2-1 Baseband Frequency Limits as a Function of the Number of Voice Channels.

Maximum Number of Voice channels, N	Frequency Limits of Baseband, kHz
24	12 - 108
60	12 - 252, or 60 - 300
120	12 - 552, or 60 - 552
300	60 - 1364
600	60 - 2792

4.2.16.2 It should be noted that transhorizon links will rarely be able to support more than 120 -voice channels because of non-linear distortions due to the transmission medium, and link design for a greater number of channels should not be attempted unless ideal knife-edge diffraction links with low transmission loss are available.

4.2.16.3 The radio frequency bandwidth, b_{rf}, in MHz is then obtained from figure 4.2-7 (for FDM-FM systems) as a function of the baseband width (given by the highest modulating frequency, f_m), or the number of voice channels, and of the RMS per-channel deviation, Ó, in kHz. For site and route selection studies, the curve for Ó = 140 kHz may be used

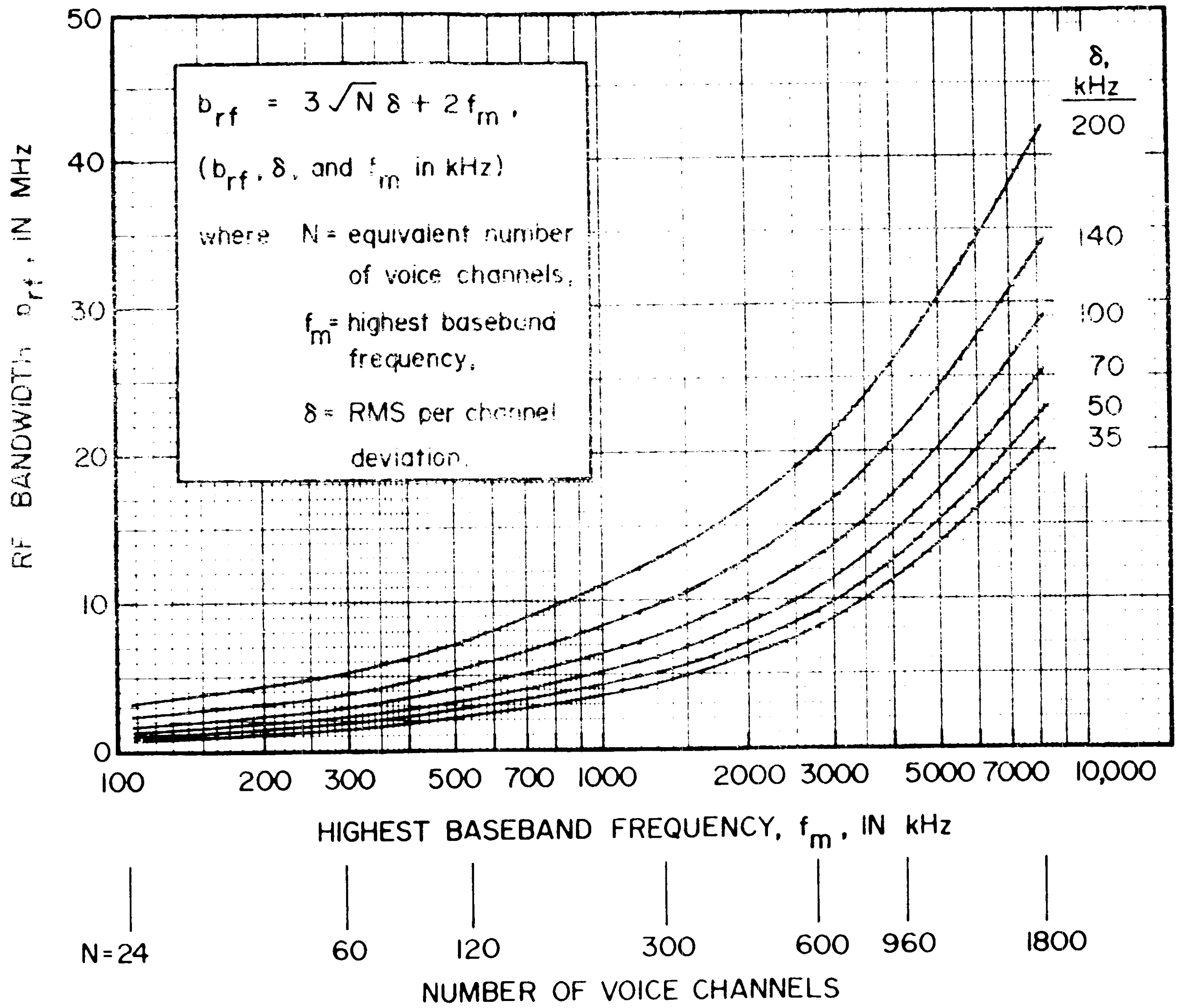

Figure 4.2-7 Dependence of Radio Frequency Bandwidth on Baseband Width for FDM-FM Systems (based on DCS loading and bandwidth specifications; see also paragraph 4.5.20.12 and 4.5.20.13).

unless equipment specifications dictate a different assumption. Figure 4.2-7 also includes the formula for calculating b_{rf} in kHz as a function of N, f_m, and Ó. This formula may be used for values of f_m beyond the range of the abscissa scale, and for intermediate values of δ. Other parameters used as a basis for these curves are discussed in paragraph 4.5.28.2.*

4.2.16.4 The radio frequency bandwidth, b_{rf}, obtained from the curves in figure 4. 2-7 is in MHz; the equation gives b_{rf} in kHz. For use in (4.2-15) it must be converted to decibels using the relation:

$$B_{rf} = \begin{Bmatrix} 10 \log b_{rf} + 60 \text{ for } b_{rf} \text{ in MHz} \\ 10 \log b_{rf} + 30 \text{ for } b_{rf} \text{ in kHz} \end{Bmatrix} \text{dB.} \qquad (4.2\text{-}16)$$

4.2.17 The Thermal Noise Power

4. 2.17.1 The thermal noise power (kTb or Johnson noise) is calculated for an ambient temperature $T_o \simeq 288°$ K, since antennas for terrestrial transhorizon links "look" at terrain at ambient temperatures. It is expressed as 10 log (kT_o) per Hz of r.f. bandwidth, where k is Boltzman's constant ($k=1.3806 \times 10^{-23}$ joules per degree kelvin). For $T_o = 288.37°$ K and the total r. f. bandwidth b_{rf} in Hz, 10 log (kT_o) = -204 dBW, and the thermal noise power is given by the parenthesis $(B_{rf} - 204)$ in (4.2-15).

4.2.18 The Receiver Noise Figure

4.2.18.1 The receiver noise figure, F, in decibels, is obtained or estimated from manufacturer's specifications. For the 500 MHz to 10 GHz frequency range, F may vary between approximately 5 and 15 dB, depending on the type of preamplifiers used. Extremely low-noise cooled amplifiers (F<3dB) such as masers are not usually used for

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*The RMS per-channel deviation will be more precisely denoted of in the subsequent discussions.

terrestrial links, since the ambient noise temperature seen by the antenna is assumed to be about 288°k and the additional 2 db of margin associated with the use of such preamplifiers can frequently be obtained by other means at less expense (see also 4.5.20, 1.5 and 4.5.28.2).

4.2.19 The Required Hourly Median Pre-detection Carrier-to-Noise Ratio

4.2.19.1 In order to calculate the maximum tolerable attenuation, Am (section 4.2.13), the required hourly median carrier-to-noise ratio $Rr_r(g)$ must be determined. For the purpose of the initial performance estimates in this section, $R_r(g)$ may be considered to be a function of thermal noise alone, and equation (4.5-42) from section 4. 5.28.2 with an allowance for diversity improvement is used as a basis for its calculation:

$$R_r(g) = S/N_t - 20 \log \frac{\delta f}{f_m} - 10 \log \frac{b_{rf}}{b_c} - I_d \text{ dB.} \qquad (4.2\text{-}17)$$

4.2.19.2 Here, the required voice channel signal -to-thermal nosie ratio S/N_t is determined as a function of distance in accordance with the CCIR criterion of 3 pWO per kilometer of path length [4], as discussed in section 4.5.15.1. The terns b_rf, δf, and f_m have been defined in section 4.2.16.3, and the voice channel bandwidth b is 3.1 kHz(300-3100 Hz). These wi11 also be further discussed in section 4.5.28.2. The allowable thermal noise power in picowatts is therefore 3d, where d is the path length in kilometers, and the signal-to-noise ratio, S/N_t, can be expressed by:

$$S/Nt = 90 - 10 \log (3d) \text{ dB.} \qquad (4.2\text{-}18)$$

Based on Brennan's work [6], and assuming Rayleigh fading and maximaml-ratio diversity combiners, median values for the diversity improvement I_d may be estimated as approximately 4 dB for dual diversity and 7 dB for quadruple diversity. These values are generally applicable to all transhorizon links since most diffraction links are also subject to fading.

4. 2019.3 Combining (4.2-17) and (4.2-18) we obtain:

$$R_r(g) = 90 - 10 \log(3d) - 20 \log \frac{\delta f}{f_m} - 10 \log \frac{b_{rf}}{b_c} - I_d \quad \text{dB.} \qquad (4.2\text{-}1$$

Equations (4. 2-17) and (4. 2-19) apply only to the linear portions of the FM characteristics; i. e., generally for $R_r(g) >$ 10 dB. See section 4.5.20 for further discussions.

4.2.19.4 Figure 4.2-8 is a plot of the required hourly median carrier-to-noise ratio R_r (g) for FDM-FM systems as a function of the number of voice channels and of the path distance in kilometers. This graph provides preliminary values for comparison of routes, and is based on the use of (4.2-19) with of = 140 kHz, b_c = 3.1kHz, and f_m and b_{rf} determined from the discussions in section 4. 2.16.3 and from figure 4.2-7. As already noted, estimates from figure 4,2-8 are based on a 3 pW0/km allowance for thermal noise. As an example, the required value of R_r(g) for a 120-voice channel capacity over a 300-km path would be 32.5 dB. This value is then inserted in the system equation (4.2-15) in order to determine the operating threshold P_m.

4.2.19.5 For currently used digital systems it is sufficient to assume $R_r(g)$= 20 dB for these initial estimates.

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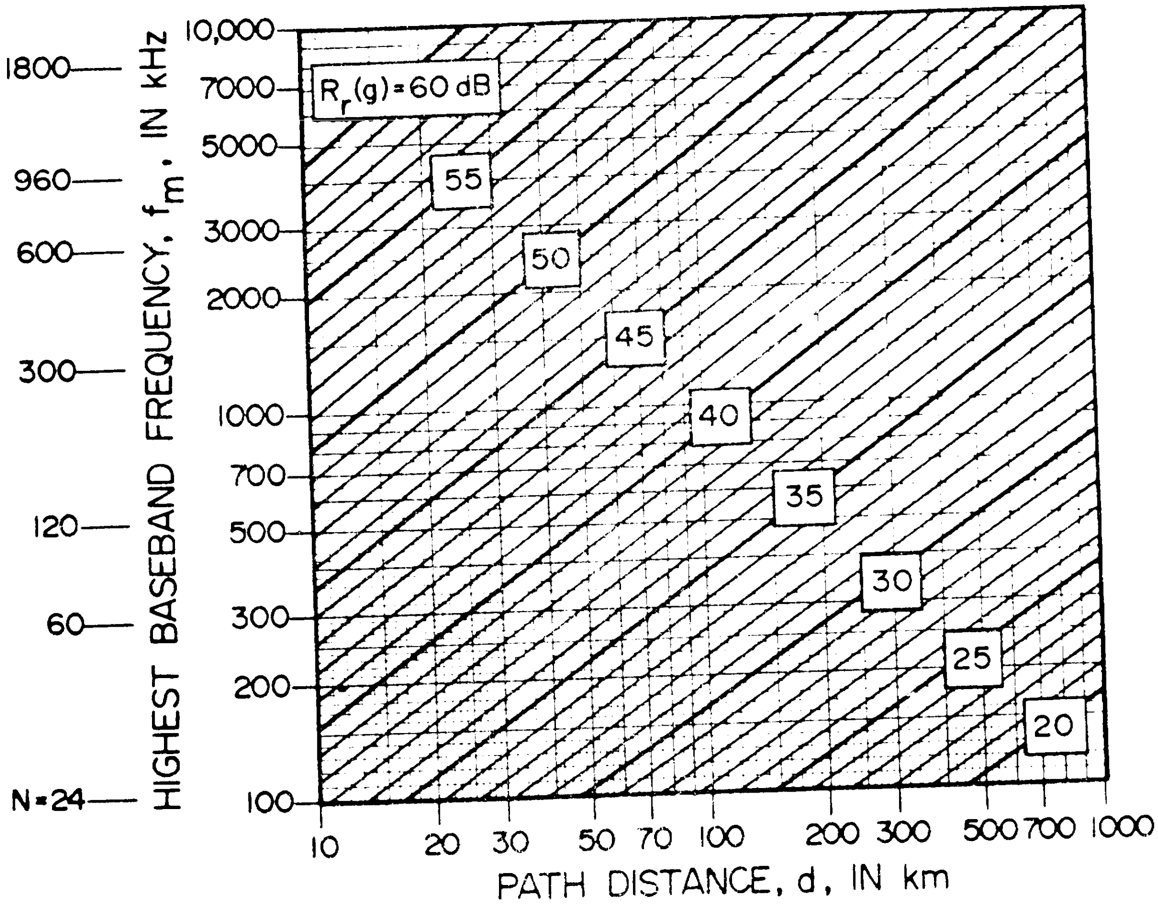

$$R_r(g) = 90 - 10\log 3d - 20\log\frac{\delta f}{f_m} - 10\log\frac{b_{rf}}{b_c} - I_d\,,\ \text{dB}$$

N = equivalent number of voice channels

$\delta f = 140$ kHz

$b_c = 3.1$ kHz

$I_d = 7$ dB

Figure 4.2-8 FDM-FM required hourly median, quadruple diversity, carrier-to-noise ratio, $R_r(g)$, in dB.

4.2.20 An Example of Estimating and Evaluating the Maximum Allowable Attenuation, A_m

4.2.20.1 ln order to summarize the discussions in the preceding subsections, an example is provided here as an illustration of the procedures. The condition for satisfactory service over a radio link is expressed in (4.2-14b) by the requirement that the maximum allowable attenuation, A_m, exceeds the worst-hour propagation attenuation A_r determined by the methods described in section 4.2.12 and using figures 4.2-5, 4.2-6, or (4. 2-11) whichever is applicable.

4.2.20.2 By substituting (4. 2-15) into (4. 2-13) the maximum permissible attenuation A_m may be expressed as follows:

$$A_m = P_t + G_p - L_{bf} - F - R_r(g) - B_{rf} + 204 \text{ dB}, \qquad (4.2\text{-}20)$$

where the transmitter power P_t is in dBW, and all other terms have been previously defined and are in dB. As an example, the following system and path parameters are assumed for a quadruple diversity FDM-FM communication link:

$P_t = 40$ dBW (10 kw)

$G_1 = G =$ 40 db (relative to an isotropic radiator)

$f = 5$ dB

$f = 2000$ MHz

$d = 200$ km

$N = 120$ channels

$\delta \equiv \delta f = 140$ kHz

$f_m = 552$ kHz.(from table 4.2-1).

For first estimates transmission line losses can be neglected. Then,

$G_p = 74.4$ dB (from (4.2-5b) and (4.2-4 b), or figure 4.2-3)

$L_{bf} = 144.5$ dB (from (4.2-3), or figure 4.2-2)

$b_{rf} = 5.7$ MHz (from figure 4.2-7)

B_{rf} = 67.2 dB (from 4.2-16)

$R_r(g)$ = 34.3 dB (from figure 4. 2-8) for quadruple diversity.

Then, from (4.2-20)

$$A_m = 67.4 \text{ dB.}$$

4.2.20.3 This is the maximum permissible attenuation over this path for the specified link parameters. It may be compared with corresponding values for alternative links if such can be considered, or for other combinations of system parameters. However, in estimating link performance it should always be compared with the worst hour propagation attenuation expected for this particular link. In order to demonstrate this procedure, assume that the given link is over a two-horizon path, and that the horizon take-off angles from the two terminals can be estimated as θ_{e1} = -0.012 radians, and θ_{e2} = +0.010 radians. Then, from (4. 2-9), the angular distance, θ, is 0.0451 radians, and the product θd is 9.02 for $d = 200$ km. From figure 4. 2-6 the diffraction attenuations $A_d(0.9999)$ and from (4.2-11) the forward scatter attenuation, $A_s(0.9999)$ are determined. The results are:

$A_d(0.9999)$ = 135 dB

$A_s(0.9999)$ = 85.5 dB.

4.2.20.4 Since the scatter attenuation $A_s(0.9999)$ is the smaller of the two, it is used to represent the worst-hour propagation attenuation A_r for this path. The next step is a comparison of A_r with A_m. In this case, A_m is less than A_r, and we conclude that the proposed system will have thermal noise in excess of that allowable by the CCIR criterion during the worst hour of the year. Later refinement of this first estimate (see sec. 4.4) may provide more accurate values, and permit in this case an evaluation of how much additional transmitter power, how much larger antennas, or how much decrease in channel capacity would be required to equalize the maximum permissible attenuation A_m to the worst-hour propagation attenuation A_r.

4.2.21 Grading Paths for Optimum Route Selection

4.2.21.1 A_r, the hourly median attenuation relative to free space not exceeded 99.99 percent of the time (section 4.2.12), must not only be compared to A_m as shown in the previous subsection, but also to corresponding values of A_r for other paths in order to properly grade potential paths. Other route considerations described subsequently in section 4.2.22 must be taken into account but if $A > A_m$ for the highest practical antenna gains and transmitter power levels the path should be removed from serious consideration. The primary consideration for selecting one path over another should generally be on the basis of the smallest value of A_r. For comparing paths on the basis of A_r, worksheet 4.2-1 has been provided in section 4.2.31.

4.2.22 Other Route Considerations

4.2.23 General

4.2.23.1 The feasibility of the various routes can be evaluated from the preceding calculations, based on topographic data and user requirements. There are, however, other practical factors that should be considered before preparing the preliminary recommendations on sites or routes. These include the following:

a. Climatological influences.
b. Engineering and construction costs.
c. Logistic support requirements.
d. Geological factors.
e. Site security.
f. Radio interference
g. Land availability

Terminal and relay sites finally selected will usually involve some compromise between these factors and the radio propagation considerations.

4.2.24 Climatological Influences

4.2.24.1 The variations in refractivity in the lower atmosphere (related to humidity, temperature, and pressure) have an important bearing on the propagation on transhorizon radio links, however, weather conditions are also an important factor in the construction, support, and operation of radio sites. Unless the designer is already very familiar with climatic conditions in the area of the proposed radio links, it is recommended that he obtain information from a source such as the Air Weather Service, Air Force Environmental Technical Application Center (ETAC), or the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). Publications such as the "World Survey of Climatology"[7} and " Climate of the Continents" [8], are useful sources of information, as are data summaries such as the ETAC "Worldwide Airfield Climatic Data" [9], and the British Meteorological Office "Tables of Temperature, Relative Humidity and Precipitation for the World" [10] .

Weather influences applicable to site selection studies include:

a. Seasonal extremes of temperature (affects field survey and construction scheduling, heating and cooling requirements) ;

b. Direction and velocity of peak wind gusts (affects tower and building design) ;

c. Average and extreme snow pack (affects site access and building construction) ;

d. Average monthly precipitation, and extreme short-period amount (related to both site access and drainage; some areas may be marshy during certain seasons -- even in mountaious areas -- and local flooding (such as rice paddies) may lead to undesirable reflections. At frequencies above about 7.5 GHz high rainfall rates may affect system reliability) ;

e. Icing probability -- freezing rain or "ice storms" (May affect Commercial electric power reliability, and is an important consideration in antenna and tower design. Also, ice falling off a tower may be a hazard to personnel and equipment).

Generally speaking, the designer should expect. t more cloudiness and precipitation, deeper snow pack, higher winds, more frequent icing conditions, and lower temperatures on mountain sites than on nearby lowlands, where weather records are most likely to be available. The temperature decrease with altitude may be as much as 10°C/km. Temperature and humidity contrasts in coastal areas, in conjunction with local wind circulations, favor extreme refractivity gradients that can cause propagation anomalies.

4.2.25 Engineering and Construction Costs

4.2.25.1 At this stage, only very rough estimates are usually possible on such site development costs as grading, leveling, excavations for foundations, water supply and sewage facilities, and provision of access roads. However, some comparison between the various sites should be possible, based upon the information given on large-scale maps, climatic and economic statistics for the area, etc. As a first step, sites might be compared as to the distance from established roads, probable soil type and roughness, estimated height of towers, distance from user's communications center, type of link required from site to center (LOS, cable), availability of water, estimated distance to commercial power line, extreme winds, snow loads, and distance to military bases or civilian housing facilities.

4.2.26 Logistic Support

4.2.26.1 Many of the considerations enumerated in the previous section are applicable to site support requirements once the installation becomes operational. Sites should be compared relative to the costs of transporting fuel, personnel, water, and other supplies. If the only means of access to a site is by aircraft or aerial tramway, the costs of development and operation are usually prohibitive.

4.2.27 Geological Factors

4.2.27.1 Geological data should be collected and analyzed for the areas being considered for radio sites. The analysis should consider earthquake frequency and severity, location of faults, results of test borings, and general soil stability.

4.2.28 Site Security

4.2.28.1 Since transhorizon terminals will normally be manned at all times, the usual security precautions relative to theft and vandalism should be nearly the same at all sites being considered in one area.

4.2.29 Potential Radio Interference

4.2.29.1 A map should be prepared for each potential site, showing station location proposed with reference to potential sources of radio interference. These include other tropospheric terminals, broadcast stations, radar installations, industrial areas, large urban areas, LOS systems, and airports. Prior to the field survey, much of the data will be very approximate, but it should nevertheless be a part of the route selection considerations.

4.2.29.2 To ascertain the ambient RF environment, desk studies on electromagnetic compatibility (EMC) must be performed before firm site selection. These are requested through command channels to the appropriate agency, having responsibility for the service-wide EMC program. Electromagnetic radiation field surveys can be recommended by this EMC agency and should almost always be conducted for major communications terminals and for terminals recommended as a result of the desk study. Independently or preferably in conduction with a field study, a theoretical analysis by a center such as the DOD Electro -

magnetic Compatibility Analysis Center (ECAC), can provide valuable insight to the desirability of potential sites. Usual the responsible EMC agency personnel will make the arrangements to attain the ECAC assistance.

4.2.29.3 The DOD Electromagnetic Compatibility Analysis Center (ECAC) can assist tropospheric transhorizon facility designers in site selection by performing comparative EMC evaluations of potential sites. In addition to environmental information, the tools available include plots of shielding provided by terrain and terrain profiles for microwave or other communication links. ECAC'S automated topographic data file makes it possible to construct topographic profiles to assist in the engineering of communication paths and the analysis of potential interference. Data are available for the 48 contiguous United States, Hawaii, and parts of Alaska, Canada, Mexico, Europe, Southeast Asia, and other areas of the world. These data are provided from 1:250,000 scale maps, but may not always be sufficiently accurate for point-to-point path profiles. Some data are also available from larger scale maps.

4.2.30 Land Availability

4.2.30.1 The site development effort should be made through command channels by the agency having the real property authority to secure land to meet a communications requirement, This agency should be contacted prior to site survey to ascertain current requirements for real estate acquisition. Site development costs can be greatly reduced if suitable locations can be found on government-owned lands. Therefore, when several tentative site locations have been determined on the basis of propagation considerations, an effort should be made by the appropriate agency to identify the owner of the property on which each site would be located. Within the U.S., this ownership information is obtained from county courthouse real property records in the county where the property is located. Once the appropriate legal description is obtained from the county court house a request to purchase the land is submitted to the Corps of Engineers. In foreign countries the pertinent Military Advisory Group (MAG) or the State Department should be contacted through command channels by the appropriate agency.

4.2.30.2 Air space for propagation must also be avilable. A link's future operation can be jeopardized when located across an urban area, military facility area or other areas having potential RF blocking construction development. Also, if the radio beam from a site will pass through an approach zone or other air corridor, undesirable multipath fading can result from reflections from aircraft. Careful military installation planning must be done to prevent these problems when the installation contains a site.

4.2.31 Select Primary and Alternate Routes

4.2.31.1 Final selection of the primary and alternate routes is made following a review of the path loss estimates and the other site and route considerations. It will be useful to tabulate certain data (as on the sample worksheet 4.2-2) so that the various factors can be readily compared by reviewing personnel. A brief justification for each route should also be prepared, outlining the design trade-offs and weighting used by the designer in making his selections. For example, two routes with approximately equal path loss and power requirements may vary greatly in accessibility during inclement weather, cost of power, site development costs, ease of communications center interconnection, etc.

Path: Martlesham Heath to: Hoek van Holland

Nominal Frequency: 4.4 Ghz Path Distance (d) 198 km

Assumed effective earth's radius a = 4250 km for worst-hour conditions(k=2/3)

Radio Hoizon Distance: d_{L1} 14 km. d_{L2} 18 km (from profile or visual inspection)

Assumed Antenna Height (above ground): h_{g1} 32.3 m. h_{g2} 26.6 m.

1. Takeoff Angles: θ_{e1} -4.011×10^{-3} θ_{e2} -3.595×10^{-3} radians

($\theta_{e1,2} = -0.000686 \sqrt{h_{g1,2}}$ for smooth terrain).

2 Angular Distance (θ) : 0.0390 radians (1° = 0.01745 radians)

($\theta = d/r + \theta_{e1} + \theta_{e2}$)

3. d: 7.722

For Two-Horizon Paths:

4. Enter Figure 4.2-6 with and the frequency (MHz).

5. Read Diffraction Loss (Ad): 137 db.

6. Calculate: $A_s = 73 + d/16$ dB= 85.4 dB.

7. Attenuation (A_r): 85.4 dB (smaller value of items 5 and 6).

For Single-Horizon Paths:

8. Calculate: $v = 2.583\,\theta\sqrt{f d_{L1} d_{L2}/d}$ = N/A.

(a in km; f in MHz; θ in radians).

9. Enter figure 4. 2-5 with parameter "v"; estimate A_r:

Attenuation (A_r): n/a db

Worksheet 4.2-1 Route Comparison-Path Loss Calculation (example)

10. Basic Transmission Loss in Free Space (L_{bf}): 151.2 dB (from Figure 4.2-2).

11. Free-space Antenna Gain: (from Figure 4.2-4)

Transmitting (diameter 9.1 meters): G_1 49.9 dB.

Receiving (diameter 9.1 meters): G_2 49.9 dB.

$G_1 + G_2$ 99.8 dB.

12. Path Antenna Gain (G_p): 87 dB (from Figure 4.2-3).

13. Radiated Power (P_t): 70 dBm.

14. a. No. of channels desired (N): 120 l

b. Baseband width = 492 kHz (from table 4.2-1).

c. Required r. f. bandwidth (b_{rf}): 7 .66 MHz (from Figure 4.2-7

d. B_{rf} = 10 log b_{rf} dB + 60 = 68.8 dB.

e. Receiver Noise Figure (F): 6 dB. (from equipment specifications)

f. Hourly Median Pre-detection Wanted Carrier-to-Noise Ratio for FDM-FM systems:

From Figure 4. 2-8, obtain $R_r(g)$: 34.2 dB directly for quadruple diversity

For dual diversity increase $R_r(g)$ by 3 dB: N/A dB.

For non-diversity increase $R_r(g)$ by 7dB: N/A db.

g. For digital systems, use $R_r(g)$ = 20 dB

Operating Noise Threshold (Pm):

$$P_m = (B_{rf} - 204) + F + R_r(g) = -95.0 \text{ dBW}$$

15. Maximum permissible attenuation (A_m) from (4.2-20), or:

$$A_m = (P_t - P_m) - (L_{bf} - G_p) \text{ ‘B } 100.8 \text{ dB.}$$

16. Evaluate difference ($A_m - A_r$) = 15.4 dB.

Worksheet 4.2-1 Route Comparison- Path Loss Calculation (contd.) (example)

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	Route No._____		Route No._____	
	Site 285	Site 325	Site_____	Site_____
Site Coordinates	52°03'08"N 01°14'30"E	51°59'07"N 04°07'01"E		
Site Elevation (MSL) - meters	30.8	14.3		
Path Length (km)	198	198		
Horizon Angle (radians)	-0.00332	-0.00243		
Type of Path	Scatter	Scatter		
Estimated worst-hour Path Attenuation (dB)	85.4	85.4		
Required Transmitter Power (kw)	10	10		
Antenna Diameter (meters)	9.1	9.1		
Tower Height (meters)	36.8	16.8		
Distance to: (km)				
Dirt Auto Road	0	0		
Paved Auto Road	0	0		
Power Line	0	0		
Airstrip	2	20		
Jet Airport	100	80		
Railroad Siding	3	1		
Military Base	20	100		
Hotels-Restaurants	2	0		
Coastline	5	0		
Water Supply	0	0		
Communications Center	20	250		
Supply Depot (Fuel, etc.).	20	120		
Link to Center (LOS, cable)	20	None		
Annual Temperature Extremes (°F/C)	92° to 3°F	100° to 2°F		
Annual Precipitation (in./mm)	27 in.	29 in.		
Maximum Snow Depth (ft/meters)	1.5 ft	1.2 ft		
Extreme Wind Velocity (knots)	78 kts	83 kts		
Land Owner (Govt., Private)	Govt.	Govt.		

Worksheet 4.2-2 Site Comparison Data (example)

4.3 FIELD SURVEY

4.3.1 General

4.3.1.1 The site locations and path profiles determined from the map studies must be checked by a field survey. The best available maps may not show recent man-made obstructions or tree growth, nor will they supply details on site access, soil conditions, land ownership, and other information needed for the final system calculations, site selection, and facilities planning. Recent aerial photographs can provide some of this information, but site visits and field surveys will still be needed.

4.3.1.2 The field survey will require appropriate liaison with area commanders and/or local officials, property owners, and representatives of host countries. These negotiations should be started as soon as the Prelirminry selection of sites has been completed, so that permission to visit and work on the sites will be available to the survey team at the earliest possible date.

4.3.1.3 The procedures to be followed in the field and the scheduling of the surveys should be decided by the leader of the system design group. Since no two paths or systems are quite the same, requirements are likely to vary from one design effort the next. A satisfactory procedure in one country or climate may be unsuited to another area, and time available for design and implementation of the system is also an important factor. Usually, the initial survey will be followed at a later time by a final survey; in some cases, however it may be necessary or desirable to perform all survey tasks on the same field trip.

4.3.1.4 Many times a new communications system will use site locations where there is existing facility housing. Facility housing should be inspected to insure that the blueprints to be used for installation planning are correct and up-to-date (see section 5.2). Also should the facility need precautions against compromising emanations , the building or site should be inspected according to MIL- HDBK-232. (see section 5.0.2)

4.3.2 Planning the Field Survey.

4.3.2.1 A succesful field survey requires careful planning, and the survey party should study the available data on each site and path before going into the field. Check list should be prepared for each site and path, outlining the specific information needed in the final stage of the system design. (See worksheet 4.3-1 for sample checklist.) Duplicate copies of system maps and path profiles should be obtained, as well as copies of topographic maps, county road maps, information on the location of benchmarks, and a current ephemeris.

4.3.2.2 Equipment required for the survey, such as altimeters, theodolites, radios, steel tapes, etc. should be examined and tested well in advance of each survey trip, and the use of equipment check lists is strongly recommended. Both delay of the project and personal emlbarrassment can result, if, for example one unpacks the theodolite at Site "X" and then discovers that the tripod is back at the home station.

4.3.2.3 Transportation and personnal requirements will vary with the type of area, time limitations, and the precision of the survey, The party chief should have experience microwave design and be familiar with the problems which may have been encountered in the preliminary design work on the specific system. The initial surveys will require only an elementary knowledge of surveying principles, but the final site surveys should be made by well-trained and experienced surveyors.

4.3.2.4 The climate of the system area should be considered in long-range planning of field surveys. Very wet or snow-covered ground adds to the difficulilty of the survey, e. g. , control markers may be hidden by snow. In remote areas clothing and shelter provided for the survey party must be adequate for the most severe weather possible in that area. Regular checking of current weather reports and forecasts while in the field can contribute to the efficiency and safety of the survey work, particularly in areas or seasons when sudden and severe changes in temperature, winds, or precipitation intensity are possible.

Site Name and Number ______________________________

Latitude ____________ Longitude ____________ (Degrees, Min, Sec)

Map reference (most detailed topographic) ____________________

Nearest town (postoffice) ______________________________

Access route: (all Year?) ______________________________

Property owner; local contact:

Site sketch _____ Site photograph _____ General description __________

Reference baseline __________ By Polaris _____ Other __________

Antenna No. __________ True bearing ________________

Ground elev. MSJ ________ Takeoff angle(beam centerline) _____

Takeoff angles to 45° right and left of centerline ____________
(Significant changes in horizon)

Critical Points: (include horizon)

Distance _______ Map elev. _______ Survey elev. ________

Tree height ________ Required clearance ________

Description:

Horizon sketch ________ Horizon photograph ______

Power availability:

a. Nearest transmission line __________ b. Voltage ________

c. Frequency _____ d. Phase ______ e. Operating utility _____

Drinking water source _______ Estimated depth to groundwater ______

Sewage disposal ____ Type and depth of soil on and near site ________

Nearest airport __________ railroad __________ highway __________

navigable river ________

Worksheet 4.3-1 Checklist for Site Survey (page 1 of 2)

Local communications facilities: telephone____telegraph____radio_____

Nearby radio transmitters____________relay stations____________

Other interference sources_____________________

Local transportation facilities: airlines________railroads________

truck__________bus__________

Warehouse and storage facilities__________

Local suppliers (hardware, lumber, concrete etc.)__________

Local contractors__________

Fuel sources (oil, gas, propane)__________

Local housing accommodations: temporary________permanent_________

Local military or civil contact__________

Meteorological data from local sources: (averages for each month)

Maximum/minimum temperature (daily)_________

Precipitation__________ (Also extreme 1- and 24-hour)

Snow depth____________ (Also maximum for period of record)

Prevailing wind direction and speed__________

Extreme wind gust and direction__________

Dewpoint or relative humidity (mean diurnal change)___________

Worksheet 4.3-1 Checklist for Site Survey (page 2 of 2)

4.3.2.5 It is well to remember that work on high plateaus or mountain tops, even in the warmer months of the year, may be compicated by much more severe weather conditions than would be experienced at a nearby lowland site. If climatological data are lacking for a mountain site, expect temperatures to be lower (than on a nearby lowlands site) by about 5.5° F/1000 ft, or about 10° C/km; also expect stronger winds and a higher incidence of cloudiness and precipitation. If climatological records indicate frequent low cloudiness in the lowlands, expect nearby sites at higher elevation to be the clouds a high percentage of the time, which will be equivant to a local fog condition with low vertical and horizontal visibility.

4.3.3 List Information Required.

4.3.3.1 The leader of the system design study will be responsible for preparing a list of the information required from the field survey. There should be a separate list for each site and path, and each one should contain any information already available that may be of use by the survey team (e.g., owner of property on which proposed site is located, recommended access routes, etc.). Specific points at which measurements are desired may be indicated on profile charts by arrows and appropriate notations.

4.3.3.2 The extent of the survey work will very considerably, depending upon whether or not operating personnel will require living quarters, messing and recreational facilities at the site. The preliminary design studies should have included an investigation of staffing requirements, possibility of using nearby military stations for quarters, or comparative costs of rental housing near the site. Remote sites may sometimes be selected on the basis of map studies because of advantages in lower tower heights or better horizons, but a field survey may show that site development costs will be prohibitive, or access will be difficult or impossible at certainties.

4.3.3.3 For transhorizon sites, the following information will usually be required (see also 4. 3. 14. 2):

a. Precise location of site. Geographical coordinates to the nearest second; elevation above sea level to the nearest 5m ±2.5m or 8 ft); also a description of the location relative to benchmarks, prominent terrain features, buiidings, roads, or a baseline established at the site from celestial observations. This information should be recorded in survey logbooks, and it should also be indicated precisely on a site sketch (see below).

b. Full description of site. Include soil type, vegetation, tree heights, existing structures, access requirements, leveling or grading requirements) drainage, etc. Use sketches and topographic maps, as in figures 4.3-1 and 4.3.2, to show distances to property lines, benchmarks, roads, etc; also locations of antennas and other proposed structures. Photographs should be made to show closeup details as well as general location with respect to surrounding terrain features. Water supply and sewage disposal information should be included (consult local well drillers, agricultural agents, contractors, etc.). On the initial site visit, general information on site location and access should be summarized on a form similar to that shown in figure 4.3-3. This will be found useful in directing suppliers and contractors to the site.

c. Description of path. Give general description of terrain and vegetation as one proceeds from site to horizon; if horizon is a hill or ridge describe its character fully and photograph (e.g.,"sharp granite ridge 1 km long") check angle from

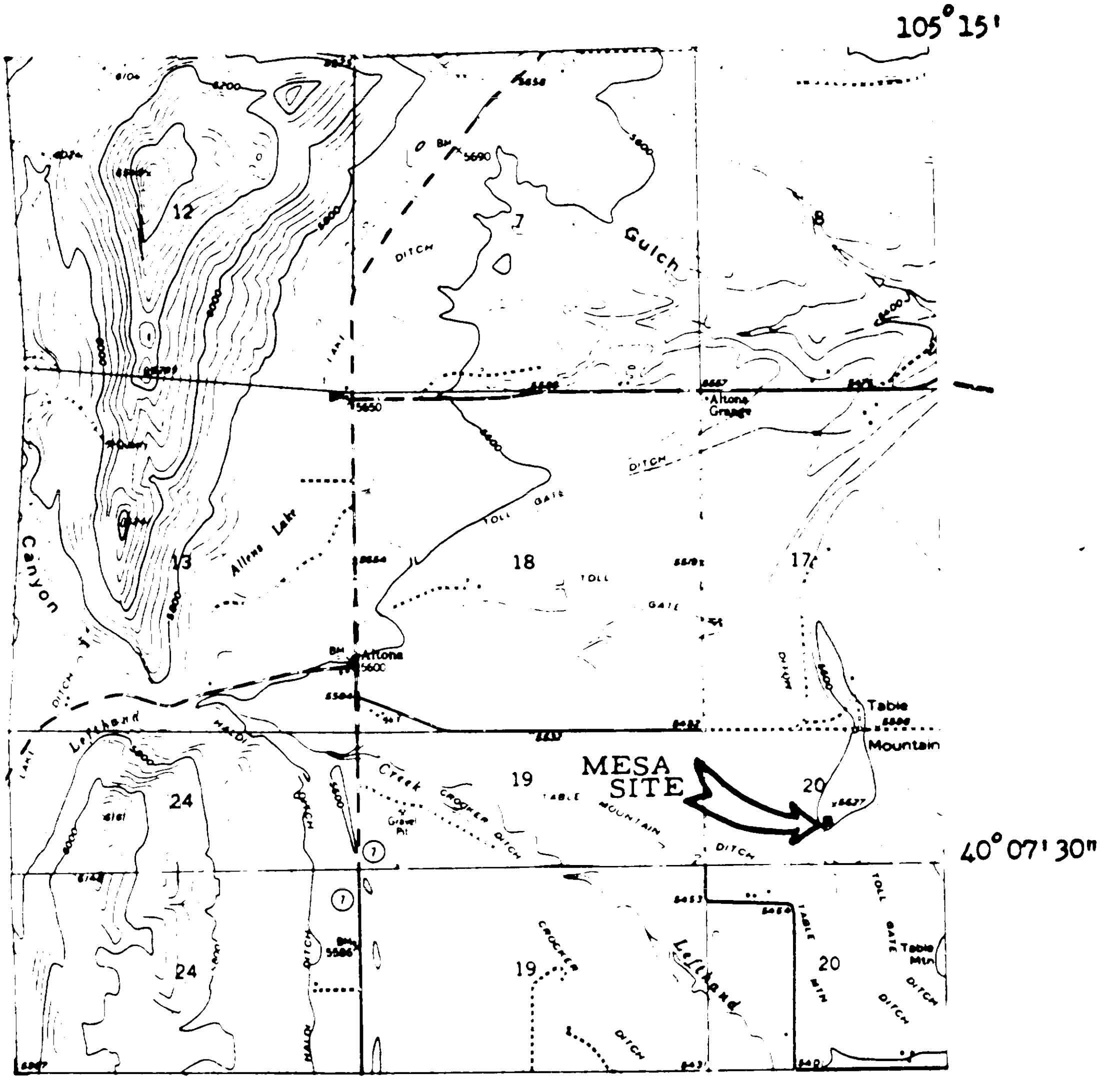

Figure 4.3-1. Section of topographic map showing Mesa Site (USGS Lyons, Colo. 7 1/2' quadrangle)

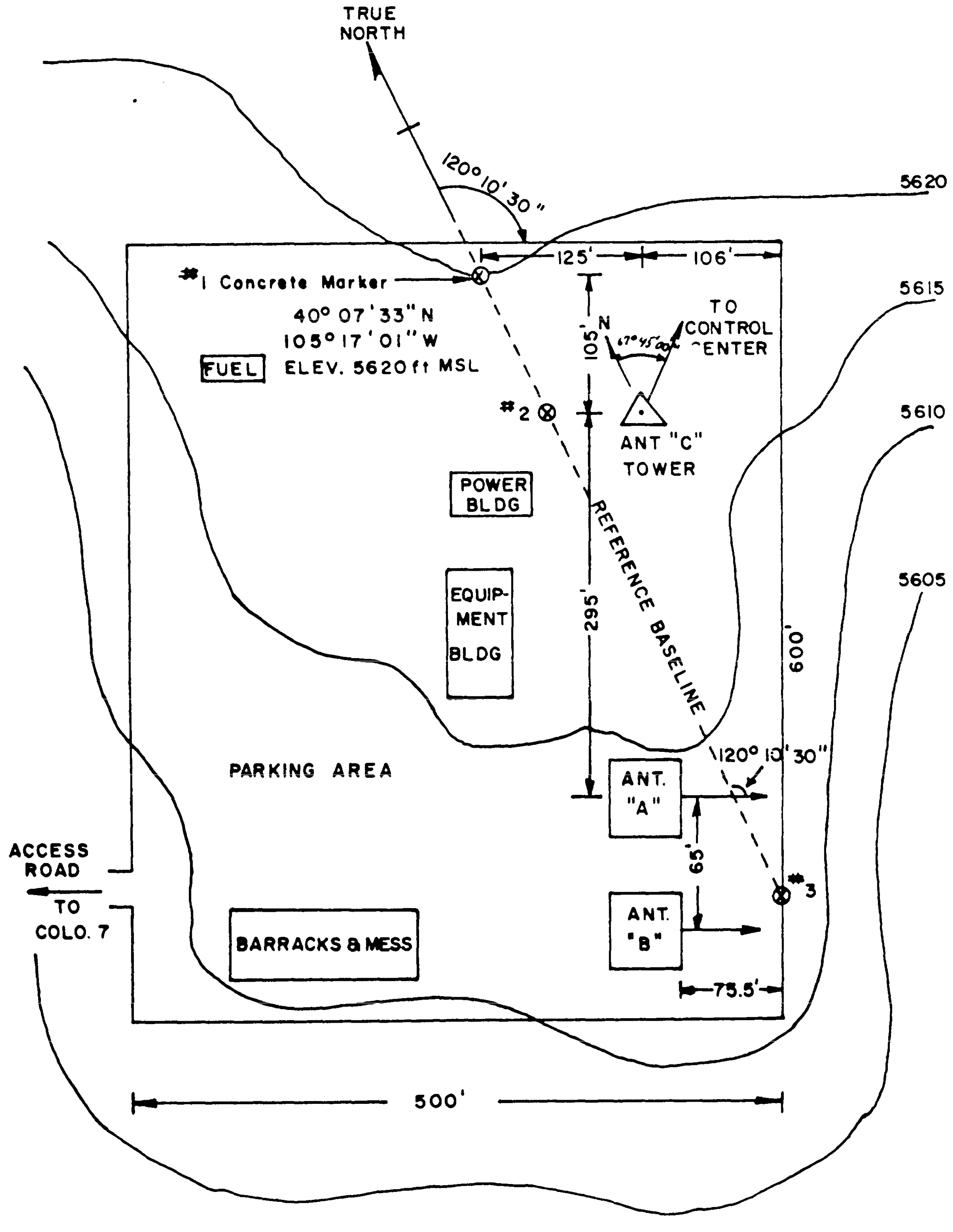

Figure 4.3-2 Example of Site Layout Sketch

SITE INFORMATION WORKSHEET

DATE : JUNE 6, 1972 OBSERVER: B. C. CARP

SITE NAME & NUMBER: MESA SITE #1

LOCATION: SE 1/4 NW1/4 SECTION: 20 TOWN: 2 RANGE 70W

COUNTY : BOULDER STATE : COLORADO COUNTRY: USA

REFERENCE MAPS: U.S.G.S. LYONS QUAD., 71/2', 1957

DESCRIPTION: Site is on south side of large flat-topped messa (Table Mtn); covered with short grass, weeds, and few low bushes, no trees, shallow sand soil over gravel and rock; many small boulders on surface.

ACCESS ROUTE: From junction of U.S. 36 and Broadway, north of Boulder, go north on State (U.S. 36) about 4 miles. After passing Beech Aircraft plant take gravel road to right just north of stoneyard (this is about 1/4 miles S of Lefthand Canyon Rd.). Go east about 1 1/2 miles to top of mesa, then take first road to right and go about 1/4 mile; SSW and then east to concrete marker.

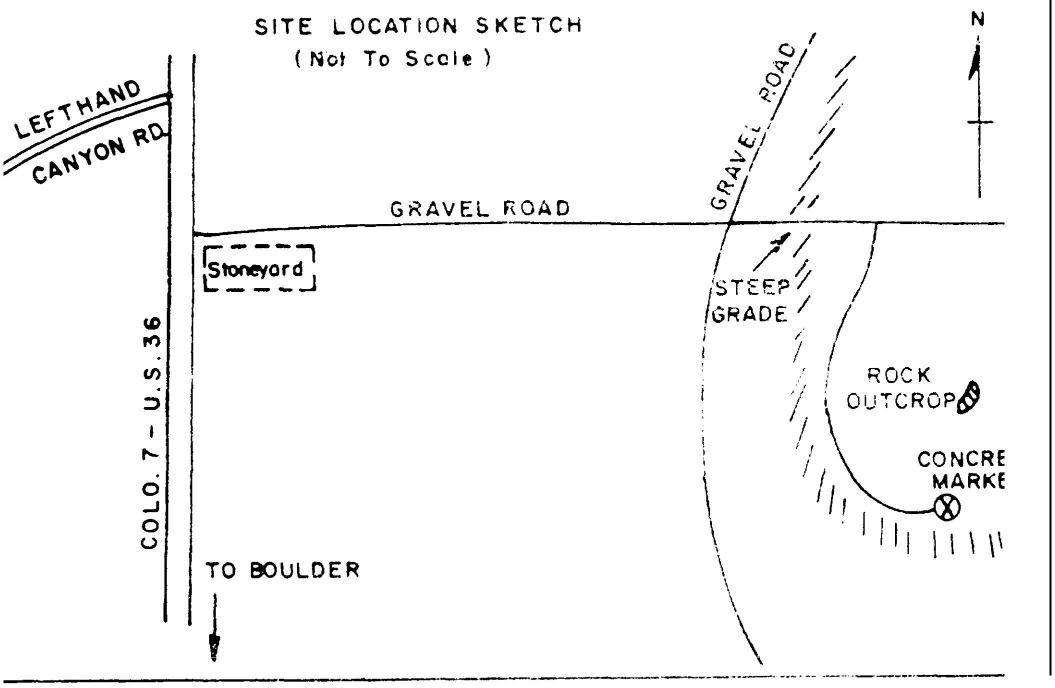

Figure 4.3-3. Example of completed site information worksheet.

site to To horizon and elevation of large buildings, height of trees, width of rivers, etc. Show by sketch and photographs new construction or other features not correctly indicated by available topographic maps. Make sketches and photographs of path centerline from site, and measure azimuth and elevation angles to prominent features. (45° either side of path center line). A telephoto lens may be useful for obtaining increased detail of distant terrain features.

d. Power availability. Give location of nearest commercial transmission line, frequency, voltage, phase, name and address of utility.

e. Fuel supply. List local sources of propane, diesel fuel , heating oils, natural gas; also provide estimates of cost of these items delivered to site.

f. Local materials and contractors. Determine if there are local sources of lumber and ready-mixed concrete; list names and addresses of local general contractors.

g. Local zoning restrictions. Make inquiry as to any that might affect use of site or height of antenna tower. Give location of nearby airports; determine if site is in runway approach corridor. Obtain estimate of number of aircraft using terminal per month.

h. Geologic and seismic data. Determine load-bearing qualities of soil at site, depth to rock and groundwater, obtain core samples, determine local foundation requirements (pilings, etc.). Check with local authorities on the frequency and severity of seismic disturbances; note locations of major fault lines in vicinity of site.

i. Weather data. General climatological data will have been assembled for the design studies, but local meteorologists can providc valuable supplemental details on small-scale variations in winds, temperatures, snow pack, precipitation, cloudiness, fog, etc. in the vicinity of sites. Check with local military or governmental weather offices as to suitability of previous estimates for each site, including

1. Average maximum and minimum temperature (monthly),
2. Average monthly precipitation, and extreme short-period totals (day, hour) ; no. of days/month with precipitation,
3. Average wind direction and velocity, direction and velocity of peak gusts,
4. Average and extreme snow pack,
5. Flooding possibilities,
6. Occurrence of hurricanes, typhoons, tornadoes,
7. Persistence of fog or low cloudiness,
8. Probability of extended periods of very light winds,
9. Icing probability (freezing rain),
10. Average dewpoint temperature; diurnal variation of relative humidity.

j. Possible sources of interference. Show location of “foreign” systems paralleling or crossing proposed route, transmitter or repeater . locations (including commercial broadcast), including names of operating agency if possible. Show nearby radars, with power and wavelength; also location of large industrial plants, railroad switching yards, heavily travelled highways, etc. A good site should have the capability of locating all electronic communication equipment including the associated antenna system a distance from these potential interference sources as well as from less obvious ones like farm vehicles/machinery as recommended by the appropriate electromagnetic compatibility office. Furthermore, to fully ascertain the ambient RF environment, it may be necessary to request through command channels for a special electromagnetic field survey. (see paragraph 4.2.29.2)

k. Shipping facilities. Nearest rail, air, or water transportation terminals; local warehouse facilities.

1. Path Loss data. These measurements may be required over a period of several weeks or more on scatter paths. On multi-hop systems, a test of the most critical link may be sufficient. In most areas, a 24-hr/day test for one month in the winter or dry season will be required.

4.3.4 Survey Equipment Requirements

4.3.4.1 Equipment necessary for the field survey will vary with the demands of the de sign study, as well as with the type of terrain and climate. In remote areas backup units should be taken for all major equipment items, but this will not be necessary where supply depots are close at hand. Each survey will need to be considered separately to assess the effects of loss of certain items of equipment.

4.3.4.2 Clothing, emergency shelter, and food supplies must be adequate for the most adverse conditions, allowing for the possibility of vehicle breakdown, road blockage, flooding, *severe* storms, etc. Climatological data obtained from military or civilian sources should be used in this planning.

4.3.4.3 Technical supplies and equipment will 11 vary somewhat with the specific requirements of the survey; the following items are recommended:

a. Topographic maps county road map, path profiles,

b. Benchmark information from U. S. G. S. or other sources,

c. Plan of proposed sites, showing space requirements for antennas, equipment buildings, barracks, fuel storage, parking, generating facilities, etc. Radiation hazard areas should be outlined;

d. Surveyor’s compass,

e. Transit or theodolite (e. g. , K & E or Wild),
f. Tripod and leveling rod,
g. Sensitive altimeter (preferably 3 each; e. g. , Wallace & Tiernan FA-18 1), with psychrometer kit,
h. Hand level-clinometer (e. g. , Abney),
i. Binoculars (7 x 35 or 8 x 50),
j. Steel surveyor's tape,100-ft,
k. Ephemeris for current year, and surveying handbook,
1. Wooden stakes, hammer, stake bag, ax or hatchet,
m. Polaroid camera and ample film. supply (a 35 mm camera with telephoto lens is also useful),
n. Field notebooks, protractor, rulers, dividers, clipboards, pencils, erasers, small hand tools,
o. First-aid and snakebite kits,
p. Several accurate watches (e. g. , Accutron); stop watch; small HF radio for monitoring standard time broadcasts,
q. Several flashlights and supply of batteries,
r. Slide rule, small hand calculater

4.3.4.4 Two-way portable radios are very useful in survey work, such as synchronizing altimeter readings, and also provide additional safety margin for work in remote areas or under severe weather conditions. On long trips an ample supply of spare batteries should be carried.

4.3.4.5 In areas with benchmarks, a recording altimeter or microbarograph can be used to improve the accuracy of elevation data.

4.3.4.6 If soil sampling is required, a shovel, auger, and sample containers should be included in the survey party supplies.

4.3.4.7 Path loss measurements, where required, involve sizeable amount of additional equipment. This is discussed in Section 4.3.13.2.

4.3.5 Transportation

4.3.5.1 In areas with a good network, a station wagon is a good choice for field survey transportation; tripods, leveling rods, and instruments are easily loaded and unloaded and are protected from sun, weather, and theft. In rough terrain, marshy areas or were roads me poor, a 4-wheel-drive vehicle is recommended. Most surveys will require at least two vehicles, and more will be required if path loss tests are planned. In some areas it may be more efficient to use a helicopter for site visits, particularly if sites are a long distance from roads. Off-road or remote area travel by vehicle can involve lengthy delays related to what would be minor problems in well-traveUed areas; it is recommended that emergency supplies include water, gasoline, oil, fan belts, and ignition parts.

4.3.6 Personnel

4.3.6.1 The survey party chief should be a member of the *system* design group, and should have had previous experience in field surveys. Other members of the party should be chosen on the basis of the particular needs of the survey; usually it will be advantageous to select individuals with varying backgrounds and skills if they are available. For example, various phases of most surveys can most suitably be performed by persons with experience in communications engineering, surveying, civil engineering, meteorology, and geology. The party may also include representatives of local commands, host countries, and contractors. Land survey of sites should be performed by fully qualifies surveyors (i.e., persons regularly employed in such work).

4.3.7 Frequency Requirements

4.3.7.1 If path loss tests are to be performed, it will be necessary to obtain authorization for use of the desired frequencies on the particular paths. Permits may also be required for the mobile or portable 2-way radios.

4.3.8 Time Requirements

4.3.8.1 The time required for the survey effort will include the time required to assemble and brief personnel, procure and test equipment, obtain permission for site visits, make the field measurements, and assemble the data in a form suitable for use in the final stages of the system design. Time estimates for field work should consider the nature of the terrain, quality of roads, and weather conditions that may be encountered. Ample time should be allowed for the site visits and path checks; accurate information from these tasks is of greater concern than early completion of the survey.

4.3.9 Request for Survey

4.3.9.1 The necessary requests for manpower and equipment should be initiated as soon as an estimate can be made of the completion date for the route alternatives study. Consideration should be given to climatic factors in areas where certain times of year are generally unsuitable for field work.

4.3.10 Obtain Permission for Site Visits

4.3.10.1 Permission should always be obtained to visit a site or a proposed site. The exact procedure to obtain the required permission may vary greatly depending upon the location of the area in question and who owns or controls it. In any event, the request should go through the appropriate military channels to the military or governmental agency authorized to conduct the negotiations. In foreign countries, government-to government agreement may be required.

4.3.10.2 A copy of the complete set of site visit authorizations must accompany the survey team. When a site is on private property, such as a farm or ranch, it is recommended that the survey party visit the owner or his tenant immediately prior to entering the site for the survey. Inquire as to preferred routes across the property (this may vary with crop development, movement of livestock, etc.) This courtesy may influence later negotiations for lease or purchase of the site.

4.3.10.3 System design or field survey personnel will not ordinarily participate in site visit negotiations, but should be prepared to furnish a representative to accompany legal or property officers on visits to property owners. Negotiating officers should be thoroughly briefed on the purpose and general operation of the proposed system, so that they will be prepared to answer questions on system interference to radio or TV reception, health hazards from radiation, etc.

4.3.11 Site Visits

4.3.11.1 Upon arrival at a site, the first task of the survey team will be to verify the location selected on the basis of the map studies. There are likely to be small variations in the topography that were not shown on the maps, and it may be desirable, in the judgement of the survey chief, to make small adjustments in the site location. The location of the antenna, or antenna tower, should be marked with a stake, and covered by a small cairn if rocks are available. The location of buildings should then be tentatively marked by stakes, using the size and distance from the tower guidelines from the preliminary site plan map. The boundaries of the desired plot of land should then be determined and marked by stakes, taking into consideration requirements for anchors of guyed towers (although free standing towers will generally be used), as well as land needed for access roads and the radiation hazard restricted area in the antenna foreground. Avoid, if possible, sites where heavily travelled roads are within about one kilometer on a radio path. Major airports should also be avoided, since a radio path crossing or closely paralleling a busy air corridor may be subject to severe multipath effects caused by aircraft.

4.3.11.2 A sketch of the site is made in a field notebook, showing the location of tower and buildinqs, trees, large boulders, ditches, etc. Then measurements are made with the steel tape and recorded with dimension lines on the sketch, so that an accurate site map can be prepared. The sketch should be clearly identified by name. site number, geographical coordinates, and quadrangle map name or number. It should be accompanied by a verbal description of the type of soil, vegetation, number and size of trees (trunk diameter and height), number of trees that will have to be removed, approximate location and extent of leveling required. If soil samples are taken, the sampling points should be marked on the site sketch.

4.3.11.3 Photographs are made of the horizon to the north, east, south and west from the tower location, and also along the centerline of each path from the site; the se should be fully identified and fastened to a Page in the notebook. Photographs should also be made at a short distance from the site to provide an overall view of the entire site; approximate site boundaries and antema location should be entered on these in ink. A more distant view, to show the site area with reference to surrounding major terrain features, will also be useful.

4.3.11.4 Generally speaking, azimuths determined by magnetic compass are not sufficiently accurate for radio path surveys. When magnetic compass bearings are used for rough orientation, they should be corrected for the local declination, which may be obtained from topographic or aeronautical charts. Irregular or local variations of compass bearings are caused by magnetic storms, iron ore deposits, large objects of iron or steel, and electric power lines; therefore, great caution must be used in interpreting compass readings, particularly in the far north (e. g. , Alaska, Iceland, Greenland) or in areas with known large mineral deposits.

4.3.11.5 The latitude and longitude of the tower location, or some other reference point on the site, should be determined to the nearest second. This can be done by map scaling, traverse survey, triangulation survey, and celestial observations. The method selected will depend upon the particular conditions, such as irregular terrain and distance from an acceptable benchmark. In most cases the required accuracy can be attained by careful scaling from a 7-1/2-minute quadrangle map with a device such as the Gerber Variable Scale. (One second of latitude = 101 ft or 31 m, approximately.) It will rarely be necessary to determine location by celestial observations, which require considerable time and skill, but it will usually be necessary to determine path azimuths from observations of Polaris, the-sun, or other stars. The Polaris method, which is useful from about 10° to 65° N, is described in detail in Appedix 6.1. Information on other methods can be found in surveying textbooks, or in the abridged ephemerides and surveying manuals furnished by the instrument makers.

4.3.11.6 On the final site survey a ~~reference base line~~ should be established on or near the site; this will consist of three concrete monuments located on a true azimuth established by celestial observations. These monuments should be spaced about 100 m apart where possible, and will contain a flush -amounted pin or plaque giving the exact location and true azimuth, and also an Identifying mark. Simplify references to one of the three markers.

4.3.11.7 The survey notes should include a descrlption of the site with reference to existing roads and towns, so that contractors and suppliers can readily be directed to the site (see example, figure 4. 3-3).

4.5.11.8 The elevation of the ground at the antenna locations should be determined at least to the nearest 5 meters (±21/2 m) and more accurately if feasible (to the nearest meter). A topographic map of the site area should be prepared to a scale on the order of 1:100 to 1:500 and contour intervals of 1 to 2 m. * This map should show the exact locations of the reference base line, existing structures, trees, utility lines, etc. True north and baseline azimuth will be indicated (see examples, figures 4.3-1 and 4.3-2).

4.3.11.9 The method used to determine elevation will vary with the type of survey, field conditions, distance to benchmarks, and the personnel and equipment available. Differential leveling, or the extension of a known vertical control point (benchmark) by' a series of instrurnent setups, is the most accurate method and is recommended for the final survey. Trigonometric leveling is useful where elevations must be determined over relatively long distances, as in very rough or inaccessible terrain; it is not ordinarily used for site surveys but may be employed to determine the elevation of obstacles along a radio path. Barometric leveling is the simplest method of determining relative ground elevations, and is particularly useful for the initial survey. It can provide the accuracy required for the final survey, if ntelligently used. Barometric techniques are treated in detail in Section 6.2.

4.3.11.10 The access to the site must be described in detail so that estimates can be made of the cost of building a road to the site. Prepare a sketch map showing the route of the proposed road with

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* Within the United States, where topographic maps are available with elevations in feet it may be more practical to prepare site maps on the same basis.

reference to the site and existing roads; also indicate the type of soil, number of trees that will probably have to be removed, degree of slope, and approximate length of the road, compared to the most direct distance from the site to existing roads.

4.3.11.11 The probability of all-year access to the site should be estimated after discussing the matter with nearby residents, highway department maintenance personnel, forest rangers, and local meteorologists. Get an estimate of the number of days per year when the existing roads in the area are impassable because of snows winds or heavy rain. Inquire as to the possibility of snow removal and maintenance of site roads by highway department crews.

4.3.11.12 The availibiliy of commercial electric power will be a major factor in determining the operating expenses of the site. If there is a nearby transmission line, show its approximate route on a topographic or road map, as well as recording pertinent details in the field notebook. Obtain the name and address of the utility company, and make inquiry as to the existing policy on line extensions for new customers. The survey party should have available information on the approxiate power requirements for the terminal radio equipment, also on the size of the various buildings and the temperature to be maintained by air conditioning, so that utility officials can estimate the overall site power demands.

4.3.11.13 If the site is in an area where heatinq of the buildinqs wi 11 be necessary, determine if there are local sources of propane, natural gas, heating oils, or other fuels. Also check on availability of fuel for the standby motor- generator. Determine approximate costs of various fuels, delivered at the site.

4.3.11.14 List nearest sources of building materials, such as lumber, brick, concrete blocks, and ready-mixed concrete. List local general, electrical, and heating contractors.

4.3.11.15 Check with local authorities on possible zoning restrictions in the site area. For example, type of construction permitted, requirements for sanitary facilities, maximum height limitations, etc. Check locations of nearby airports to see if proposed site is in approach corridor of any of the runways, or if radio path will pass over the airport. Also determine if there are any explosives stored in the area, particularly in the foreground of each antenna.

4.3.11.16 Determine the possibility of water supplies for the site. Get a local opinion on the depth to potable ground water, depth to bedrock, and the load-bearing qualities of the soil at the site. In some areas it will be appropriate to check with local sources on the frequency and severity of seismic disturbances.

4.3.11.17 Heather conditions should be discussed with local meteorologist, as outline in 4.3.3.3.i.

4.3.11.18 If there are any foreign microwave system in the area of a site(i.e. , systems operated by any other military or civil agency, industrial or transportation firms, etc.) note the locations of these repeater or terminal sites on a system map. Determine the operator, frequency, equipment nomenclatures, antenna nomenclatures, power output, and if the antenna is directional, its aximuth and elevation angle. Also, show the same items for radars.

4.3.11.19 If path loss testing is performed by a team independent of the survey party, it will be important that they have information on the exact locations selected for the antennas by the survey party. Path loss testing procedures are discussed in Section 4.3.1.5.

4.3.11.20 Interference measurements may be required on some sites, depending upon what is already known, or learned during the field survey, about possible interference sources.

4.3.11.15 Check with local authorities on possible zoning restrictions in the site area. For example, type of construction permitted, requirements for sanitary facilities, maximum height limitations, etc. Check locations of nearby airports to see if proposed site is in approach corridor of any of the runways, or if radio path will pass over the airport. Also determine if there are any explosives stored in the area, particularly in the foreground of each antenna.

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4.3.11.19 If path loss testing is performed by a team independent of the survey party, it will be important that they have information on the exact locations selected for the antennas by the survey party. Path loss testing procedures are discussed in Section 4.3.1.5

4.3.11.20 Interference measurements may be required on some sites, depending upon what is already known, or learned during the field survey, about possible interference sources.

4.3.12 Survey Terrain Clearance and Elevation Angles

4.3.12.1 The elevation angle from each antenna location tO the horizon should be checked by theodolite if visibility conditions are satisfactory. Site along the path centerline, and also take readings along the horizon 45° on either side of the centerline. Record the angles on sketches and photographs, and also tabulate the angles with the true azimuth readings. lf there are any obstructions in the antenna foreground that were not indicated by the preliminary map study, describe them fully, locate on a map, and make sketches and photographs.

4.3.12.2 Haze and clouds will frequency prevent visual observation of the radio horizon, therefore the survey party should Se alerted to take such observations at the first favorable opportunity after arrival at a site. If no such opportunity arises, the party should visit the horizon area indicated by the map studies, describe the terrain and vegetation, check elevations at several points, and make sketches and photographs in both directions along the radio path.

4.3.12.3 Elevation of terrain or man-made obstructions in the foreground of each antenna should be checked, also the elevation of the ground at the horizon, and the elevation of the effective horizon (ground elevation plus height of trees or buildings). When the horizon is a hill or ridge it should be described as completely as access conditions permit, since the type of surface on the ridge and its sharpness are factors in estimating the propagation across the obstacle.

4.3.12.4 Elevation checks of map-derived path profiles can in most cases be made satisfactorily by altimeter. Section 6.2 qives details on altimeter survey procedures. The 'two-base' method is recommended if sufficient equipment and personnel are available. In any case, the altimeter readings should be recorded in a field notebook with the date, time of day, and identification number of the instrument used, so that possible errors related to pressure changes or defective instruments can be readily corrected.

4.3.12.5 Optical methods may at times be useful for checking location and height of nearby obstructions. Light flashes from xenon tubes or sunlight reflections from mirrors are used in conjunction with theodolites.

4.3.13 Profiles from Aerial Surveys

4.3.13.1 Profiles can also be obtained by using a Terrain Profile Recorder (TPR) on aerial surveys of the proposed routes. The TPR system consists of a precision radar altimeter, a pressure sensing device called a hypsometer, and a continuous-strip 35 mm camera, which has been bore-sighted to the axis of the radar beam. The hypsometer measures the aircraft deviation from a preselected barometric altitude, while the radar altimeter measures the terrain clearance. The continuous-strip camera is set to take overlapping photographs to record the exact aircraft position; the recorded data include the tripping time of each exposure, the indication of the aircraft and radar altimeters, and the deviation shown by the hypsometer. A similar system employs a laser altimeter instead of the radar altimeter; however, this system has an operational limit of about 6000 ft, while the system with the radar altimeter can be employed from about 6000 to 32000 ft.

4.3.13.2 Path profiles can be obtained quickly by aerial methods, but there are a number of potential sources of error. These include the following:

(a) Determination of the radio path center line -- the pilot needs markers and checkpoints but these may be difficult to provide in rugged or inaccessible terrain, and may be of questionable accuracy if available maps are poor.

(b) Beamwidth-- the radar beamwildth will try from 100 to 500 ft at the surface, depending upon the altitude of the aircraft. Since the recorded signal corresponds to the high point in this strip, the indicated elevation of the radio path could be considerably in error in rough terrain.

(c) The radar beam penetrates foliage of trees to a variable and unknown degree.

(d) The effects of thermal or mechanical turbulence and wind drift make it difficult to hold a precise course and altitude, and any tilt of the radar beam causes errors in the "on-course" elevations.

(e) General errors in pressure altimetry are discussed in section 6.2. These include instrumental lag, temperature errors, and errors related to movement of pressure systems. Sizeable errors may occur in the vicinity of thunderstorms, where “pressure jumps” frequently occur. In addition, there are errors related to the static pressure system of aircraft altimeters.

4.3.14 Profiles from New Maps Drawn from Aerial Photographs

4.3.14.1 Profiles may be obtained from maps based on three-dimensional aerial photographs, using photo grammetric techniques. Very high accuracy is possible if a sufficient number of precise ground control points are used. A series of photographs is made of the desired are from altitudes between about 300 m and 10, 000 m, depending on the scale and accuracy required. Each photograph has a 6071$_0$ overlap with adjacent photographs, and a set of two adjacent pictures forms a “stereo pair” that gives a three-dimensional model of the terrain, when seen through a special viewer/plotter device. This has a measuring system for determining horizontal and vertical distances from the projected model by reference to the photo control points previously surveyed and marked on the ground. Auxiliary equipment can be set to trace a particular elevation and plot the contour lines over the area to the desired interval.

4.3.14.2 The comparative cost of this method and more conventional techniques of preparing path profiles is not known at present. It is doubtful if photogrammetric methods would be economically feasible for single links, but for an extensive system the costs should be more competitive. If recent photographs are available, photogrammetric techniques may provide much more current path information than could be obtained from the best available topographic charts, which may be several years old, and may not show recent changes on the radio path that could significantly influence path performance such as new construction, or perhaps the highly reflecting surface of a new reservoir. Interpretation of the stereo photographs by experts can also provide information on the type, height, and density of trees, as well as the best location for access roads, sources of water supply, location of power lines, and sources of possible interference.

4.3.15 Path Loss Measurements

4.3.15.1 Path loss are made by transmitting all modulated RF carrier between adjacent repeater sites and measuring the received power; if transmitter power, antenna gains, and wave guide losses are known the path loss is readily determined. Path loss testing is expensive but it increases the probability that the desired results will be obtained, particularly in areas where climatic effects on propagation are not well known. When the system design indicates a need for very large antennas and high transmitter power, the cost of a test program may easily be justified in terms of the high cost of overdesign; on the other hand, if the design decision is between relatively small antennas, the designer must consider the possibility that the money required for a test program might perhaps be better invested in larger antennas, which would give a permanent increase in system margin. On multi-hop systems, a test of the most critical link is often sufficient for the entire system.

4.3.15.2 The reliability of data is generally proportional to the period of measurement, and since seasonal changes are known to occur on beyond the horizon paths it would be desirable to have path loss data over a complete year. Economic factors usually rule out such an extensive program, however, and in most cases only a few weeks testing be possible. Path losses are usually greatest in the winter months (or in the dry season), so that measurements for one month [76] during the wints will generally provide satisfactory indications of the worst propagation on the link. Measurements over a period of only a few days can be very misleading, because of the changes in large-scale weather patterns that typically occur at intervals of a few days. It is important that measurements be made 24 hours per day, since there are defirite diurnal effects on most tropospheric radio paths.

4.3.15.3 Large portable towers are ordinarily not required for path loss measurements on scatter paths, provided foreground obstacles are cleared, since it has been found that changes in antenna height do not greatly affect troposcatter paths unless the horizon angle is changed significantly [11]. The essential equipment includes a stable transmitter, transmission lines, antennas receiver, recorders, and calibration equipment. In general, low transmitter powers and narrow receiver bandwidths are used, in order to keep the equipment size and weight within a reasonable range; for example, a 1OO-W transmitter, 500-Hz bandwidth, and 28-ft antennas may be adequate for paths of more than 450 miles at a frequency of 900 MHz [12]. As noted in 4.3.7, frequency authorization must be obtained prior to any testing.

4.3.15.4 The short-term fading on long transhorizon paths is usually approximated by a Rayleigh distribution but on the shorter paths (primarily diffraction) it may be useful to sample short-term signal characteristics for estimating the gain to be expected from diversity. The mean attenuation, however, is of more importance, and this can more easily be studied if integrating time constants of about one minute are used [13].

4.3.15.5 The location of the antennas during path loss testing should be very close to the permanent sites selected on the basis of the map study and site surveys; in particular the horizon elevation angles should be the same. The initial orientation of the antennas should be by survey methods, using calculated elevation angles and azimuths; the final orientation is made by adjusting each antenna for maximum received signal level. (If reference baselines have not been established at the sites, a true azimuth should be determined by observation of Polaris (or other stars)). A satisfactory method of final alignment is to locate the approximate peak received signal position, then determine the angular setting on each side of this peak position(in aximuth and elevation) that gives an equal decrease in level from the maximum. The final setting of the antenna should be exactly half-way between these two side points. An orientation of this type requires a steady signal for accuracy, and this condition is not always easy to obtain on transhorizon paths; if there is any signal variation during the alignment procedure, several sets of readings should be taken and the median elevation and azimuth values used for the final antenna setting [12].

4.3.15.6 Complete and detailed records are essential in path loss and performance testing. Field data should be recorded in a bound notebook, in chronological sequence , and should include the following:

a. List of personnel involved,
b. Location description of sites, antenna locations and heights, with sketches and photographs,
c. Description of equipment used (identify by serial number),
d. Calibration data,
e. Local weather observations (at each site, preferably several times daily),
f. Record of any changes in antenna placement or polarization,
g. On-off times for recorder chart rolls or tapes,
h. Record of equipment malfunctions, and corrective action taken.

4.3.15.7 The on-site weather observation, when used in conjunction with weather maps and other information from the meteorological services, are important in the analysis of the propagation data. Observations at the sites should include the following items:

a. Cloud amount, type, and height,

b. Visibility in miles or km, as estimated by reference to prominent objects or terrain features,
c. Wind direction and approximate speed,
d. Precipitation forms, amounts, obstructions to vision (fog, etc.),
e. Temperature and dewpoint or relative humidity.

It is recommended that, as a minimum, the on- site observations be made at 0600, 1200, and 1800 local time daily while path tests are in progress. Surface and upper air (radiosonde) data from local military or civilian weather stations should also be collected.

4.3.16 Analyze, Compare, and Select Sites

4.3.16.1 On conclusion of the field observation, the survey data are summarized for use in the final system design studies. Most of the analysis and report preparation is best done while the survey is in progress, since omissions or discrepancies noted can then be readily checked while the survey party is still in the area. Site maps are prepared for each site, showing reference marker, antenna locations access roads, property lines, etc; also significant discrepancies between the survey and original path and site selection data should be noted on the maps of the area.

4.3.16.2 The site survey report should contain the following information (see also 4.3.3.3):

a. Name of site (nearest town, numerical designation),
b. Latitude, longitude, elevation above sea level of the reference mark.
c. The location of antennas with respect to the marker.
d. Overall rating of site by party chief (satisfactory, unsatisfactory), with brief synopsis of factors upon which the rating is based.

e. Description of site--general area, access, specifics of topography, soil, etc. Include sketches, tographs, amended site plans .

f. Elevation angles from each antenna to the horizon along path centerline, and to 45° either side of centerline (only significant changes need be noted). Include sketches and photographs, and identify azimuths by reference to true north.

g. List of locations and elevations of significant foreground obstructions,

h. Description of terrain from site to horizon, and identification at c critical points.

i. Site development problems- -discuss legal restrictions (zoning, building codes), grading, clearing, drainage, soil type and load-bearing qualities, water supply, sewage disposal access roads, power availability, labor supply, environmental factors (earthquakes, flooding, snow pack, ice loading, high winds, blowing dust and sand, extremes of temperature and humidity),

j. Power supply company, with address; location of nearest line and available capacity for site, volt age, phase, frequency.

k. Site owner ship- -name, address, telephone number Of owner or legal representative; for government lands give department or agency having jurisdiction,

1. Nearby airfields, railroads, navigable rivers, highways; list names of local commercial carriers,

m. Local contractors -- general, electrical, plumbing, steel erection, fuel suppliers, etc. ,

n. Local sources of building materials, warehouse facilities,

o. Existing communications facilities (land lines, radio),

p. Present or future sources of potential interference (radars, factories, microwave systems, high-density air traffic corridors, highways).

q. Copies of locally-obtained maps (county, district, forest, highway dep., etc),

r. Name and address of local contact (military, civilian, host country official).

4.3.16.3 In using the various data collected by the survey party, technical desirability must be weighed against potential cost of site acquisition and development, all-weather accessibility, long-term operating costs, security considerations, and cost of facilities for operating personnel. Some remote sites may have distinct advantages in terms of horizon elevation angles, but a complete analysis will show the development and operating costs to be prohibitive.

4.3.16.4 An indication of long-term median signal levels and short-period fading characteristics can be obtained from the path loss measurements. The meteorological data collected during the measurement program should be analyzed by an experienced meteorologist to detemine if the measurement period was representative of the particular area and month, or if abnormal conditions prevailed. If received signal levels are much higher or lower than expected, it may be desirable to calculate refractivity gradients from nearby radiosonde observations and make a ray tracing analysis of the radio path. Conditions of the winds, temperature, and humidity in the common volume can also be estimated from radiosonde data.

4.3.16.5 Requests forwarded to area commands for approval of sites should be accompanied by maps and other detailed information, such as legal description of the property, name and address of owner, and estimated period of use if acquired.

4.3.17 Select Frequencies

4.3.17.1 Tentative availability of frequencies will have been determined during the feasibility studies, as outlined in section 4. 1. 11. When the final site selections have been made, the specific number Frequencies required for the system should be determined, taking into consideration changes in system design resulting from study of the survey data. The proposed frequency usage on each link of the system is forwarded to the appropriate frequency assignment coordination office, accompanied by a system map keyed to the tabulated frequencies.

4.4. TRANSHORIZON LINK DESIGN

4.4.1 Introduction and Outline

4.4.1.1 It is assumed that the work discussed so far resulted in selection of routes, terminal sites, and repeater sites. Limitations on antenna size and height, usable frequency bands, and logistic support are known, system requirements have been established) and approximate transmission loss estimates are available. The purpose of this section is then to discuss detailed procedures for link deign including calculations of basic transmission loss, estimating equipment parameters, and determining expected channel noise. The results are used two-fold: first in a final determination of the technical feasibility of each link, and then in fitting each link into the total system as an ultimate test of whether performance requirements have been met, or whether changes in the overall concepts are necessary. Prior to the discussion of transmission loss calculations, necessary atmospheric parameters and the drawing of path profiles will be explained. Thus, the outline for the remaining subsections is as follows:

4.4.2-4.4.4	Atmospheric parameters
4.4.5-4.4.12	Path profiles
4.4.13-4.4.25	Transmission loss calculations
4.4.26-4.4.33	The system equation, confidence limits, and service probability
4.4.34-4.4.38	Diversity
4.4.39-4.4.43	Radio frequency interference
4.4.44-4.4.70	Equipment considerations

4.4.1.2 For simplicity, equations and figures will be numbered sequentially throughout section 4.4. Step-by-step procedures are given at the end of the section. These are arranged in four groups as follows:

A. Procedures for great circle calculations (section 4.4.9).

B. Procedures for determination of at. ospheric and terrain parameters (sections 4.4.3, 4.4, and 4.4.7).

C. Procedures for transmission loss calculations (sections 4.4.13 to 4.4.25).

D. Procedures for determining path antenna gain and for frequency optimization (section 4.4.29 and 4.4. 30).

Steps are numbered sequentially in each group. Note that the step-by-step procedures do not always follow the sequence of the discussions in the main text primarily because in the text the atmospheric effects are discussed first as an introduction and background to transhorizon transmission loss calculations.

Following step-by-step procedures are several worksheet formats which also may be used as an aid in performing the transmission loss calculations and in keeping track of the numerous required parameters.

4.4.1.3 The formulas and graphs in this section have been taken from various sources such as [16], [30], or [69], and have in many cases been modified or simplified by the authors and contributors to this handbook. Generally it was intended to provide easily readable graphs, and formulas for Slide rule or pocket calculator use. These procedures should be adequate for most trans horizon link design problems. References to previous publications and other material are made as required in order to provide information for unusual problems.

4.4.2 Atmospheric Parameters

4.4.3 Refractivity

4.4.3.1 The radio refractive index is defined as the ratio of the velocity of propagation of a radio wave in a vacuum to the speed in a specified medium. At standard atmospheric conditions near the earth's surface, the radio refractive index (n) has a value of approximately 1.0003. When evaluating refraction effects on radio propagation, it is generally more convenient to use a scaled-up value, called refractivity (N), which may be obtained as follows:

$$N = (n-1)10^6 = \sim \quad P + \frac{4810 e_s RH}{T} \qquad (4.4\text{-}1)$$

where P = pressure in millibars
T = temperature in degrees Kelvin
e_s = saturation water vapor pressure in millibars
RH = relative humidity expressed as a fraction

Thus, under standard conditions, the refractivity is about 300 N-units.

4.4.3.2 The bending of a radio ray passing through the atmosphere is controlled by the gradient of refractivity. For most purposes, the horizontal gradient is so small that it may be neglected.* The vertical gradient under standard atmosphere conditions is approximately -40 N-units/km, which is close to the average value observed near noon on a clear day in summer (this is sometimes referred to as the "normal" value). However, the vertical gradient in the lowest layers of the atmosphere may vary between values as extreme as +500 to -1000 N-units/km, as a function of climate season time of day, or transient weather conditions; it is influenced by terrain, vegetation, radiational conditions, and atmospheric stratification. ** The more extreme gradients tend to occur in layers less than 100-m thickness, and these are not likely to extend over long distances, such as those common to transhorizon radio links (exceptions may be links over extremely smooth terrain

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*The refractivity is strongly influenced by change in pressure, which amounts to about 35 mb in the first 300 m above sea level; such a pressure change in the horizontal plane would normally occur only over a distance of several hundred kilometers. Vertical changes in temperature and humidity also tend to be more pronounced than those in the horizontal.

**It is customary to normalize all refractivity gradients, even for very shallow layers, to terms of "N-units/km".

or over the sea surface under very stable arrnospheric conditions), When averaged over 500-m to 1000-m heights above groun" the refractivity gradient is likely to range between 0 and -300 N-unit/km furthenmore, it is near the standard value of -40 N-units/km during a large percentage of a year.

4.4.3.3 Various refractivity parameters have been used in estimating radio propagation effects, for example, the surface refractivity (N_8), the surface refractivity reduced to sea level (No), the gradient in the lowest 50 to 100 meters, and the average gradient in the lowest 1 km (generally referred to as "AN/Ah," and approximated by t@ difference between the refractivity values of the surface and 1 km above the surface). Details of the derivation and application of these parameters may be found in a number of publications [13, 14, 15, 18, 71].

4.4.3.4 The concept of the "effective earth radius" is a convenient means of accounting for the bending of radio rays caused by changes in the vertical refractivity [15, 16]. This is related to the atmospheric refractivity gradient, AN/Ah, by the following equation:

$$a = a_o[l + a_o/Ah \times 10^{-6}] \qquad (4.4\text{-}2)$$

Where a is the effective earth radius in km, a_o. is the actual earth radius (6370 and ΔN/Δh is the refractivity gradient"* The standard atmosphere or "normal" gradient of -40 N-units/km corresponds to an effective earth radius 4/3 larger than the actual

---

*ΔN/Δh is generally used to refer to the average gradient in the lowest 1 km, however, the calculation may also be based upon the gradient in the lowest 50- or 100-m layer (sometimes referred to as the "initial" gradient to distinguish it from the l-km layer) [71] are based on radiosonde observations of pressure, temperature, and humidity Therefore, AN/Ah is usually given In N-units per km by the difference between the calculated refractivity at the surface and 1 km above the surface which is a good approximation of average gradient.

earth radius, a/a_0, is commonly used, and has been designated the "effective earth radius factor", k. Thus for a standard atmosphere k= 4/3. Although this concept is based on a gross oversimplification of very complex atmospheric processes and characteristics, its use is satisfactory for most applications to transhorizon communications links. Figure 4. 4-1 shows the relationship of (4.4-2) in graphical form [15].

4.4.3.5 Large positive gradients are associated with subrefraction and mean smaller effective earth radii. They generally produce larger path loss values. Large negative gradients are associated with superrefraction and atmospheric ducts which favor radio wave propagation far beyond usual limits. The likelihood of subrefractive conditions must be considered when high link or system reliability is required, whereas super refraction may produce overreach of signals and interference between links operating on the same frequency.

4.4.3.6 Since complete statistical information on the occurrence of meteorological parameters has seldom been available, the practice has been to base transmission loss calculations on average atmospheric conditions. This procedure results in quite reliable estimates of long-term median basic transmission loss values [16,17], whereas the time variability of transmission loss is largely based on empirical data obtained from measurements. However, if the occurrence of extreme refractivity gradients can be reliably estimated in terms of percent of time, such gradient values can be used to provide direct estimates of basic transmission loss for comparison with the resuits obtained from the empirical variability curves.

4.4.3.7 For long-term median estimates an empirical relation has been established between the average monthly mean refractivity gradient $\overline{\Delta N/\Delta h}$ for the first kilometer above the surface, and the value of the average monthly mean refractivity, $\overline{N}_s$, at the surface. In the U. S.,

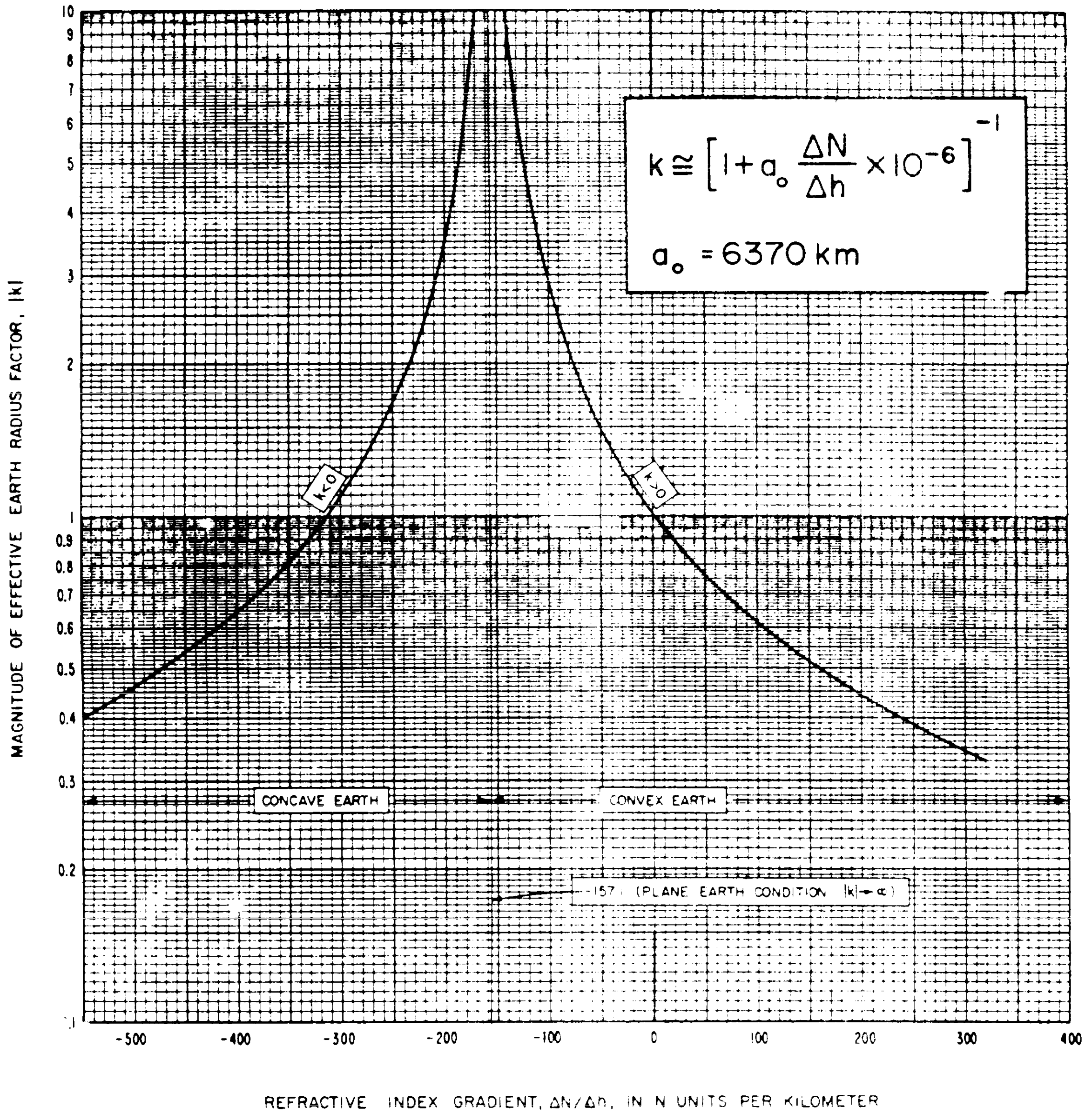


Figure 4.4-1 Effective Earth Radius Factor, k, versus Linear Refractivity Gradient [15]

$$\overline{\Delta N}/\Delta h = -7.32 \exp(0.005577 N_s) \qquad (4.4\text{-}3a)$$

where $\overline{\Delta N}/\Delta h$ is in N-units/km, and Ns in N-units.

Similar relations have been developed for other countries [1]:

$$\overline{\Delta N}/\Delta h = -9.30 \exp(0.004565 N_s) \qquad (4.4\text{-}3b)$$

in the Federal Republic of Germany

$$= -3.95 \exp(0.007 N_s) \qquad (4.4\text{-}3C)$$

in the United Kingdom.

These relations have been derived for average or long-term median conditions, and should be used only for $250 \leq \overline{N}_s \leq 400$ N-units or for the corresponding gradient values between -29.5 and -68. 1 N-units per kilometer. They are not applicable to Positive gradients.

4.4.3.8 Transmission loss calculation formulas, particularly in the region where tropospheric scatter is the dominant propagation mechanism, have been based on n_s rather than on $\overline{\Delta N}/\Delta h$ because more complete statistics of surface refractivity are available than those of the gradient.

4.4.3.9 The surface refractivity Ns is a function of temperature, pressure, and humidity, and decreases therefore with elevation. Figure 4.4-2 is a map showing minimum monthly mean values of surface refractivity normalized to mean sea level [181. For a particular link, the applicable values of n_0 are read from this map and converted to values of n_s by:

$$n_s = N_0 \exp(-0.1057\, h_s)\ . \qquad (4.4\text{-}3d)$$

4.4.3.10 For transhorizon links, h_s is the elevation in km of each radio horizon above mean sea level, and the two values of n_s obtained from (4.4-3d) in this manner are averaged in order to obtain the N_s applicable to a particular link. Its use will be further discussed in section 4.4.18. An exception to the rule for determining n_s is the case

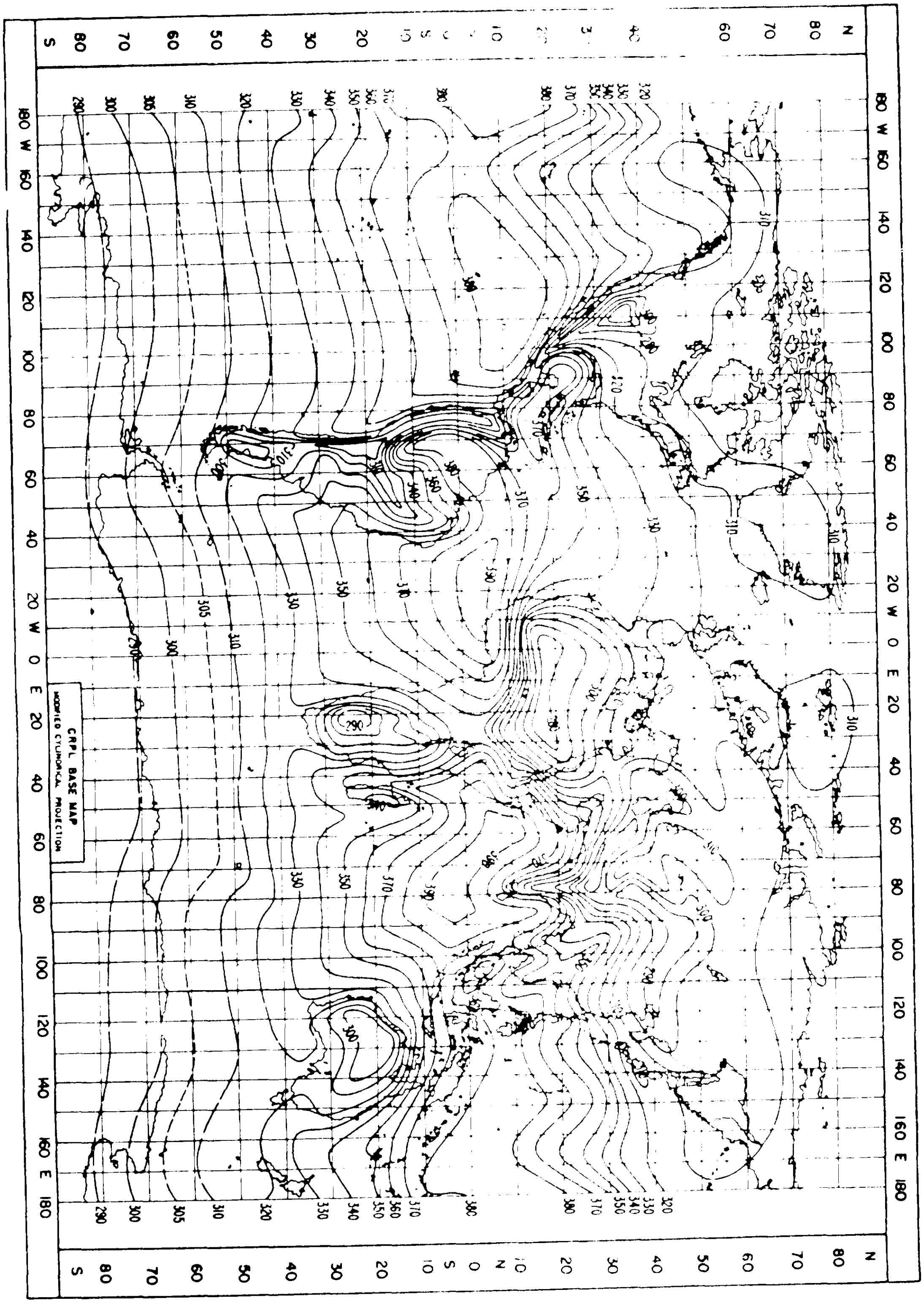


Figure 4.4-2 Minimum Monthly Mean Surface Refractivity Values, $\bar{N}_0$, Referred to Sea Level [18]

when an antenna is more than 150 meters lower in elevation than its radio horizon; in such cases the antenna site elevation is substituted for the horizon elevation in defining h_s . That is to say, h_s in (4.4-3d may take the form of $h_{L1,2}$ or $e_{s1,2}$ as discussed in steps 3 and 4 of the step-by-step procedures.

4.4.3.11 Using (4.4-1) and (4.4-2), a direct relation between N_s and the effective earth radius, a, can be established for $250 \leq \overline{N}_s \leq 400$ N -units:

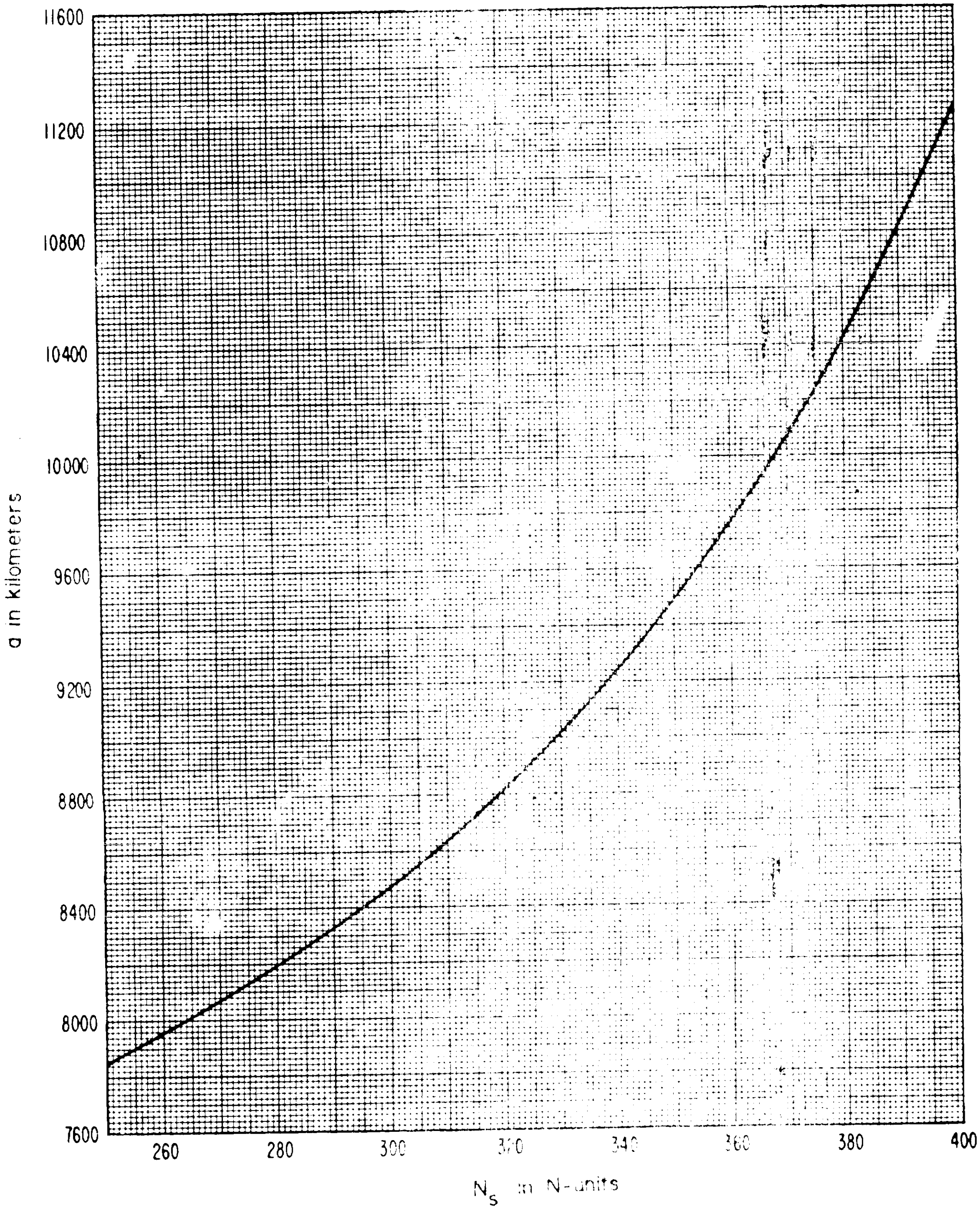
$$a = a_0 \, [1 - 0.04665 \exp (0.005577 n_s)]-1 \text{ km}, \qquad (4.4\text{-}4)$$

where a_0 = 6370 km, as before. This relation is shown graphically in figure 4.4-3.

4.4.4 Atmospheric Absorption and Rainfall

4.4.4.1 For terrestrial transhorizon links at frequencies up to about 5 GHz, absorption of the radio energy by atmospheric constituents, and, specifically, rain, is not a really serious source of attenuation. Figure 4.4-4 shows median values, A_a, of atmospheric attenuation as a function of carrier frequency in GHz and path distance in km for a climate such as Washington, D. C. These values may be used generally without too much error, and are added to the reference basic transmission loss values, as shown in section 4.4. 16.

4.4.4.2 Although heavy rainfall can cause appreciable attenuation of radio energy at frequencies above about 5 GHz, the lateral extent of cells producing cloudbursts is quite small. As an example, for a cloudburst-type rainfall (100mm/hr), the attenuation at 5 GHz is approximately 0. 3 dB per kilometer. However, cells producing such a rainfall rate usually extend only over a few kilometers; therefore the attenuation due to a cloudburst will seldom exceed 1.5 - 2 dB over any transhorizon link. Lesser rainfall rates will produce much less attenuation per kilometer; thus the total effect can usually be neglected, or,



N_s in N-units

Figure 4.4-3 Effective Earth's Radius, a, versus Sutface Refractivity N_s [16]

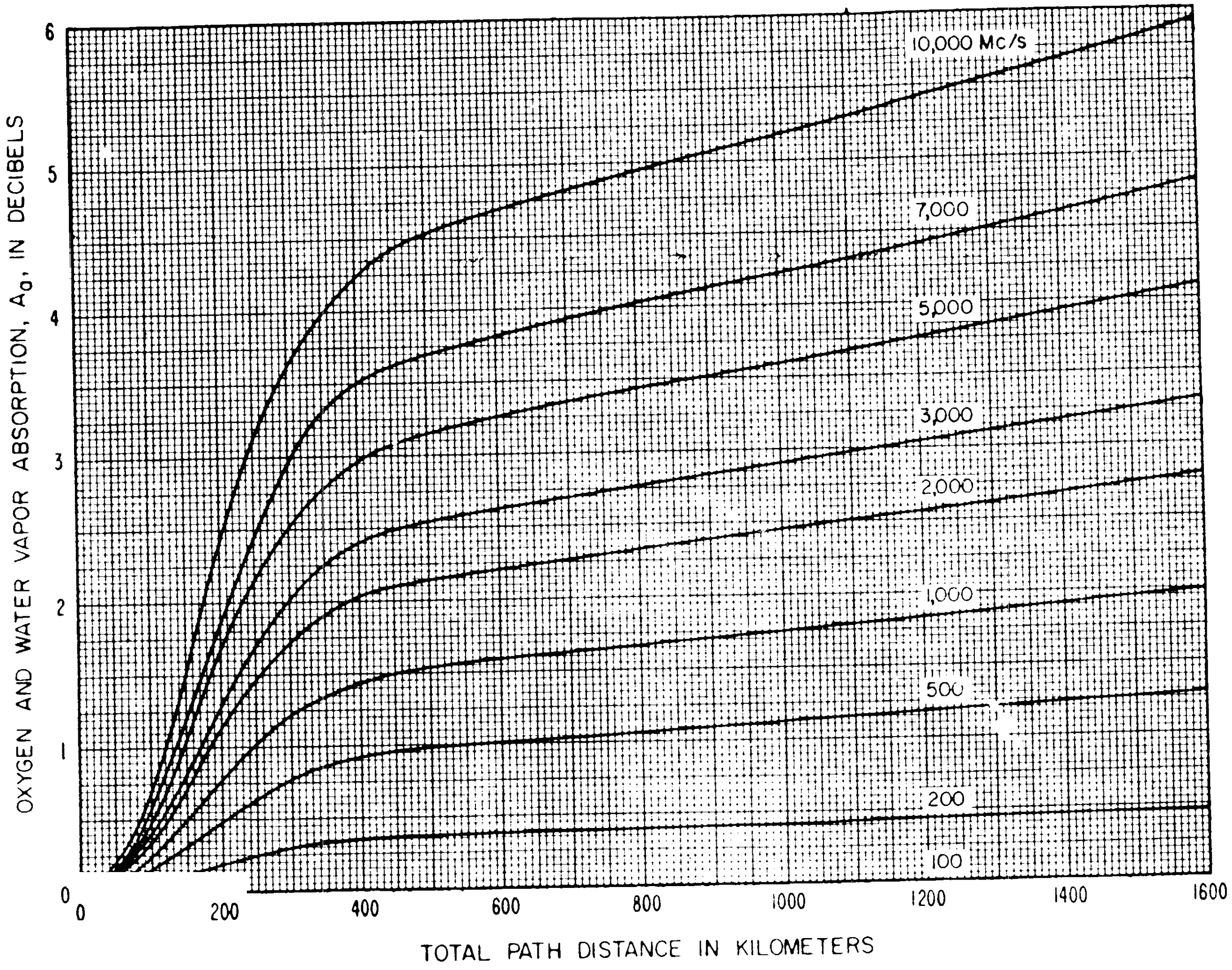


Figure 4.4-4 Estimate of Median Atmospheric Absorption (based on Washington, D. C. August data for oxygen and water vapor absorption [16]

For all practical purposes, be considered to be included in the empirical transmission loss variability (see sec. 4.4.25), or the general prediction uncertainty (see sec. 4.4.27). More specific numerical information on rain effects is given in [14] and [19].

4.4.5 Path Profiles

4.4.6 Purpose of Path Profiles

4.4.6,1 Radio frequency energy between two fixed points on the earth' s surface travels along the shortest path, which, from geometry, is approximately a great circle on the nearly spherical surface of the earth. Since antennas for point-to-point radio links have generally ery narrow beams, the terrain along the direct, great-circle route is most important in determining transmission loss and its variability, except in very special cases. The path profile either in graphical form (plotted), or in numerical form (tabulated) provides the data from which essentilal propagation path parameters can be determined.

4.4.7 Path Parameters

4.4.7.1 Parameters which can be determined or estimated from terrain profiles are actual antenna heights above ground (h_{g1}, h_{g2}) and above mean sea level, (h_{s1}, h_{s2}), distances to the radio horizons (d_{L1}, d_{L2}), elevations of the radio horizons above mean sea level (h_{L1}, h_{L2}), the horizon elevation angles($_{e1}$, θ_{e2}), and the angular Path distance, θ. These are identified in figure 4.4-5. The effective earth radius, a, has been defined in section 4.4, 3,4, and this definition is based on a constant atmospheric refractivity gradient over the range of interest. All "vertical" scales in figure 4. 4-5 are greatly exaggerated, and all angles are actually very small. All distances and heights are also very small in comparison with the effective earth radius. In the following formulas, all distances and heights are in kilometers, and all angles are in radians.

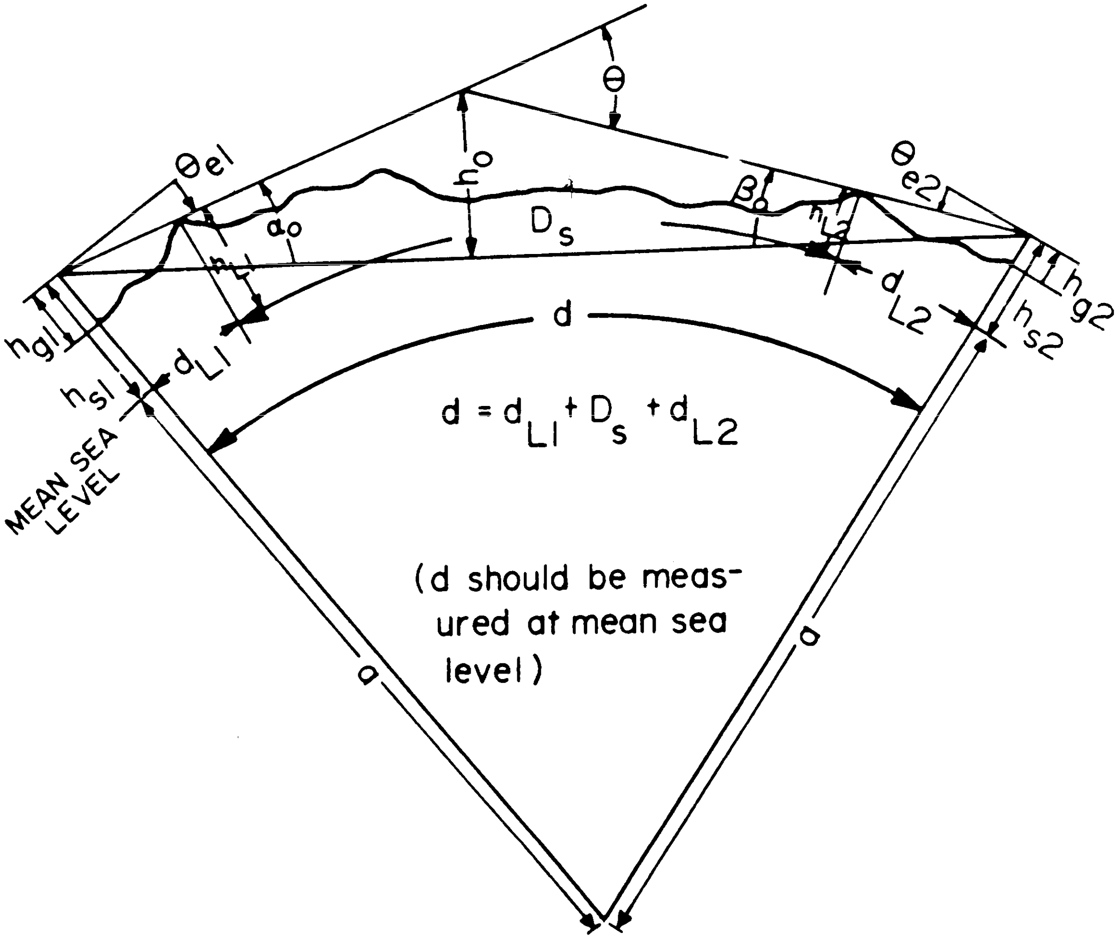


Figure 4.4-5 The Gemetry of a Transhorizon Path

4.4.7.2 The angular distance, θ, is given by the expression:

$$\theta = d/a + \theta_{e1} + \theta_{e2} \text{ radians} \qquad (4.4\text{-}5)$$

where d is the total path distance, a is the effective earth radius and θ_{e1} and θ_{e2} are the angles from each antenna to its horizon relative to the horizontal; i.e.e., relative to a tangent to that surface through the antenna which is concentric with the mean sea level surface.

4.4.7.3 The horizon elevation angles can be determined in the field using surveying instruments, and allowing for the difference between optical and radio refraction (see 4. 2.4. 2). They can also be calculated from the terrain profile information using the antenna heights h_{s1} an h_{S2} above mean sea level, the distance d_{L1} and d_{L2} from the antennas to their radio horizons, and the elevations h_{L1} and h_{L2} of the radio horizons above mean sea level:

$$\theta_{e1} = \frac{h_{L1} - h_{S1}}{d_{L1}} - \frac{d_{L1}}{2a} \text{ radians} \qquad (4.4\text{-}6a)$$

$$\theta_{e2} = \frac{h_{L2} - h_{S2}}{d_{L2}} - \frac{d_{L2}}{2a} \text{ radians.} \qquad (4.4\text{-}6b)$$

4.4.7.4 Actual terrain profile plots may suggest several possible horizon locations. In such cases, θ_{e1}, or θ_e are calcuated for all potential horizons, and the largest value obtained for each is the one to be used.

4.4.7.5 For smooth earth, where the horizon is the surface concentric with mean sea level through the antenna base, the relation between antenna heights h_{g1} and h_{g2} above the surface, the horizon distances and the horizon angles are given by:

$$_{L1,2} = \sqrt{2ah_{g1,2}} \text{ km} \qquad (4.4\text{-}7)$$

and

$$\theta_{e1,2} = -\sqrt{2h_{g1,2}/a} \quad \text{radians} \qquad (4.4\text{-}8)$$

$$= -d_{L1,2}/a \quad \text{radians.}$$

The distance Ds between radio horizons is generally defined by:

$$D_S = d - d_{L1} - d_{L2} \text{ km} \qquad (4.4\text{-}9a)$$

For smooth earth, the angular distance, θ, may then be approximated by:

$$\theta \cong D_s/a \quad \text{radians.} \qquad (4.4\text{-}9b)$$

4.4.7.6 The angles ao. and BO, which are used in diffraction and scatter calculations, are given by:

$$\alpha_o = \frac{d}{2a} + \theta_{e1} + \frac{h_{s1} - h_{s2}}{d} \quad \text{radians} \qquad (4.4\text{-}10a)$$

and

$$\beta_o = \frac{d}{2a} + \theta_{e1} + \frac{h_{s1} - h_{s2}}{d} \quad \text{radians} \qquad (4.4\text{-}10b)$$

Note again, that in 4. 4-5 to 4.4-10 all distances and elevations are in kilometers, and all angles are in radians .

4.4.7.7 It is clear from the geometry and from combining (4. 4-5), (4.4-10a) and (4.4-10b) that:

$$\alpha_o + \beta_o = \theta \quad \text{radians.} \qquad (4.4\text{-}11)$$

Finally, the parameter ho shown in figure 4. 4-5 is given by:

$$h = \frac{sd\theta}{(1+s)^2} \qquad (4.4\text{-}12)$$

where s is the ratio of the angles : α_o and β_o:

$$s = \alpha_o / \beta_o \text{ (if } \alpha_o < \beta_o \text{; } \beta_o / \alpha_o \text{ otherwise} \tag{4.4-13}$$

h_o and s are used primarily for scatter calculations.

The expressions given above are generally valid for ground-to-ground links with the effective antenna heights as defined in paragraph 4.4.17. 1 (m) less than 1 km. Additional allowances for refraction effects at greater heights, and formulas and graphs for special cases are given in [16. sec. 6.41].

4.4.8 Map Requirements

4.4.8. 1 Availability of maps, recommended scales, and required accuracy have been discussed in section 4. 2. Generally, approximate path profiles will already be available from the initial feasibility and route determination studies. From such profiles one determines by inspection which regions along the great-circle path are critical for obtaining the path parameters listed in section 4. 4. 7. 1. These regions are usually between the antenna sites and their radio horizon, and maps at the largest scale and smallest contour interval available should be used. Within the U. So , the best maps are the 1:24, 000 series of the U.S Geological Survey, which have contour intervals of 5, 10, or 20 feet depending on the ruggedness of the terrain covered. Most of the available sheets also include indications of ground cover which enables the user to estimate the height of trees, buildings, etc.

4.4.8.2 Although large areas of the United States are now mapped in this manner, there are still regions for which only older maps at smaller scales are available, or which have not been mapped at all under current programs. In such cases the designer has to make estimates based on the best available information including special survey work as discussed in section 4.3.

Available maps of foreign countries vary similarly. The best source is usually the Defense Mapping Agency Topoqraphic Center. British Ordance Survey maps and those from certain other countries are also available at large scales and include considerable detail, such as the nature of vegetation (forests, vineyards, swamps, etc.)=

4.4.9 Great-Circle Path Calculations

4.4.9.1 The terrain profiles to be evaluated for path loss calculations must be along the great-circle paths between transmitter and receiver location. Depending on the length of the path, the great-circle arc departs to some degree from a straight line drawn on a map because the earth’s curvature is usually not portrayed on topographic maps in a manner which preserves the true angles and azimuths.

4.4.9.2 A great-circle path must therefore be represented by a series of straight-line approximations (rhumb lines) between selected points on the great-circle arc, which can be accurately determined. This procedure should generally be followed for path lengths greater than about 30 miles, unless the terrain is sufficiently smooth so that small bearing errors will not result in erroneous radio horizon locations and elevations.

4.4.9.3 From the initial planning studies and field survey work (see sec. 4.3), the terminal antenna locations are given to the nearest second of latitude and longitude. Then the bearings between terminals, the total great-circle distance, and the coordinates of intermediate points can be calculated by trigonometric formulas using logarithmic tables or computer programs. An example of the organization of a map study for determination of the terrain profile for an actual transhorizon link is shown in figure 4.4-6. Here, the rhumb line, which is a straight line between terminals, is plotted first on an index map showing the boundaries of the available detailed topographic sheets. This

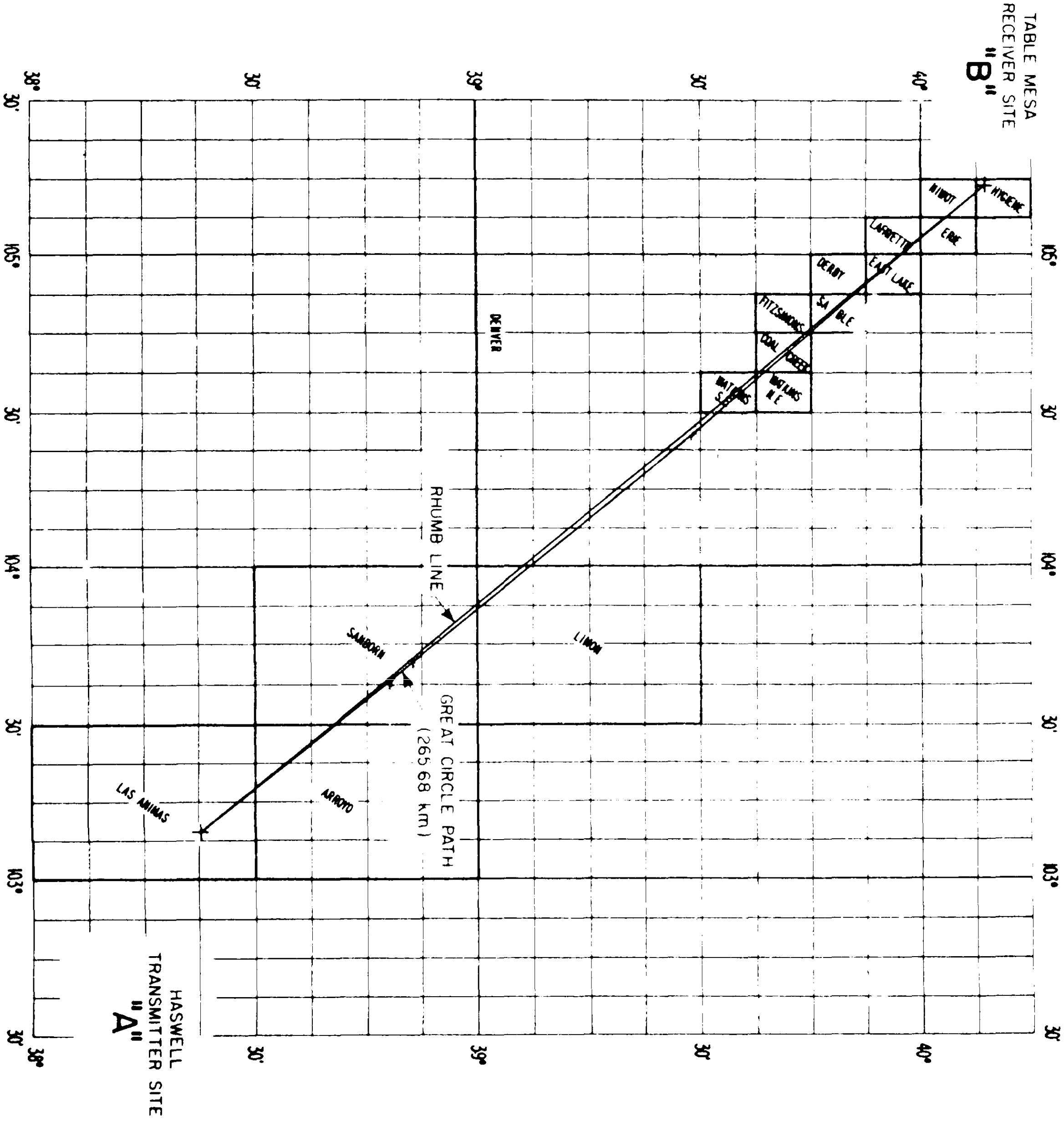


Figure 10

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rhumb line diverges from the actual great-circle path as shown, but is normally sufficiently close to it so that the necessary sheets can be easily identified.

4.4.9.4 The spherical triangle used for the computation of points on a great-circle path is shown on figure 4.4-7, and is denoted by PAB, where A and B are path terminals and p is the pole. B has greater latitude than A, and for clarity, P is in the same hemisphere as A and B. The triangle shown is for the northern hemisphere, but may be readily inverted to apply to the southern hemisphere. B′ is any point along the great-circle path between A and B, and the triangle PAB′ is the one actually solved. The latitudes of the points are denoted by ϕ_A, ϕ_B, and $\phi_{B'}$, respectively, and Z and Z′ are the corresponding great-circle path lengths. The following formulas are particularly useful for hand computations using logarithmic-trigonometric tables but can also be programmed for digital computers. They have been taken in this form, from a well-known reference book [20, pp. 730 - 739].

4.4.9.5 The initial bearings (X from terminal A, and Y from terminal B) are measured from true north. They are calculated as follows :

$$\tan\frac{Y - X}{2} = \left(\cot\frac{C}{2}\right)\left(\sin\frac{\phi_B - \phi_A}{2}\right)\Big/\left(\cos\frac{\phi_B + \phi_A}{2}\right) \quad (4.4\text{-}14a)$$

$$\tan\frac{Y + X}{2} = \left(\cot\frac{C}{2}\right)\left(\cos\frac{\phi_B - \phi_A}{2}\right)\Big/\left(\sin\frac{\phi_B + \phi_A}{2}\right) \quad (4.4\text{-}14b)$$

$$\frac{Y + X}{2} + \frac{Y - X}{2} = Y, \text{ and } \frac{Y + X}{2} - \frac{Y - X}{2} = X. \quad (4.4\text{-}15)$$

The great-circle angular distance, Z, is obtained from:

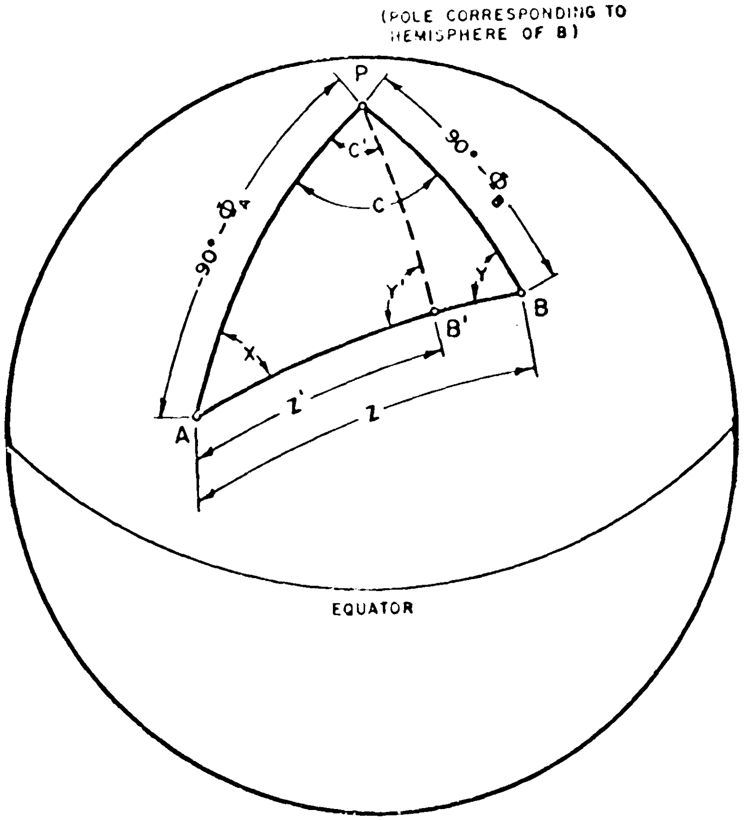

Figure 4.4-7 Spherical Triangle for Great Circle Path Computations [20].

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$$\tan \frac{Z}{2} = \left(\tan \frac{\phi_B - \phi_A}{2}\right)\left(\sin \frac{Y + X}{2}\right)\bigg/\left(\sin \frac{Y - X}{2}\right). \qquad (4.4\text{-}16)$$

4.4.9.6 Coordinates of intermediate points are calculated using two sets of formulas in accordance with the direction of the map edge intersected by the great-circle arc. For points selected at fixed longitudes chiefly along "vertical" (north-south) map edges, values of longitude are given, and solutions are obtained for the corresponding latitude values. For points selected at fixed latitudes chiefly along "horizontal" (east-west) map edges, values of latitude are given, and the corresponding longitude values are calculated.

To calculate the Latitude, $\phi_{B'}$' for a given longitude difference C', use:

$$\text{Cos } Y' = (\sin X)(\sin C')(\sin \phi_A) - (\cos X)(\cos C') \qquad (4.4\text{-}17a)$$

$$\cos \phi_{B'} = (\sin X)(\cos \phi_A)/(\sin Y'). \qquad (4.4\text{-}17b)$$

4.4.9.7 To calculate the longitude difference, C', for a given latitude $\phi_{B'}$, use:

$$\sin Y' = (\sin X)(\cos \phi_A) / (\cos \phi_{B'}) \qquad (4.4\text{-}18a)$$

$$\cot \frac{C'}{2} = \left(\tan \frac{Y' - X}{2}\right)\left(\cos \frac{\phi_{B'} + \phi_A}{2}\right)\bigg/\left(\sin \frac{\phi_{B'} - \phi_A}{2}\right). \qquad (4.4\text{-}18b)$$

4.4.9.8 The angle Z obtained in degrees from 4.4-16 is converted to units of length as follows (based on a mean sea level earth's radius of 6370 km):

$$d_{\text{km}} = 111.12\ Z^{\circ} \qquad (4.4\text{-}19a)$$

$$d_{\text{stat. mi.}} = 69.102^{\circ} \qquad (4.4\text{-}19b)$$

$$d_{\text{naut. mi.}} = 60.032^{\circ}. \qquad (4.4\text{-}1.9C)$$

4.4.9.9 Since tropospheric transhorizon propagatic paths may be relatively short, care must be taken that sufficent accuracy in desk calculations is maintained, particularly in interpolation of logarithmic-trigonometric functions. However, the above formulas are easily ized with five-place logarithmic-trigonometric tables. Another useful scheme with appropriate tables of the required functions is given by Ageton [21].

4.4.9.10 A computer program, based on expressions given by Bowditch [22], has been described and listed in an ESSA Technical Report [23]. It will give accurate results even for paths as short as a few kilometers although it will rarely have to be used in such cases .

4.4.10 Reading and Evaluating Profile Elevations

4.4.1001 After the path segments are plott::d on the maps, the next objective is the listing of terrain elevations as a function of distance from one or both terminals. This is, of course, tedious work, and should be undertaken with a well-defines objective in mind, so that unnecessary length y efforts are avoided. For applications to fixed point-to-point links, the objective is tc determine from the terrain profile the location and elevation of potential radio horizons, and other features, which are inputs to the path loss calculations. Any uncertainty of location or elevation of potential radio horizons may produce uncertainties in the calculation results, and could, in extreme cases, produce completely wrong estimates. It is therefore not important to determine elevation at equidistant intervals but to list all high points? low points, and apparent changes in slope along the propagation path. Since high prints are not always marked with the precise elevation value, such elevations must be estimated from the configuration and spacing of the contour lines. Of primary importance are the regions where potential radio horizons are located, and the regions between antenna sites and their horizons for which an average terrain elevation has to be estimated for long-term variability calculations. In some cases, off-path obstacles are also important, because they could contribute multipath components by reflection.

4.4.10.2 Generally at frequencies above about 200 MHz trees and other terrain clutter should be considered opaque to radio energy, and a part of the terrain. As an example, if the map indicates a forest along a ridge which constitutes a potential radio horizon, the height of the trees at the appropriate distances should be estimated and added to the listed terrain elevations at the proper distances.

4.4.11 Plotting Terrain Profiles

4.4.11.1 After compilation of the list of terrain elevation versus path distance, the profile can be plotted in several ways. As already noted in section 4.2, the effective earth radius is usually taken into account when plotting terrain profiles, so that radio rays always appear as straight lines. Various types of graph paper have been developed which have curved coordinate systems along their abscissas) so that the actual terrain elevations, when plotted to these coordinates, will provide straight-line radio ray relations for standard atmospheric refraction (with the effective earth radius 4/ 3 times the actual radius, corresponding to approximately 8500 km). An example of such a graph paper with an actual profile plotted on it is shown in figure 4.4-8. Note that this paper was designed for an effective earth radius of 9000 km and corresponds to slightly better than average atmospheric conditions. This presentation is especially useful for an over-view because it indicates for what portions of the path more detailed information should be secured. * Graph paper developed for this type of presentation usually specifies which abscissa and ordinate scales must be

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*As already noted in section 4.2.12.5, a value of the effective earth radius factor k = 2/3 should not be used in the design calculations.

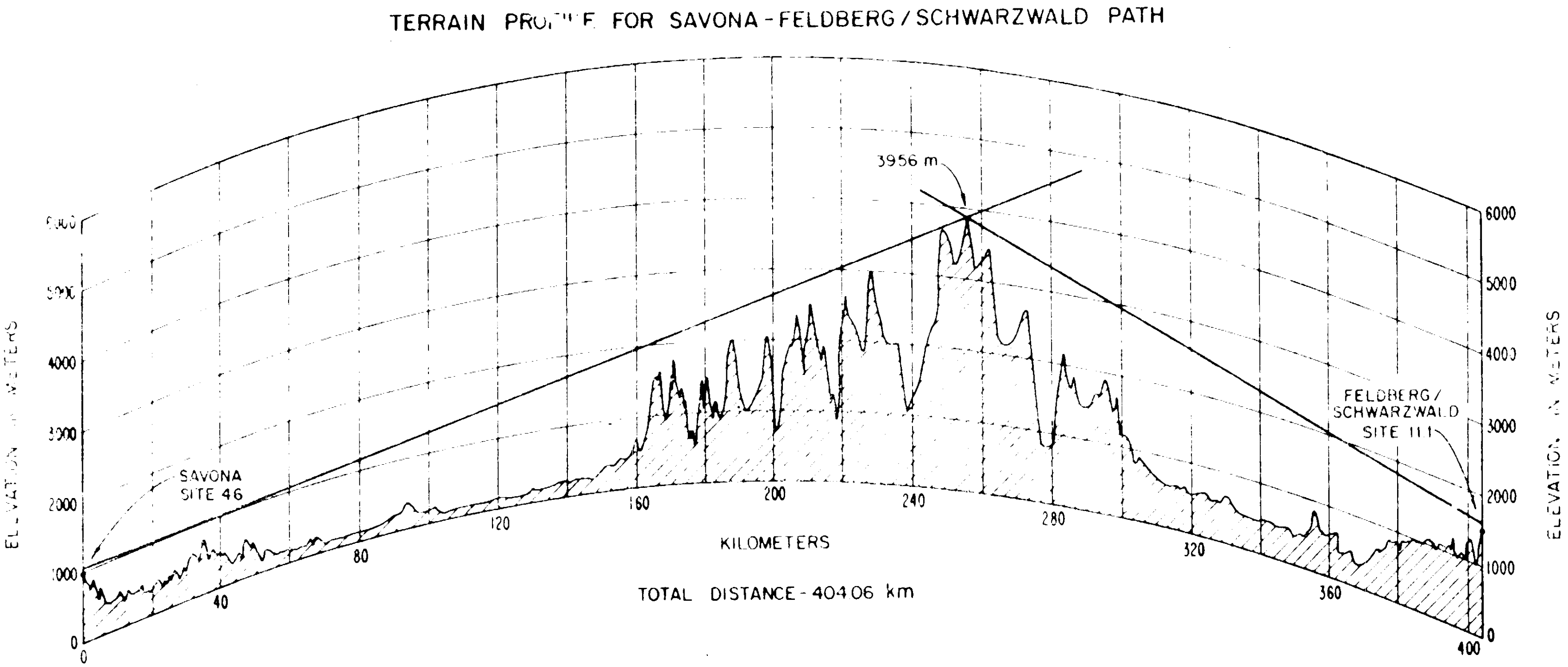


Figure 4.4-8 Example of Terrain Profile Plotted on Special Graph Paper for a = 9000 km [26]

[8-59240]

used together in order to show radio rays as straight lines. However, it is designed for only one nominal value of the effective earth radius, a. This constitutes a serious limitation in many applications where it would be more practical to plot terrain profiles for several values of the effective earth radius on graph paper. In such cases the elevations must be modified in order to allow for the effects of atmospheric refraction, as follows.

4.4.11.2 Terrain elevations determined at distances xi from any fixed reference point along the profile are designated by hi. The reference point may conveniently be either one of the terminals, or possibly the path midpoint. For a given effective earth radius, a, the modified elevations are found by simple geometry using the formula:

$$y_i = h_i - x_i^2 / (2a) \qquad (4.4\text{-}20a)$$

In (4.4-20a), all distances and heights as well as" the effective earth radius, a, must be in the same units. If terrain profile data are read from U. S. Geological Survey maps, where elevations are in feet and distances can be determined in statute miles, a very simple expression results for an effective earth radius 4/3 times the actual radius, or 5280mi (corresponding to a "standard atosphere"). Then (4.4-20a) reduces to:

$$Y_i = h_i - x_i^2 / 2, \qquad (4.4\text{-}20b)$$

where the distance x_i is in statute miles and the heights hi and y_i are in feet. Similarly, for an effective earth radius, a, of 9000 km, which (as already noted) is somewhat greater than the value corresponding to a standard atmosphere, a simplified formula is:

$$Y_i = h_i - x_i^2 / 18, \qquad (4.4\text{-}20c)$$

where y_i and h_i are in meters and xi is in kilometers. This formulation is useful for maps with contour intervals in meters.

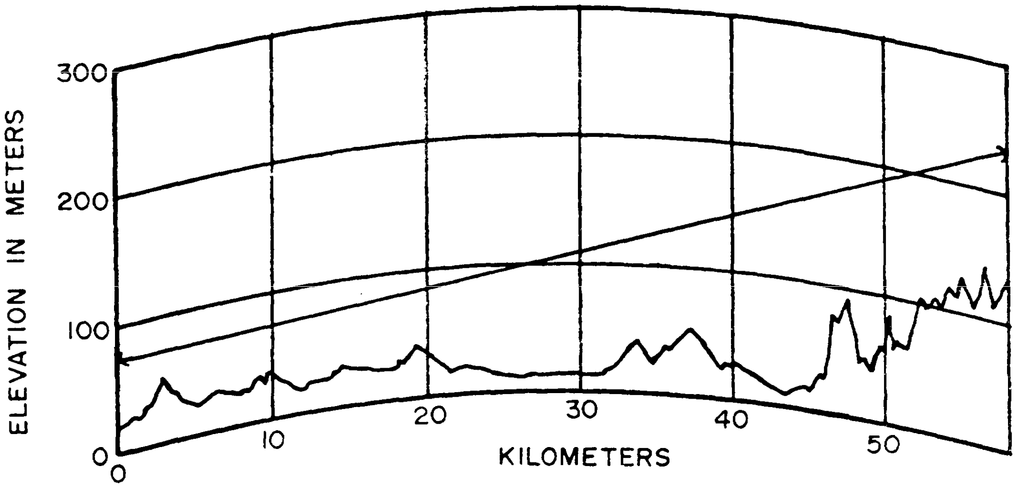
4.4.11.3 If the formulation of (4.4-20a - 4.4-20c Is 1= used, the modified terrain profile is obtained by plotting y_i versus on linear on linear graph paper for each desired value of a. The ray paths will then be straight lines.

4.4.12 Computer Procedures and Utilizaton of Profile Plots

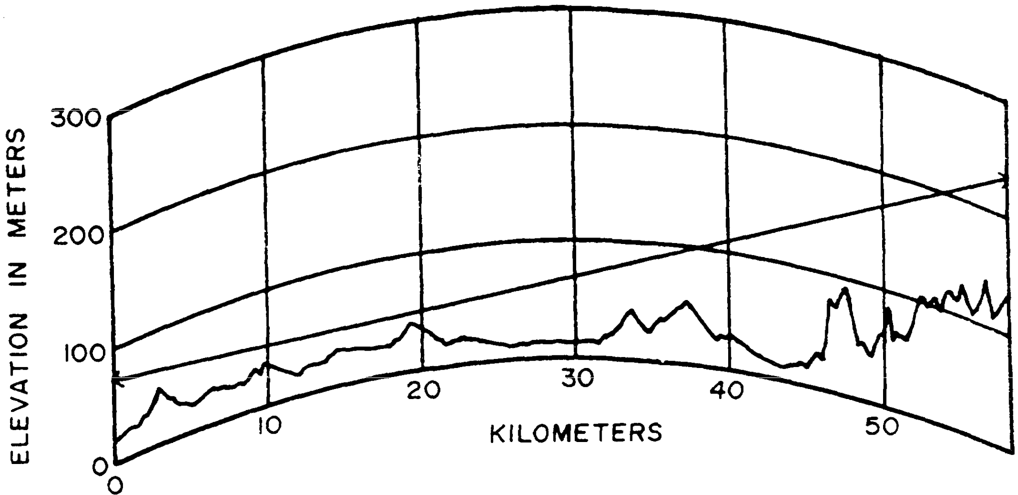
4.4.12.1 When electronic computers are available, plotting of profiles can be automated by (1) storing the elevations and distances in the computer and (2) by utilizing appropriate programs to calculate the effects of the refractive index gradient, and (3) plotting the profile automatically by peripheral devices. This facilitates investigation of link performance as a function of changing atmospheric parameters or if a more refined model than that correspondirg to a single, constant gradient value over the entire path muse be considered.

4.4.12.2 An example of a program printout for a 58-km link is shown in figure 4.4-9, and demonstrates how a line-of-sight path can become a transhorizon path for increasing positive refractive index gradients which correspond to decreasing values of the effective earth radius, a. If the percentage of time is known durlng which such positive gradient values are expected, one has at least a first estimate of the likelihood of failure of such a link. In this example, the link ceases to be line-of-sight for an effective earth radius factor somewhat less than 3/4, corresponding to a gradient greater than approximately 50 N-units/km. Within the geographical area where the system is located, such values may be expected to occur during O. 5 percent of the time; consequently- its performance evaluation must include transhorlzon design methods if high reliability is desired.

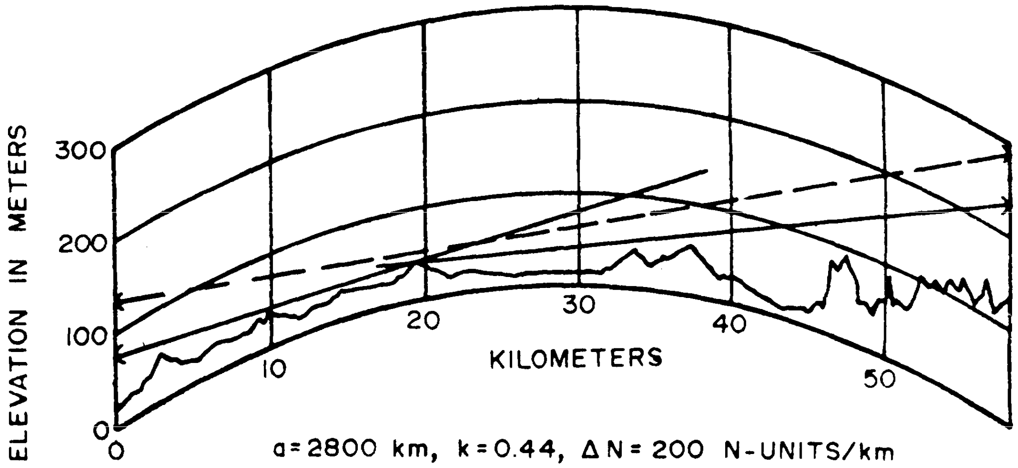
4.4.12.3 A representation such as in figure 4. 4-9 permits also a quick estimate of antenna heights required to assure line-of-sight properties for extreme values of the refractivity gradient. From the example, an increase in antenna height of 60 m (about 200 ft) would



a = 8480 km, k=1.342, ΔN = −40 N-UNITS/km



a = 4830 km, k = 0.76, ΔN = 50 N-UNITS/km



a = 2800 km, k = 0.44, ΔN = 200 N-UNITS/km

Figure 4.4-9 Example of Computer Printouts for Path Profiles assure a Line-of-sight link with adequate clearance *or a* gradient value of +200 N-units/km, which for this case is likely to be exceeded only 0.025 percent of the time.

4.4.12.4 In addition to the parameters already discussed in section 4.4.7.1, the terrain profile plot can also be used to provide:

1. A rough estimate of the average terrain elevation between each antenna and its radio horizon (required to estimate effective antenna heights for transmission loss variability calculations),
2. A qualitative evaluation of terrain characteristics between radio horizons (required for determining the probable propagation mechanism for the link such as various types of diffraction or tropospheric scatter), and
3. An estimate of the "rounding" of a single obstacle forming the common radio horizon for both terminal antennas (used in calculating diffraction loss).

4.4.12.5 Additional parameters, which may be derived from terrain profile plots, will be defined in section 4.4. 17 in conjunction with the transmission loss calculation procedures.

4.4.13 Transmission Loss Calculations

4.4.14 Introduction

4.4.14.1 The performance of a fixed (point-to-point) wideband transhorizon link is ultimately a function of the amount of usable radio frequency energy which is available to the receiving, demodulating, and decoding equipment. The total system can be represented by combination of gains and losses in power level (see sec. 4.4. 28) which are partially dependent on the equipment used, and partially on the propagation medium between the transmitting and receiving antennas. This medium is the atmosphere and the boundary between the atmosphere and the earth, namely the earth's surface with its terrain irregularities and clutter such as vegetation and man-made objects. The medium introduces losses which depend in a very complicated and not fully understood manner on the ever changing properties of the atmosphere and on characteristics of the boundary. The purpose of this chapter is to present methods to calculate these losses (including their variability) so that their effects on link and system performance can be assessed in the design process.

4.4.15 Limitations and Definitions

4.4.15.1 Transhorizon wide-band systems are Limited in useful link length by the losses in the propagation medium, and in useful bandwidth by non-linear distortions introduced by the same medium. For practical purposes, only frequencies between about 200 and 10, 000 MHz need to be considered, since the required bandwidth is not available at lower frequencies, and frequencies higher than 10,000 MHz (10GHz) are subject to excessive losses so that huge amounts of radio frequency power would be required for transmission. Limitations on bandwidth can be translated to voice channel transmission capability (see figure 4.2-8 and section 4.5.20); the medium is not likely to support more than 120 voice-channels without very substantial non-linear distortion [64,65].

4.4.15.2 Point-to-point transhorizon links are usually designed for high-gain antennas with relatively narrow beams, which are removed from terrain clutter by at least several wavelengths. Thus they are essentially in free space and certain types of losses which have been defined for more general cases can be neglected [24]. Antenna polarization effects and resulting cross-polarized components of the received power will generally not be of interest except in the case of interference fields. The antenna-to-medium coupling losses due to the irregularity of the wave front and the illumination of the atmospheric irregularities must, however, be considered for certain types of transhorizon links, as already discussed in section 4.2.11.

4.4.15.3 The result of the simplifying assumption. is that transmission loss may be defined as the ratio of the power p_{ta} in watts supplied to the input terminals of the (loss-free) transmitting antenna to the power p_{ra} in watts available at the output terminals of the (loss -free) receiving antenna [3]. Transmission loss is usually expressed in decibels and designated by L:

$$L = 10 \log (p_{ta}/p_{ra}) \text{ dB.} \tag{4.4-21}$$

4.4.15.4 If it is assumed that both the transmitting and receiving antennas are replaced by loss-free isotropic antennas (which have equal, unity gain in all directions), the transmission loss L in this case bercomes the normalized basic transmission L_b. Expressing the free-space antenna gains $g_{1,2}$ relative to isotfopic in decibels ($G_{1} = 10 \log g_{1,2}$) and again under the assumption that losses may be neglected, the relation between transmission loss and basic transmission loss is:

$$L_b = L + G_p \text{ dB,} \tag{4.4-22}$$

where the effective path antenna gain G_p has been discussed in section 4.2.11.

4.4.15.5 It has been customary to use the term “path loss” to express basic transmission loss or transmission loss under various assumptions. For the purposes of this Handbook we will attempt to use only “basic transmission loss”, and avoid possible ambiguities.

4.4.15.6 In some instances available data may be utilized which are presented in terms of field strength, E. Field strength at frequencies above 100 MHz is customarily expressed in decibels relative to 1 microvolt per meter available from 1 kW effective radiated power (ERP). 1 kW ERP is the power radiated from a loss-free half-wave dipole with 1 kW input power. This unit is denoted dBu. The relation between basic transmission loss in dB and field strength, as defined above is :

$$E = 139.37 + 20 \log f - L_b \quad \mathrm{dBu/kW_{ERP}} \qquad (4.4\text{-}23)$$

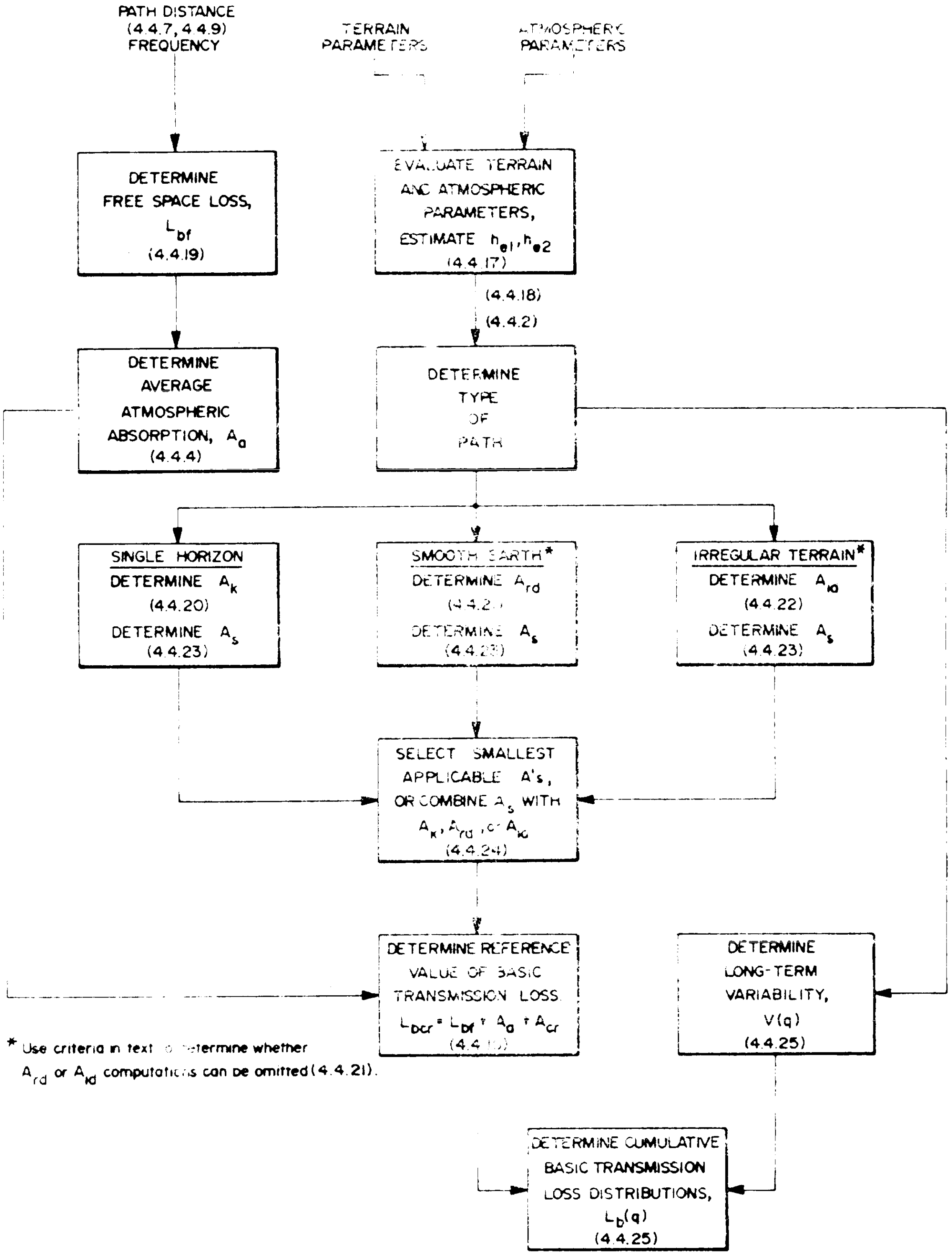
where f is in MHz. The user should be careful to ascertain the units in which field strength is presented, since the above definition has not always been followed.

4.4.16 Transmission Loss Calculations

4.4.16.1 In section 4.2.11 an approximate method was presented to estimate basic transmission loss for the worst hour of the year using only a limited number of atmospheric and terrain parmeters. This method served to provide a choice between various alternative routes and links. After a final selection of routes, links, terminals and relay sites has been made, more precise calculations of basic transmission loss and its long-term variability are required for performance calculations using the specific atmospheric and terrain parameters determined in the previous sections of this chapter.

4.4.16.2 Transmission loss calculations involve several steps, but not all may be necessary for any specific link. Figure 4.4-10 is a "flow diagram", which indicates the sequence of these steps with reference to the subsections where the applicable formulas and graphs can be found. All components of transmission loss are expressed in decibels.

4.4.16.3 First, the basic transmission loss in free space, L_{bf}, is determined. To this is added (1) a reference value of attenuation below free space, A_{cr}, which is a function of the terrain and average atmospheric parameters, and (2) the median atmospheric attenuation A_a (from fig. 4.4-4). Several methods will be shown which correspond to assumptions regarding applicable propagation mechanisms, and usually that one is used which yields the smallest value of A_{cr} in decibels. The free-space basic transmission loss value, L_{bf} the reference attenuation value, A_{cr}, and the atmospheric attenuation, A_a, are added to obtain the reference basic transmission loss value L_{bcr}, in dB. The next step



* Use criteria in text to determine whether A_{rd} or A_{id} computations can be omitted (4.4.21).

Figure 4.4-10 Flow Diagram for Path Loss Calculation (numbers in parentheses refer to sections of the text).

(shown in sec. 4.4.25) is to determine the long-term variability functions, V(q), which are algebraically added to L_b to produce ^{a} cumulative distribution of hourly median basic transmission loss values for the average year.

4.4. 16.4 These steps can be summarized in the following equation for I-b(q), which is the hourly median basic transmission loss value not exceeded during q percent of all hours of an average year (or exceeded during (100-q) percent hours)):

$$Lb(q) = L_{bf} + A_{cr} + A_a - V(q) \text{ dB.} \qquad (4.4\text{-}24a)$$

The sum of the terms L_{bf} + A_{cr} and A_a is the calculated reference basic transmission loss value denoted by L_{bcr}:

$$L_{bcr} = L_{bf} + A_{cr} + A_a . \qquad (4.4\ \text{-}24b)$$

4.4. 16.5 The terrain and atmospheric parameters required for transmission loss calculations will be listed in sections 4.4.17 and 4.4.18. Procedures for obtaining the various terms in (4. 4-24) will be discussed as follows:

L_{bf}	Section 4.4.19
A_{cr}	for single-horizon diffraction links, Section 4.4.20
....	for diffraction over smooth terrain, Section 4.4.21
....	for diffraction over irregular terrain (two horizons), Section 4.4.22
....	for tropospheric scatter, Section 4.4.23
....	combining of values of A for several mechanisms, Section 4.4.24
V(q)	Section 4.4.25.

Since it is not always necessary to calculate smooth-earth and irregular terrain diffraction, section 4.4.21 also includes appropriate criteria for elimination of these somewhat involved procedures. The application of prediction uncertainty concepts and confidence limits will be discussed in section 4.4.27 including methods to assess the probability that the required grade of service can be provided over a specific link,

4.4.16.6 The distribution of hourly medians of basic transmission loss obtained in the manner described above will provide in almost all cases an adequate and reliable basis for system performance calculations. However, as already noted in section 4.4.3.5, supplementary values of Lb(q) may be obtained by basing calculation methods directly on specific values of the effective earth radius factor, κ, as a function of the refractivity gradient. If the time distribution of the occurrence of such gradients is known, or can be reasonably reliably estimated, the resulting transmission loss values can be compared with those obtained using the regular method described above. The designer can then judge the reliability or applicability of both sets of values and use that one for performance estimates which is more appropriate in the specific case. However, transhorizon links are usually too long, or traverse too many different terrain types, to permit reliable estimates of uniformly applicable extreme k-values. more climatic studies are required before such a method can be generally utilized, and this will be further discussed in section 4.4.33.

4.4.17 <u>Required Terrain Parameters</u>

4.4.17.1 Terrain parameters required for transmission loss calculations have been discussed in section 4.4.7. They are:

(a) The path distance, d, in kilometers which is determined from the great-circle calculations described in section 4.4.9.

(b) The antenna heights {center of antenna feed) above ground, h_{g1} and h_{g2}, in kilometers, from system specifications or engineering assumptions.

(c) The elevation of the antenna sites in kilometers above mean sea level, e_{S1} and e_{S2}, from maps or surveys as discussed in section 4.2.4, 4.3.11.8, and 4.4.7.

(d) The heights of the antennas (center of antenna feed) above mean sea level, h_{S1} and h_{S2} in kilometers, are:

$$h_{S1} = e_{s1} + h_{g1} \quad \text{KM} \tag{4.4-25a}$$

$$h_{S2} = e_{s2} + h_{g2} \quad \text{km} \tag{4.4-25b}$$

h_{S1} and h_{S2} should not be confused with the parameters h_s used in (4.4-3d), which refers to the elevation of the radio horizon.

(e) The distances from the antenna sites to the radio horizons, d_{L1} and d_{L2}, in kilometers, are obtained from the path profiles or, in the smooth earth case, from (4. 4-7).

(f) The elevations of the radio horizons above mean sea level, h_{L1} and h_{L2}, in kilometers.

(g) The horizon take-off angles θ_{e1} and θ_{e2} in radians (4*4-8)

(h) The angles α_o. and β_o. in radians (4.4-10).

(i) The angular distince, θ, in radians (4.4-5, 4.4-11).

(j) The distance between radio horizons, D_S, in kilometers from (4.4-9a). For single-horizon paths, Ds is defined as the width of the diffracting obstacle, and is used as a parameter to estimate the additional attenuation due to the departure of the obstacle from an ideal knife -edge.

(k) The parameter h_o from (4.4-12).

(1) The parameter s from (4.4-13).

(m) The effective antenna heights, h_{e1} and h_{e2}' in kilometers=

These are estimated from the terrain profiles relative to a potential reflecting surface between the antenna site and its radio horizon. For smooth ground or water surfaces they are simply the antenna heights about the surface including the height of buildings, cliffs, or isolated peaks where the antenna might be located. For irregular terrain, the designer should estimate the position of an average reflecting surface through the terrain, and determine the antenna heights relative to that surface. Note that exact values for effective antenna height are not required; therefore, rough estimates are usually sufficient. The effective antenna heights h_e and h_{e2} are used primarily for determining the variability functions Y(q) in section 4.4.25, but are also required in the calculation of single -obstacle diffraction attenuation (sec. 4.4. 20) in cases where the ray paths are not isolated from the terrain, and for calculation of the scatter attenuation, A_S (sec. 4.4..23). Not all of these parameters will be required in every case, but they are relatively easily obtained from the terrain profile and map information.

4.4.18 Required Atmospheric Parameters

4.4.18.1 These have been discussed in section 4. 4.3 and 4.4.4. The sea-level surface refractivity N_0 is read from figure 4.4-2, and converted to n_s using (4.4 -3d). The required terrain parameters h_{L_1} and h_{L_2} (or, in sore cases, e_{s_1} and e_{s_2}j have already been discussed in sections 4.4-7 and 4.4.17. The effective earth radius a corresponding to the minimum monthly mean value of $\bar{n}_S$ is determined from figure 4.4-3 or (4.4-4). The median atmospheric attenuation, A_a, is determined as a function of carrier frequency and path length from figure 4.4-4. The alternative transmission loss calculation method discussed briefly in section 4. 4.16.6 requires statistical distribution of the refractive index gradient $\Delta N/\Delta h$. This will be further outlined in section 4.4.33.

4.4.19 Basic Transmission Loss in Free Space

4.4.19.1 In addition to the terrain and atmospheric parameters, the carrier frequency must be known before transmission loss calculations are begun. The basic transmission loss in free space, L_{bf} (given in figure 4.2-2), is by definition not variable with time. and is a function of carrier frequency and path length:

$$L_{bf} = 32.45 + 20 \log f + 20 \log d \text{ dB} \qquad (4.4\text{-}26a)$$

where the carrier frequency, f, is in MHz and the path length, d, is in kilometers. If the path length is in other units, the following expresions result:

$$L_{bf} = 36.58 + 20 \log f + 20 \log d_{mi} \text{ dB} \qquad (4.4\text{-}26b)$$

for d in statute miles, and:

$$L_{bf} = 37.80 + 20 \log f + 20 \log d_{nm} \text{ dB} \qquad (4.4\text{-}26c)$$

for d in nautical miles.

4.4.20 Attenuation over Single-horizon Diffraction Links

4.4.20.1 The attenuation relative to free space for links which have a single obstacle as a common (or nearly common) horizon will be denoted by A_k. It is calculated as a function of the carrier frequency and several terrain parameters. The obstacle may be considered to be an ideal knife-edge if its width at the top is a few tens of meters, or less, such as a sharp mounain ridge. For rounded, or flat-topped ridges, an allowance can be made for the additional attenuation introduced by rounding as a function of D_s, the distance between the two radio horizons. For large values of Ds, the obstacle is not likely to be isolated (as discussed later), and the irregular terrain diffraction methods should be used (see sec. 4.4.22).

4.4.20.2 The attenuation A_K over a diffracting obstacle is given by:

$$A_K = A(v,p) - G(h_1) - G(h_2). \qquad (4.4\text{-}27)$$

The height gain functions $G(h_{1,2})$ are estimates of the effects of ground reflections from the terrain between an antenna and its radio horizon. They should be used when more than half of the terrain between an antenna and its radio horizon is intersected by a first Fresnel zone ellipse in the great circle plane containing the propagation path which has the antenna and its horizon as the foci [16;p. 7-31. The maximum half width of this ellipse occurs midway between the antenna and its horizon, and is given by $\sqrt{\lambda d_{L1,2}}$. Here, λ is the wavelength in kilometers. It may be determined from the frequency, f, 0in MHz, and the free space velocity of light 299,790 km/sec; i. e.)

$$\lambda = 299,790 \times 10^{-6}/f_{MHz} = 0.29979/f \ \mathrm{MHz}. \qquad (4.4\text{-}27a)$$

The resulting half-width is of course also in the same units; i. e. , km.

For the purpose of applying this criterion, it is sufficient to sketch the ellipse on the path profile such as in figure 4.4-8. In this case, as an example, the path portion between Savona and the obstacle is approximately 255 km long, and for the operating frequency of 4,500 MHz the wavelength is 6.66×10^{-5} km. Thus, the first Fresnel zone half-width is approximately 0.065 km. This value may be plotted at about 127.5 km from the Savona terminal, and the ellipse sketched in accordingly. In this case, very little, if any, of the terrain would be intersected, and the G(h) could therefore be neglected.

An alternative criterion may be used if not all details of the terrain profile are known [16;p. 7-3]. It is based on the difference between the elevations of the antenna $h_{S1,2}$ and its horizon $h_{L1,2}$ above mean sea level:

If $\sqrt{\lambda d_{L1,2}} > |h_{L1} - h_{s1}|$, use $G(\bar{h}_{1,2})$ in (4.4-27)

If $\sqrt{\lambda d_{L1,2}} \leq |h_{L1} - h_{s1}|$, $G(\bar{h}_{1,2}) = 0$.

Here again, the parameters λ, $d_{L1,2}$, $h_{L1,2}$ and $h_{s1,2}$ are in kilometers. Calculation of the height gain functions $G(h_{1,2})$ will be discussed after the methods to calculate A(v, p).

4.4.20.3 The attenuation A(v, p) is a function of the parameter v, and the rounding coefficient, p. The parameter P will be discussed in paragraph 4.4.20.6, and the parameter v is calculated using

$$v = 2.583\,\theta\sqrt{f\,d_{L1}\,d_{L2}/d} \qquad (4.4\text{-}28)$$

where θ is in radians, the frequency f is in MHz, and all distances are in kilometers. This expression holds strictly only for $\theta \leq 10^\circ$, but this value will rarely be exceeded in practical applications. Also, for transhorizon links, v is always positive.

4.4.20.4 The attenuation for an ideal knife-edge (P = 0), A(v, 0), is plotted on figure 4.4-11 versus v. A useful asymptotic expression for $v \geq 3$ is:

$$A(v, 0) = 12.953 + 20 \log V \text{ dB}. \qquad (4.4\text{-}29)$$

The dashed curve on figure 4.4-11 represents an empirical expression for mountain obstacle diffraction links, which was derived from available data by Nishikori, et al. [25], and tested against measurement results from Colorado and Europe [26]. It may be used to estimate A(v, p) without having to determine the curvature or rounding of the diffracting knife-edge. Note that the A(v, p) curve in figure 4.4-11 differs from a similar curve in section 4.2 (fig. 4.2-5). The curve in section 4.2 includes the time variability function in order to provide first estimates for the worst hour (attenuation exceeded 0.01% of all hours), whereas the curve in figure 4.4-11 of this section provides reference attenuation values in accordance with the outline in section 4.4.16.

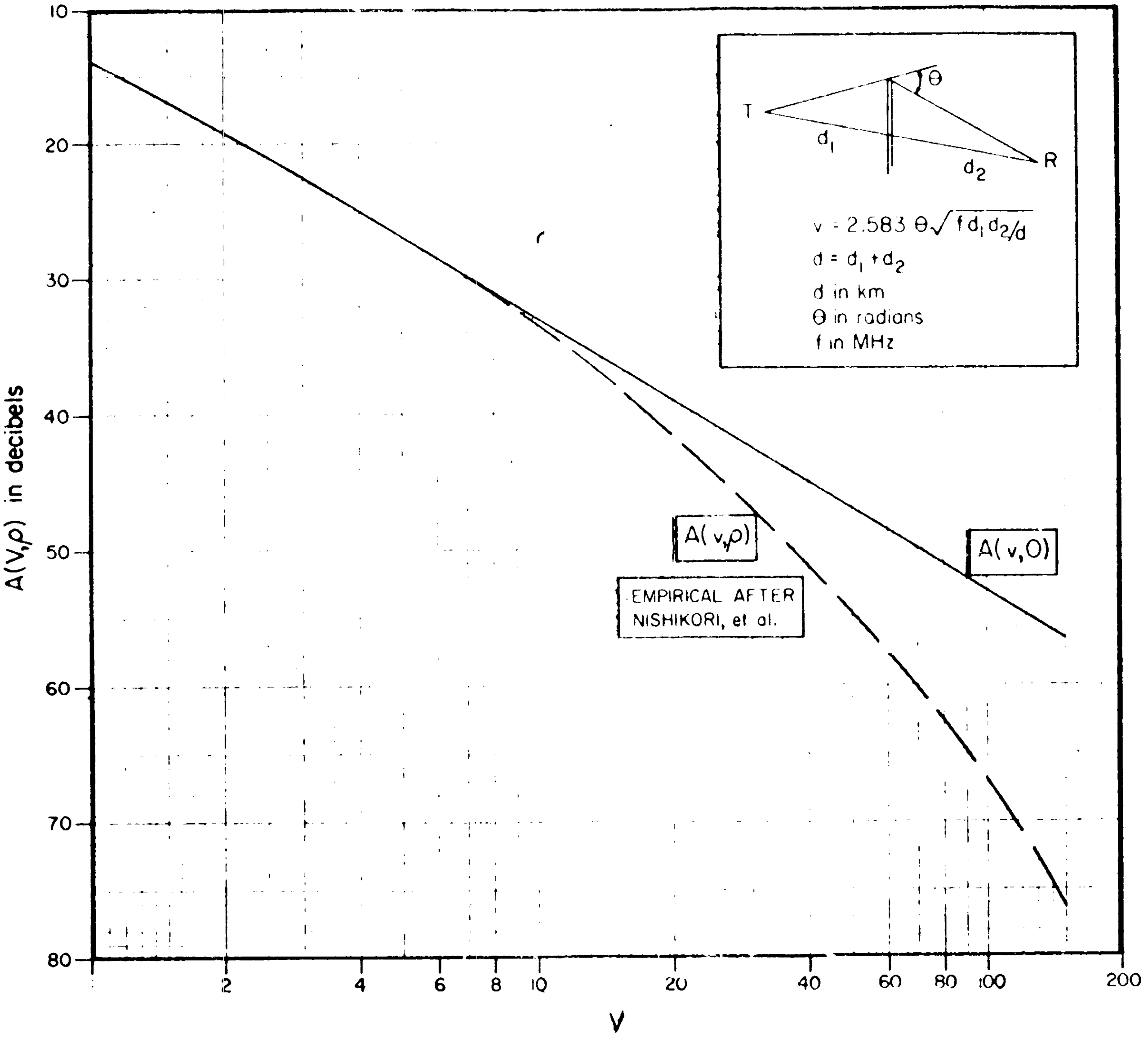


Figure 4.4-11 Empirical obstacle diffraction loss.

4.4.20.5 In some cases it is possible to estimate the rounding of an isolated diffracting obstacle from detailed terrain profile drawings or from map studies. The attenuation A(v,p) may then be calculated more precisely using procedures developed by Dougherty and Maloney [27] based on previous work by Wait and Conda [28]. First, the radius of curvature r of the obstacle is approximated by:

$$r = D_s/\theta, \qquad (4.4\text{-}30)$$

where D_s and r are in kilometers and θ is in radians. Next, a test is made to determine whether the obstacle is isolated from the surrounding terrain using the relation [16]:

$$kh[2/(kr)]^{1/3} >> 1. \qquad (4.4\text{-}31)$$

Here, $k = 2\pi/\lambda$, r is the radius of curvature of the rounded obstacle from (4.4-30), and h is the smaller of the two values

$$\left(\sqrt{d_{L1}^2 + r^2} - r\right)$$

and

$$\left(\sqrt{d_{L2}^2 + r^2} - r\right),$$

with all distances and the wavelength λ in km. Other criteria given in [27] are usually met for the applications of concern here; they are partially stated later in this section. If the relation in (4.4-31) does not hold for a specific path, the methods in section 4.4.22 (diffraction over irregular terrain) may be used. Note that the term "isolated" is used here in a different manner than in the determination of Fresnel zone clearance for - applicability of the height gain functions.

4.4.20.6 If the relation (4. 4-31) holds, the rounding parameter, p, is determined by calculating the product vp using (4. 4-32) below and dividing vp by v which has been determined earlier (see equation 4. 4-28). The product vp will also be required in a subsequent step.

Here the radio frequency is in MHz, the radius of vurvature r is in km,f and the angular distance θ is in radians.

4.4.20.7 The diffraction loss A(v,p) in decibels is plotted as a function of v for various values of p in figure 4.4-12. It may also be determined from:

$$A(v,\ p) = A(v,\ 0) + A(0,\ p) + u(Vp)\ db, \qquad (4.4\text{-}33;$$

where the function A(v , 0) is the attenuation for an ideal knife-edge (p = 0) plotted in figures 4.4-11 and 4.4-12, and the functions A(0,p) and u(vp) are plotted in figure 4.4-13 . Equation (4.4- 33) is applicable under many conditions of propagation over irrugular terrain between good antenna sites using either horizonal or vericai propagation. Criteria for its validity are (a) the distance d. , d_2, and r must be much larger than the wavelength, λ, (b) the obstacle obstacle dimension at righ angles to the propagation path must be at least the width of the first Fresnel zone, (c) the components α_o and β_o (See equation 4.4-l0a and b) of the diffraction angle θ must each be less than 0. 175 radians, and (d) the radius of curvature, r, must be large enough so that $(\pi r/\lambda)^{\frac{1}{3}} \gg 1$ These criteria are quite easily met in the frequency range applicable to transhorizon links. For small radii of curvature witk D_s much less than 0. 1 km, the attenuation A(v, 0) for the idea knife-edge is a suitable approximation.

4.4.20.8 The height gain functions $G(h_{1\ 2.,})$ introduced in (4. 4-27) at the beginning of this section are a convenient method to allow for terrain effects in cases where the ray paths are close to terrain,as defined earlier, One or both of the functions are used dependining on terrain characteristics on the two sides of the obstacle. Figure 4.4-14 is a graph of G(h) as a function of the normalizedzed parameter h,* and of two

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* G(h) is called the residual height gain function in the originalformulation by Norton, et al. [69[.

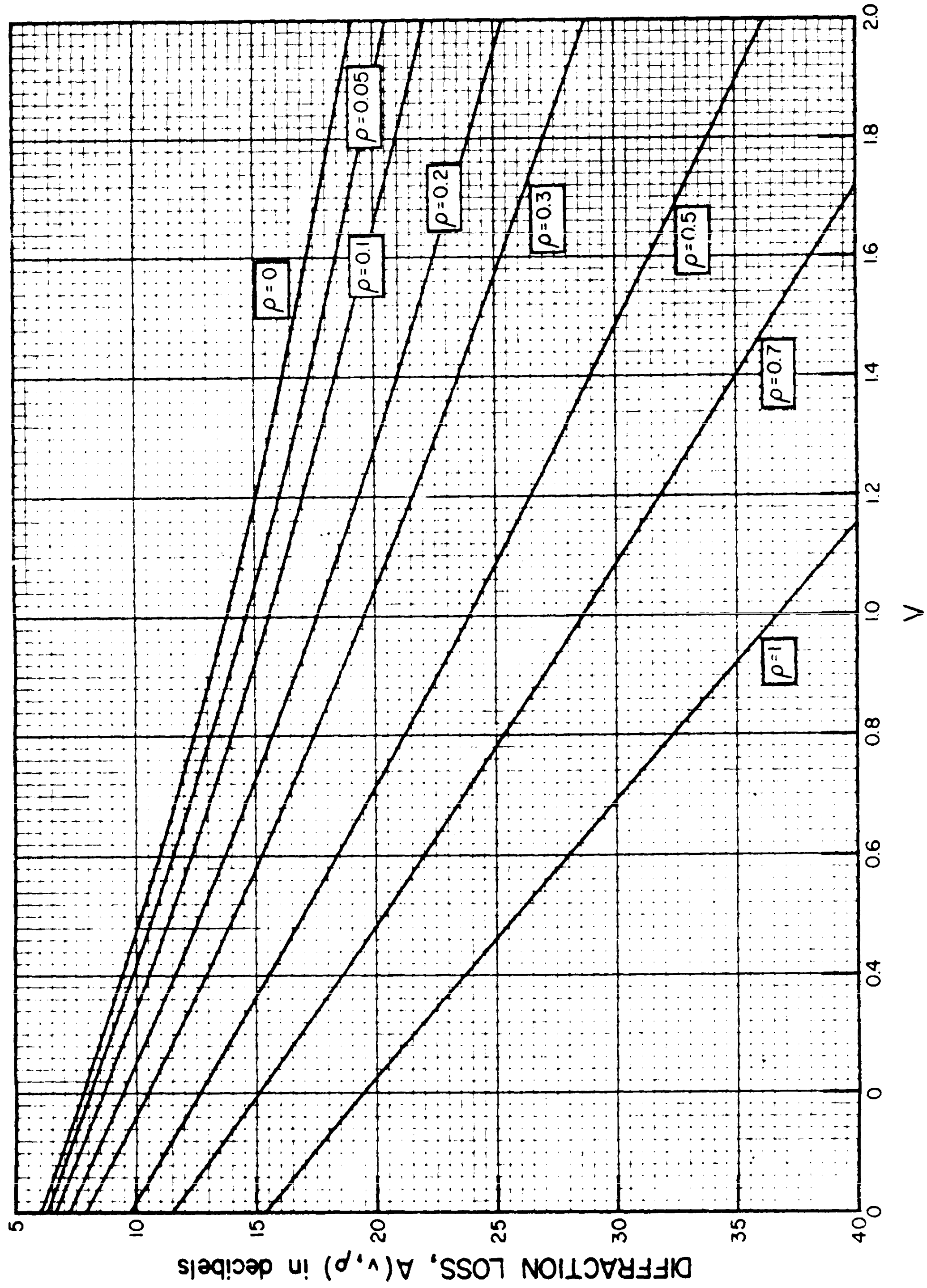

Figure 4.4-12 The Diffraction Attenuation A(v, ρ) over a Rounded Obstacle

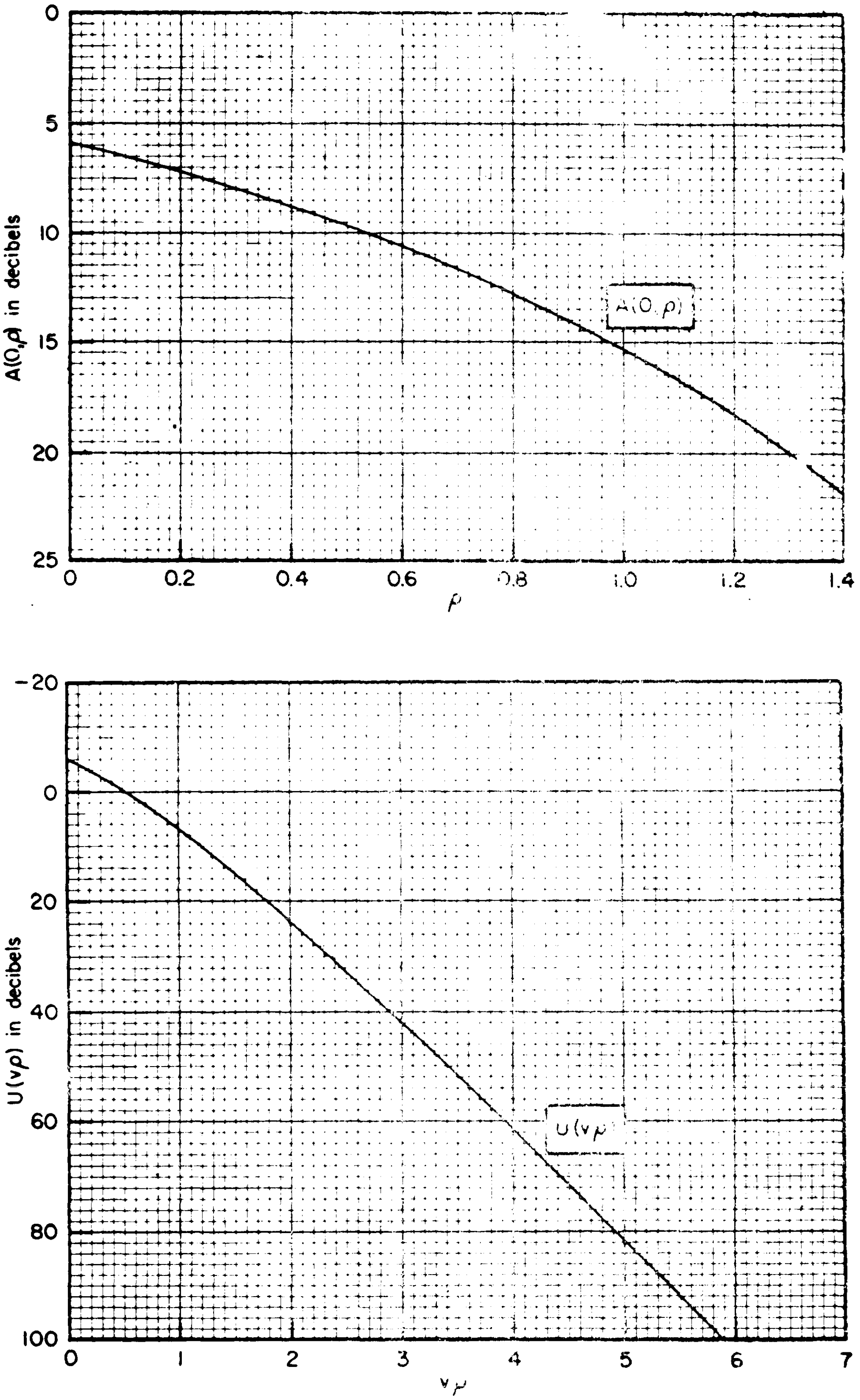

Figure 4.4-13 The Functions A(0, ρ) and U(vρ) in Obstacle Diffraction (after Dougherty and Maloney [27]

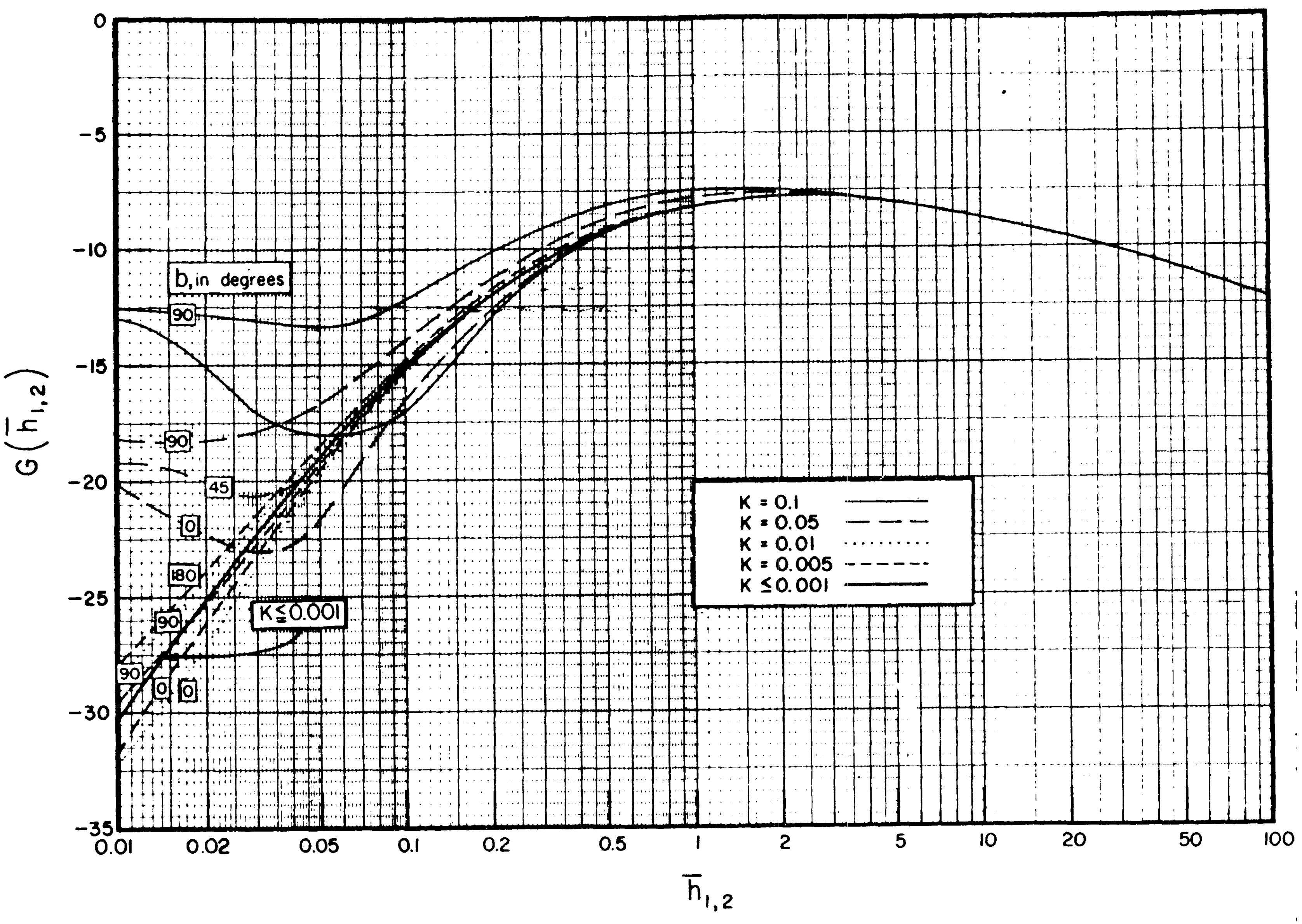

Figure 4.4-14 The Residual Height Gain Function $G(\bar{h})$ (after Norton, et al [69])

other parameters K and b, which depend on conductivity and dielectric constant associated with the terrain, on the polarization, and on the carrier frequency.

4.4.20.9 In order to calculate h_1 and h_2, one must first determine effective radii a_1, and a_2, as a function of the horizon distances, d_{L1} and d_{L2} and the effective antenna heights h_{e1} and h_{e2}, which were defined in paragraph 4.4.17.1 (m).

$$a_1 = d_{L1}^2/2h_{e1} \text{ km} \tag{4.4-34a}$$

$$a_2 = d_{L2}^2/2h_{e2} \text{ km}. \tag{4.4-34b}$$

All parameters including the heights must be in kilometers. For horizonal tal and vertical polarization over land or fresh water, and for horizontal polarization only over sea water, the parameters $\bar{h}_1$ and $\bar{h}_2$ may be approximated for frequencies above approximately 100 MHz by:

$$\bar{h}_1 \cong 5.74 \, (f^2/a_1)^{\frac{1}{3}} h_{e1} \tag{4.4-35a}$$

$$\bar{h}_2 \cong 5.74 \, (f^2/a_2)^{\frac{1}{3}} h_{e2}, \tag{4.4-35b}$$

where $a_{1,2}$ and $h_{e1,2}$ are in kilometers, and f is in MHz. Then $G(\bar{h}_{1,2})$ in decibels is read from figure 4.4-14 using the curve marked "K ≤ 0.001" and substituted into (4.4-27) to obtain the diffraction attenuation A_k. Note that the G(h) functions are negative and that the sign must be watched when substituting in (4.4-27) ; thus $|G(h_{1,2})|$ is added to the total attenuation.

4.4.20.10 The procedure described above is applicable in almost all cases of single -obstacle diffraction. In some instances, however, a communication link may extend over sea watcr with portions of land such as an island or topographic features on a peninsula forming the diffracting obstacle. Here the method to obtain $G(\bar{h})$ is somewhat more complicated with vertical polarization, since the parameter K is significantly greater than 0.001 and may approach 0. 1 particularly at lower frequencies, and b is between 0° and 90°. Thus, K and b must be determined first from the curves shown in figures 4.4-15 and 4.4-16, respectively. They are shown versus frequency for horizontal and vertical polarization, and for various combinations of the surface constants σ (conductivity) and (dielectric constant) corresponding to poor, average, and good ground, and to sea water*, In figure 4.4-15, K. is defined for an effective earth radius a = 8500 km corresponding to a "standard atmosphere". For use in the determination of $\bar{h}_{1,2}$, K_o must be modified by the factors $C_{o1,2}$+ These are:

$$C_{o1} = (8500/a_1)^{1/3} \qquad (4.4\text{-}36a)$$

$$C_{o2} = (8500/a_2)^{1/3} . \qquad (4.4\text{-}36b)$$

where a_1 and a_2 are in kilometers. The applicable values $K_{1,2}$ are then determined by:

$$K_1 = C_{o1}K_o \qquad (4.4\text{-}37a)$$

$$K_2 = C_{o1}K_o . \qquad (4.4\text{-}37b)$$

4.4.20.11 The next step is the determination of the parameters $B(K_{1,2}b)$ from figure 4.4-17 as a function of K_{12} and of b in degrees. Then h_1 and h_2 are calculated from the following equations, which are used instead of (4.4-35a) and (4.4-35 b):

$$\bar{h}_1 = 2.232\, B^2(K_1, b)\ (f^2/a_1)^{1/3}\, h_{e1} \qquad (4.4\text{-}38a)$$

$$\bar{h}_2 = 2.232\, B^2(K_2, b)\ (f^2/a_2)^{1/3} h_{e2}, \qquad (4.4\text{-}38b)$$

and $G(h_1)$ and $G(h_2)$ are read from figure 4.4-14, as before, but using the appropriate curve for K_12 and b with visual interpolation where. required. Actually, (4.4- 35a,b) is a simplification of (4.4-38a, b) for

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* Approximate guidelines for estimation of these parameters are as follows: Poor ground is represented by mountainous areas and exposed continental shields typical of New England or northeastern Canada. Average ground is characteristic of the U.S Midwest between the Appalachians and the Missouri River, and good ground is represented by the plains west of the -Missouri River, the Canadian prairie provinces, or the Central Valley in California. Fresh water surfaces correspond roughly to average ground. For frequencies above 100 MHz, precise values of conductivity and dielectric constant are not required.

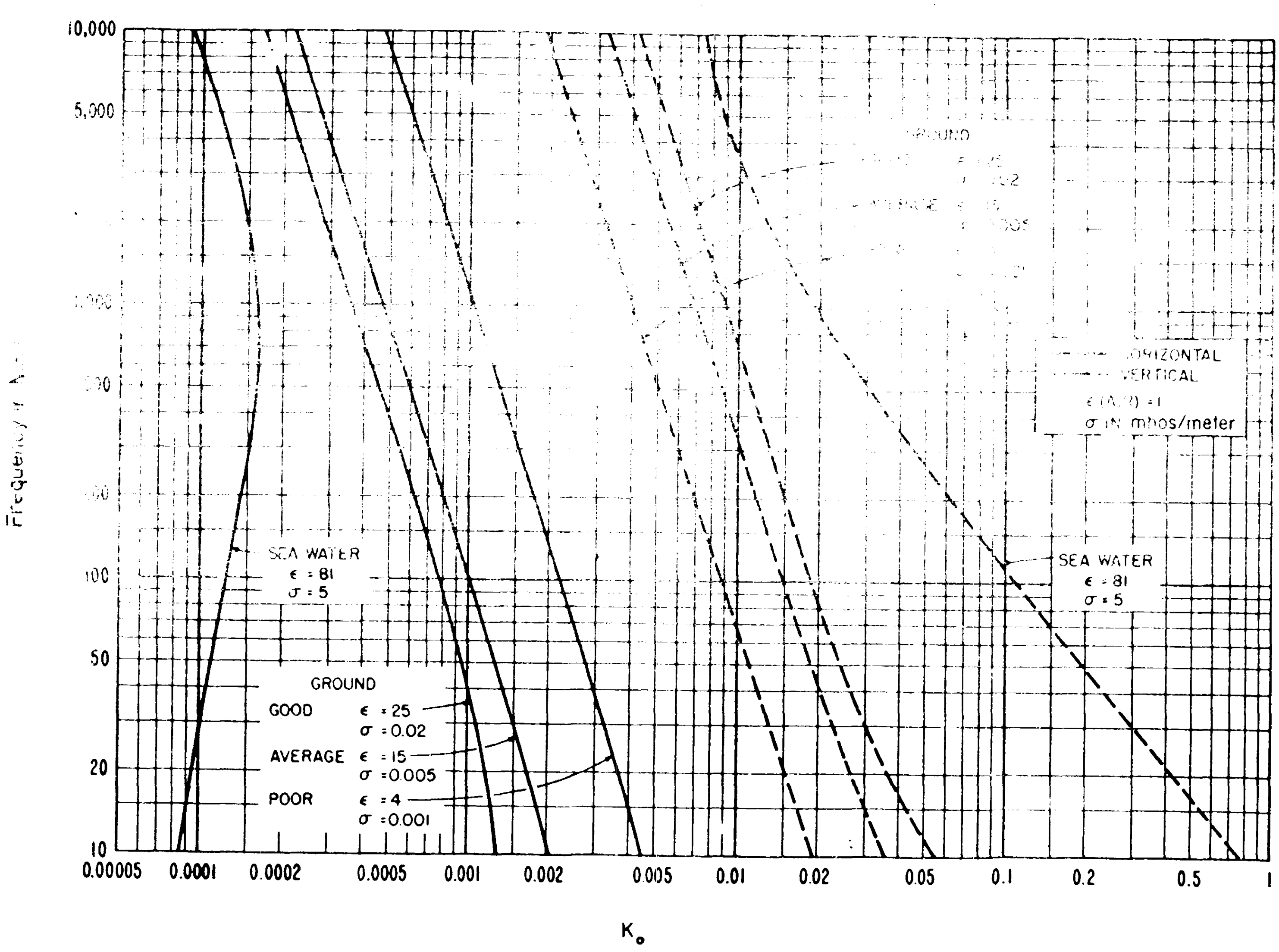

Figure 4.4-15 The Parameter K_o (for a = 8500 km)

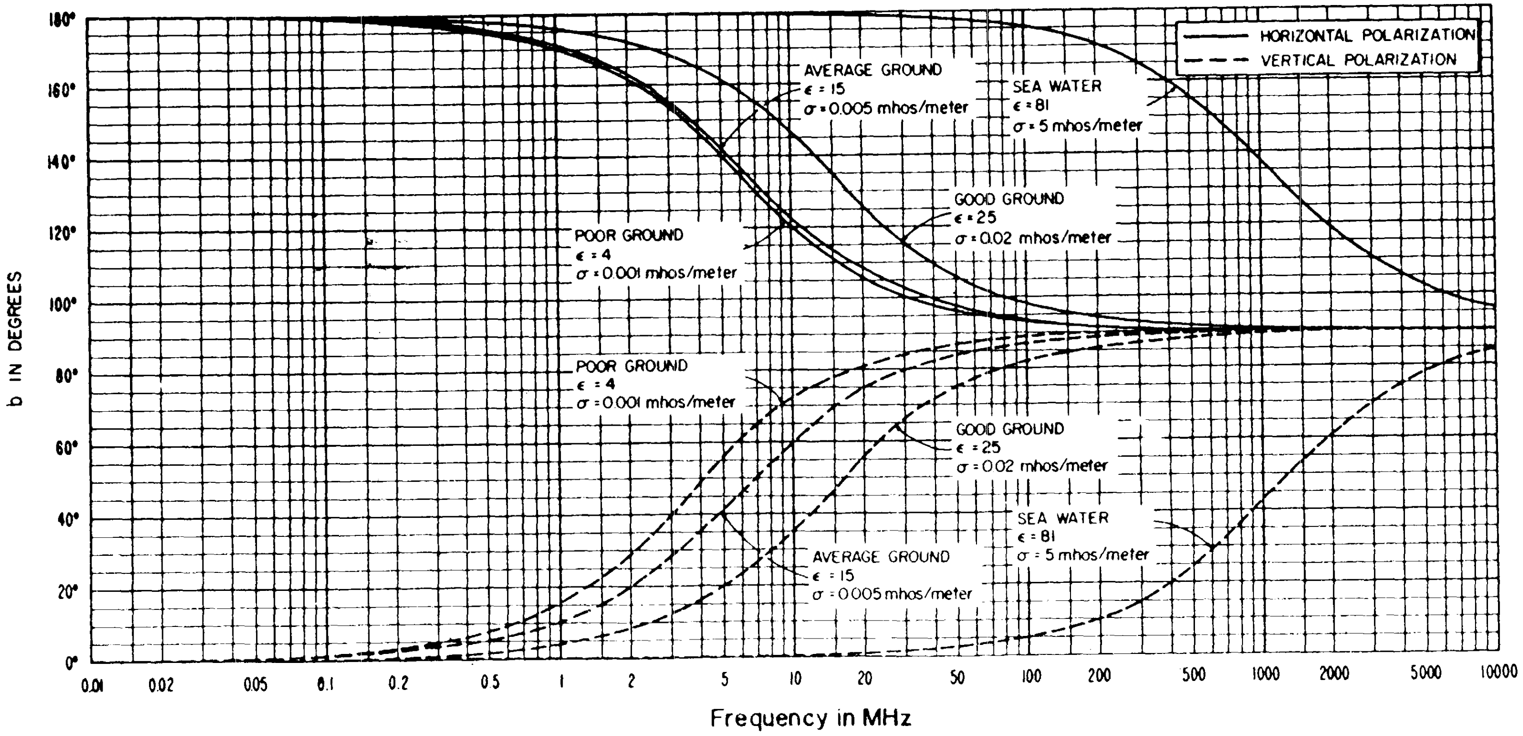

Figure 4.4-16 The Parameter b in degree as a Function of Carrier Frequency and Surface Constants

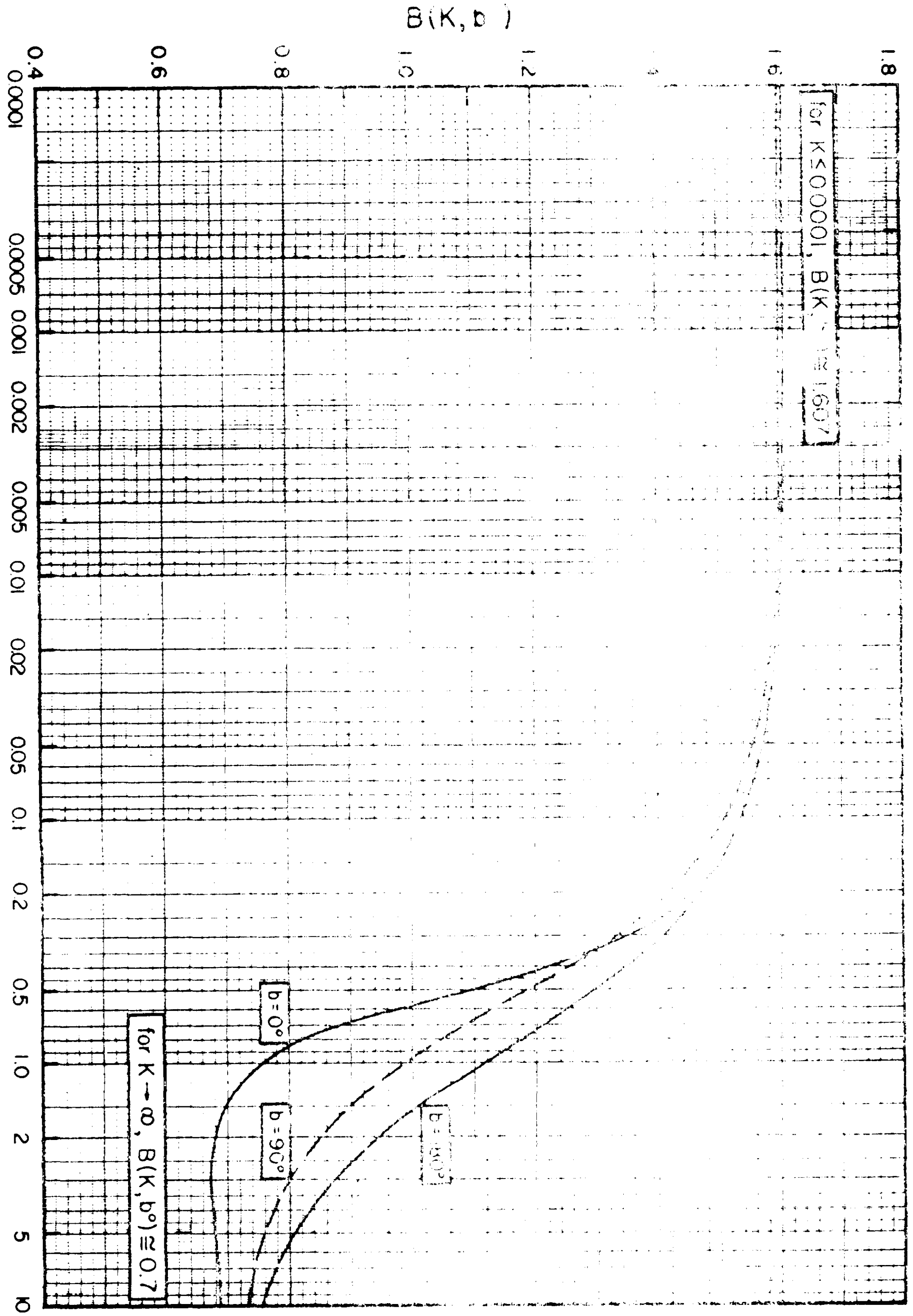

Figure 4.4-17 The Parameter B(K,b)

those cases where K is very small, and not a function of b to any significant extent. In (4.4-38a) and (4.4-38b) the distances a_1 and a_2 and the effective antenna heights h_{e1} and h_{e2} must be in kilometers and the frequency f in megahertz. If any parameter values outside the given range are encountered, the user should consult the original curves in [69] or [30]. The $G(h_{12})$ values in decibels are then substituted in (4.4-27) as before to determine the attenuation A_k over the diffracting obstacle.

4.4.20.12 In cases where terrain details over the entire path are well known, and it is possible to identify pronounced reflecting surfaces, four-ray geometric optics methods may be applicable which must be modified to allow for attenuation and phase shift of each ray by the diffracting obstacle. Applicable methods and procedures for such cases are given in appendix 6.3.

4.4.20.13 In summary, the single -obstacle diffraction attenuation A_k may be obtained by calculating first the parameter v, and using figure 4.4-11, or by calculating the parameter p in addition to v and using (4.4-33); furthermore, the residual height gain functions $G(h_{12})$ must be included where required. The reference value of basic trasmission loss, L_{bcr}, is obtained by adding A_k and the median atmospheric attenuation, A_a, to the free-space loss, L_{bf}.

4.4.21 Diffraction Over Smooth Terrain

4.4.21.1 Before undertaking calculation of transmission loss for diffraction over smooth or irregular terrain with more than one horizon, it is useful to check whether such calculations are really necessary. The diffraction loss increases rapidly with distance beyond the radio horizon, so that the received radio frequency energy particularly at the higher frequencies becomes negligible in comparison with that received from tropospheric scatter mechanisms. Table 4.4-1 below, provides approximate guide lines in terms of the product θd, where θ is the angular distance in radians (see section 4.4.7) and d the path distance in kilometers. The table provides the minimum value of for which scatter calculations of basic transmission. loss (as outlined in section 44.23) will suffice and diffraction calculations in this section can be neglected.

Table 4.4-1. Criteria for use of two-horizon diffraction calculations.

Frequency, MHz	Minimum θd for neglect of two-horizon diffraction calculations	
	Smooth terrain or water	Irregular terrain
200	0.8	4.3
500	0.5	2.6
1000	0.4	1.6
2000	0.4	0.9
5000	0.3	0.3
10000	0.3	0.3

Note that these criteria apply only to two-horizon. paths. Diffraction losses over single-horizon (obstacle diffraction) paths in accordance with section 4.4-20 should always 'be calculated, since they usually are less than scatter losses.

4.4.21.2 Except for table 4.4-1, the methods in this sub--section should only be applied to smooth earth; i. e, , water surfacees or Very level terrain so that the radio horizons for the termlnal antennas are not formed by prominent ridges or mountain peaks, out are determined solely as a function of antenna height above ground and the effective earth radius. horizon distances in such cases are given by (4.4-7) in section 4.4.7. This equation is repeated here for convenience:

$$d_{L1,2} = \sqrt{2ah_{g1,2}} \text{ km} \qquad (4.4\text{-}7)$$

where the horizon distances $d_{L1,2}$, the antenna heights $h_{g1,2}$, and the effective earth radius a must all be in the same units (usually kilometers). For the calculation of reference has basic transmission loss values the effective earth radius used here is that corresponding to the minimum monthly mean value of the surface refractivity, N_s, used in (4.4-4). The heights $h_{g1,2}$ include here the total antenna structure above the level surface, and also the elevation of the cliff, or hill where the antenna might be located. As an example, an antenna might be on a hill or mountain overlooking a large, level surface such as a smooth prairie or a desert; the height h_g is then the elevation of the antenna feed point above that surface.

4.4.21.3 The simplified graphical method used here for calculating ground wave attenuation over a spherical homogeneous earth was developed by Vogler [30], and is applicable to either horizontal or vertical polarization.

4.4.21.4 The rounded earth diffraction attenuation relative to free spaces A_{rd}, may be expressed in terms of a distance dependence, the dependence on antenna heights, and the dependence on electromagnetic ground constants, the earth's radius, and the radio frequency:

$$A_{rd} = G(x_0) - F(x_1) - F(x_2) - C_1(K, b) \ \text{dB}. \qquad (4.4\text{-}39)$$

The parameters x_0, x_1, and x_2 are given by:

$$x_0 = d\,B_o, \ x_1 = d_{L1}\,B_o, \ x_2 = d_{L2}\,B_o, \qquad (4.4\text{-}40)$$

with

$$B_o = f^{\frac{1}{3}} C_o^2\, B(K, b). \qquad (4.4\text{-}41)$$

Here, C_o is determined using (4.4-36) for the effective earth radius a from (4.4-4), and B(K, b) as shown in figure 4.4-17 as a function of the parameters K and b. These are also determined in the same manner as was shown in section 4.4.20 for the calculations of the residual height gain functions $G(h_{1,2})$.

4.4.21.5 In (4.4-40) and (4.4-41), the distance d_{Lp} d_{L2}, and the effective earth's radius a, are in km and f is the radio frequency in MHz . The parameter K_0 read from figure 4.4- 15 as a function of the ground constants must be modified as before to allow flow the effective earth radius used when it differs from the 8500-km value:

$$K = C_o K_o \tag{4.4-42}$$

Equation (4.4-42) is the same as (4.4-37a, b) and is repeated here for convenience. The parameter B(K, b) shown in figure 4.4-17 has a limiting value of B = 1.607 for K - 0, which may be used for most cases of horizontal polarization. The parameter C_1(K, b) is shown in figure 4.4-18. It has a limiting value of 20, 03 db which is applicable to small values of K (less than 0.01). The functions $f(x_{1,2})$ and $G(x_0)$ are shown-in figure 4.4-19 and $G(x_o)$ is also defiaud by:

$$G(x_0) = 0.05751X_0 - 10 \log X_0. \tag{4.4-43}$$

For large positive values of xl or X_2, beyond the range of the graph, F(x) is approximately equal to G(x). The range of tile parameter provided in this graph should be sufficient for most applications at frequencies above 100 MHz; otherwise the graphs in [69] should be used.

4.4.21.6 The method shown here is based on only the first term of the Van der Pol - Bremmer residue series, and is theref'~re~ inaccurate for short distances [31]. A useful criterion [30] insuring accuracy of the attenuation A_{rd} within approximately 1.5 dB and applicable to K ≤ 0.01 is given below as a function of the normalized distances X_0, xl, and x_2, and of a function Δx shown in figure 4.4-19 as a function of $X_{1,2}$:

$$x_0 - x_1(\Delta x_1) - x_2(\Delta x_2) > 335, \text{ for } B = 1.607, \ (K \leq 0.01). \tag{4.4-44}$$

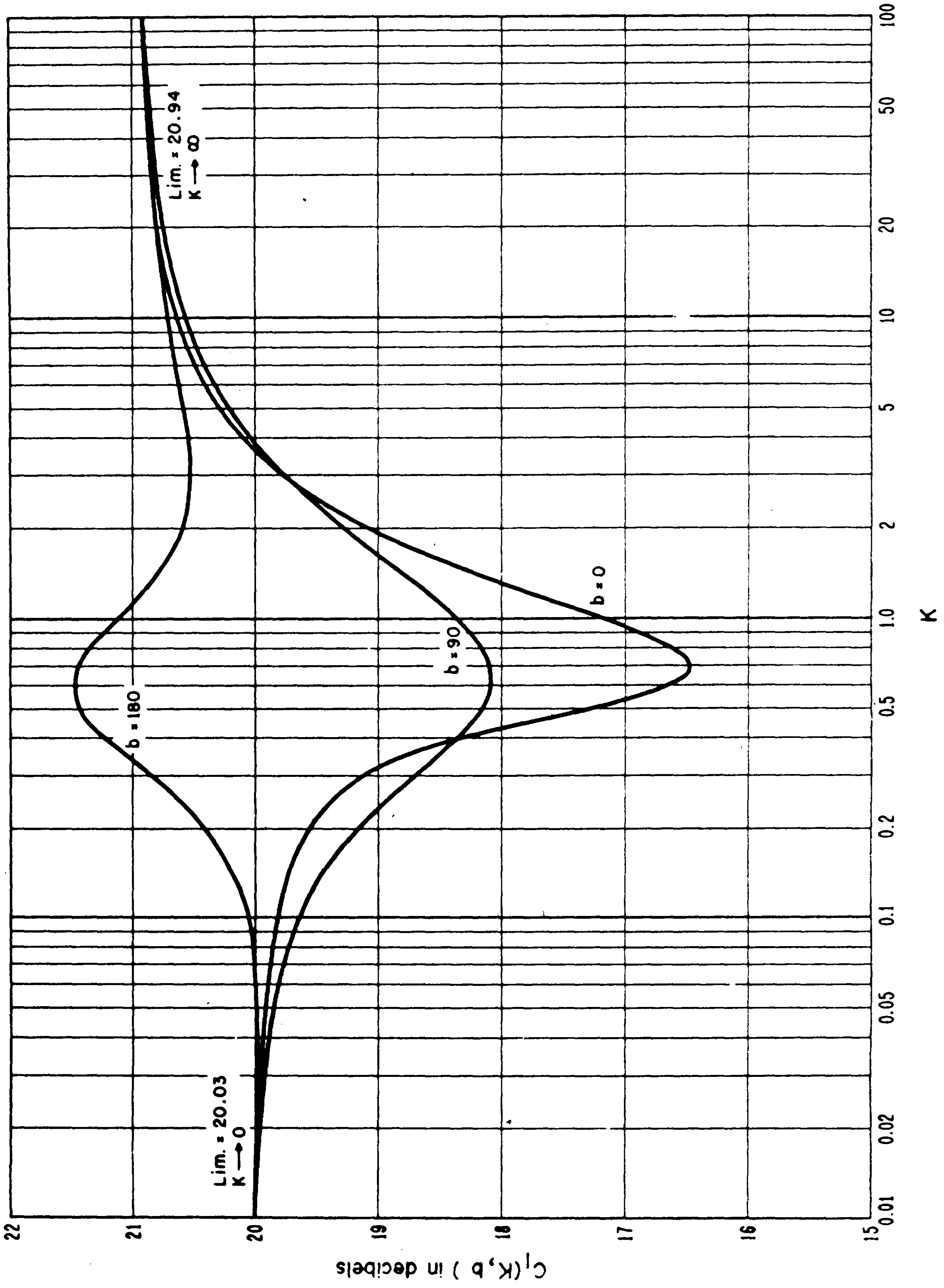

Figure 4.4-18 The Parameter $C_1(K, b)$ in Decibels

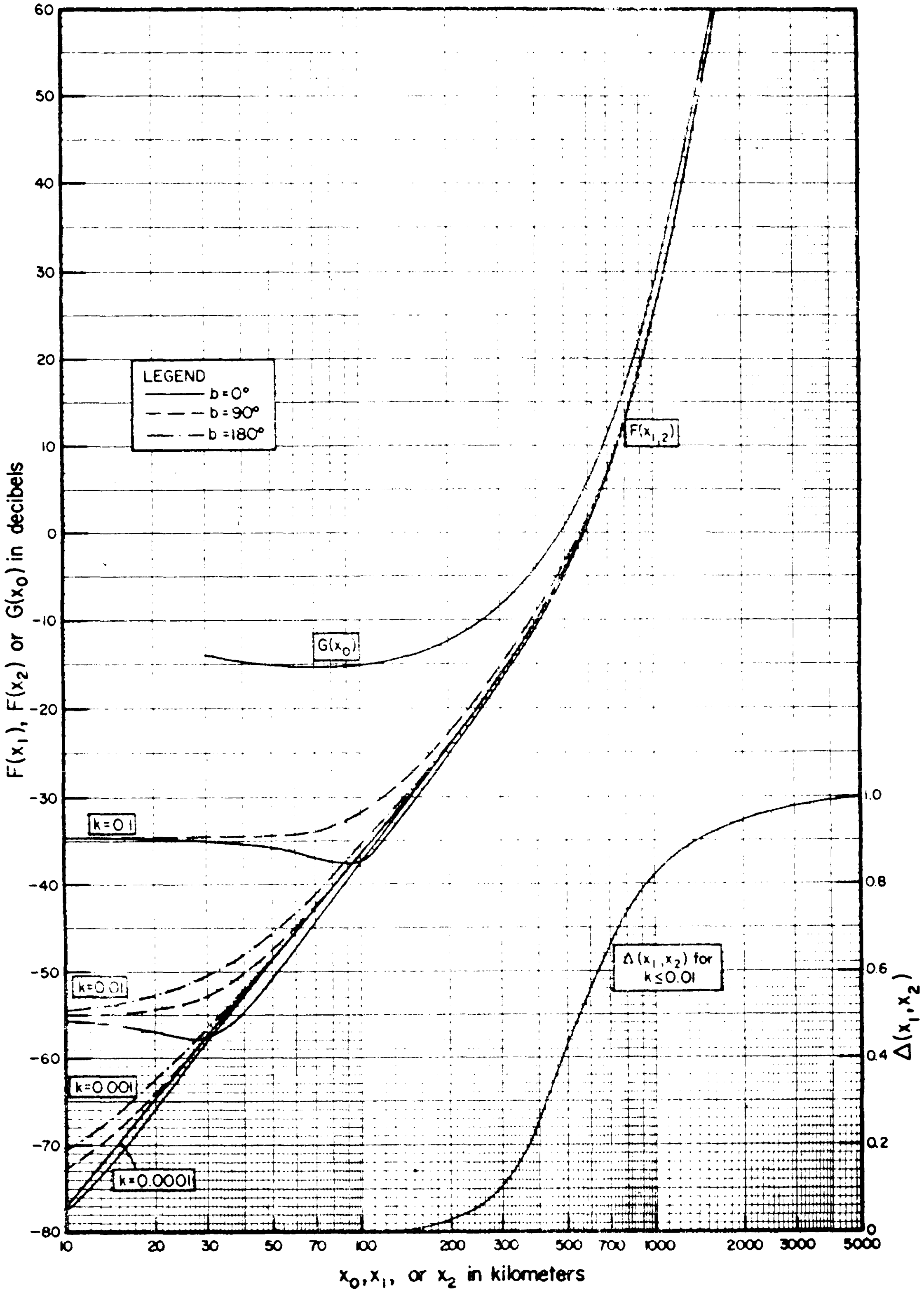

Figure 4.4-19 The Function F(x)and G(x) for Diffraction Calculations

4.4.21.7 After all necessary parameters have been determined, the diffraction attenuation over smooth earth, A_{rd}, is calculated from (4.4-39). The corresponding reference value of basic transmission loss, L_{bcr}, is obtained by adding A_{rd} and the median atmospheric attenuation, A_a to the free-space loss L_{bf}, with all terms in decibels, as discussed in section 4.4.16.

4.4.22 Diffraction Over Irregular Terrain (Two Horizons)

4.4.22.1 In order to calculate the diffraction attenuation, Aid, over irregular terrain for cases where there is no common horizon for the terminal antennas, the method given in the previous section is modified by replacing the single effective earth radius, a, by four different radii. As in the case of smooth-earth diffraction, the criteria in table 4. 4-1 - should be used first to determine whether diffraction calculations are required in any specific case.

4.4.22.2 The geometry for the irregular terrain diffraction case is shown in figure 4.4-20. Some of the parameters shown here have been defined in section 4.4.7. Additionally, the distances d_3 and d_4 are given by:

$$d_3 = d\beta_o/\theta - d_{L1} \quad \text{km} \tag{4.4-45a}$$

$$d_4 = d\alpha_o/\theta - d_{L2} \quad \text{km} \tag{4.4-45b}$$

and the distance between the radio horizon, D_s is also

$$D_s = d_3 + d_4 \text{ km} \tag{4.4-45C}$$

The four effective earth radii a_1, a_2, a_3, and a_4 are then calculated using:

$$a_1 = d_{L1}^2/(2h_{e1}) \quad \text{km} \tag{4.4-46a}$$

$$a_2 = d_{L2}^2/(2h_{e2}) \quad \text{km} \tag{4.4-46b}$$

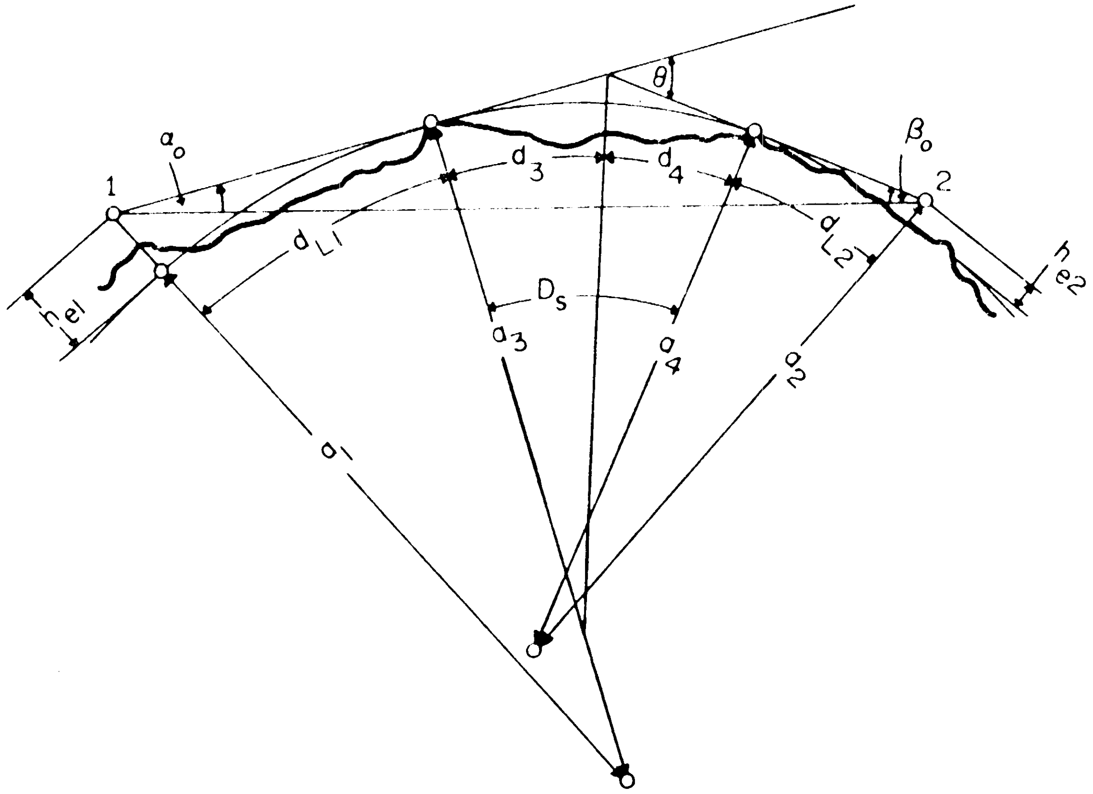

Figure 4.4-20 Geometry for Diffraction over Irregular Terrain

$$a_3 = D_s d_3/(\theta d_4) \text{ km} \qquad (404\text{-}47a)$$

$$a_4 = D_s d_4/(\theta d_3) \text{ km.} \qquad (4.4\text{-}47b)$$

In these expressions, all distances and heights are in kilometers and all angles are in radians. Equations (4.4-46a, b) are of course the same as (4.4-34a,b) used in section 4.4.20 and utilize the effective antenna heights defined in section 4.4.17.

4.4.22.3 The calculation method is basically the same as that for smooth earth diffraction discussed previously. Using (4.4-36) in section 4.4.20, four values of Co are computed; i. e. , $C_{01,2,3,4} = (8500/a_{1,2,3,4})^{\frac{1}{3}}$.These are used to obtain values of $K_{1,2,3,4}$ from the relationship in (4.4-42); $B_{1\,2\,3\,4}$ is then read from figure 4.4-17 corresponding to each values of $k_{12,3,4}$

4.4.22.4 The diffraction attenuation relative to free space is then:

$$A_{id} = G(x_0) - F(x_1) - F(x_2) - \overline{C}_1(K_{1,2}) \text{ dB.} \qquad (4.4\text{-}48)$$

This is similar to (4.4-39) with G (x_0) defined by (4. 4-43) Or read from figure 4.4-19. $F(x_1)$ and $F(x_2)$ are also read from figure 4.4-19. However, the parameters x_0, X_1 and x_2 are defined differently, and $\overline{C}_1(K_{1,2})$ is the weighted average of $C_1(k_1,b)$ and $C_1(K_2,b)$ read from figure 4.4-18. The equations are as follows:

$$x_1 = B_1 C_{o1}^2 f^{\frac{1}{3}} d_{L1}, \quad x_2 = B_2 C_{o2}^2 f^{\frac{1}{3}} d_{L2} \qquad (4.4\text{-}49)$$

$$x_0 = \left(B_1 C_{o3}^2 d_3 + B_4 C_{o4}^2 d_4 \right) f^{\frac{1}{3}} + x_1 + x_2 \qquad (4.4\text{-}50)$$

$$\overline{C}(K_{1,2}) = \left[x_1 C_1(K_1, b) + x_2 C_1(K_2, b) \right] \Big/ (x_1 + x_2) \text{ dB.} \quad (4.4\text{-}51)$$

4.4.22.5 This method is applicable to computation of diffraction attenuation over irregular terrain for both vertical and horizonal polarization. It may be somewhat simplified for two speclal cases: diffraction over paths where $d_3 \simeq d_4$, and for most paths when horizontal polarization is used. For paths where the distances d_3 and d_4 are approximately equal, the effective radii a_3 and a_4 may be replaced by a single value as defined by:

$$a_s = D_s/\theta \text{ km.} \qquad (4.4\text{-}52)$$

The parameter X_0 for determination of $G(x_0)$ in (4.4-48) is then driven by:

$$x_0 = B_{0s} D_s + x_1 + x_2 \qquad (4.4\text{-}53)$$

where

$$B_{os} = f^{\frac{1}{3}} C_{os}^2 B(K_s, b), \qquad (4.4\text{-}54a)$$

$$C_{os} = (8500/a_s)^{\frac{1}{3}} \qquad (4.4\text{-}54b)$$

and

$$K_s = C_{0s} K_0 \qquad (4.4\text{-}54C)$$

4.4.22.6 For horizontally polarized radio waves, at frequences above 100 MHz, and with $K(a) < 0.001$, the parameter $B(K, b)$ approaches the constant value $B \approx 1.607$, and $C_1(K, b) = 20.C3$ dB. The diffraction attenuation, with $d_3 = d_4$, is then.

$$A_{id} = G(x_0) - F(x_1) - F(x_2) - 20.03 \text{ dB} \qquad (4.4\text{-}55)$$

where

$$x_1 = 669(f/a_1^2)^{\frac{1}{3}} d_{L1}, \quad x_2 = 669(f/a_2^2)^{\frac{1}{3}} d_{L2} \qquad (4.4\text{-}56)$$

and

$$x_0 = 669(f\theta^2 D_s)^{\frac{1}{3}} + x_1 + x_2. \qquad (4.4\text{-}57)$$

As before, all distances and heights are in kilometers and all angles are m radians. For the determination of $F(x_1)$, and $G(x_0)$ the graphs in figure 4.4- 19 are used.

4.4.22.7 In some cases over rather regular terrain a common horizon may be formed by the bulge of the earth rather than by an isolated ridge or mountain. For such paths the obstacle diffraction methods in section 4.4.20 should not be used. The path length d is then approximately the sum of the horizon distancences,

$$d = d_{L1} + d_{L2} \text{ km}, \qquad (4.4\text{-}58)$$

and t he method for irregular terrain is simplified using only two earth' s radii. The parameters x_1 and x_2 are defined by (4.4-49) and $x_o = x_1 + x_2$. The attenuation is then calculated as before using (4.4-4S) . For paths over the sea, with a common horizon on the surface of the sea, the attenuation may be estimated using the smooth-earth diffraction methods of section 4.4.21 with $x_o = x_1 + x_2$ The diffraction attenuation, A_{id}, is again added to the free-space loss L_{bf} and the median atmospheric attenuation, A_a, to obtain the reference value of basic transmission loss, L_{bcr}, with all terms in decibels (see sec. 4.4.16.4).

4.4.23 Tropospheric Scatter

4.4.23.1 The attenuation in decibels relative to free space for trans-horizon links where tropospheric scatter mechanisms are dominant will be denoted by As. However, to conform to earlier work [16, sec.4] [69] the calculation model has been set up directly in terms of the reference basic transmission loss value, L_{bsr}, in decibels, corresponding to tropospheric scatter. The attenuation, A_s, can be obtained from L_{bsr} for comparison with the diffraction attenuation values A_k, A_{rd}, or A_{id} by subtracting the free-space loss, L_{bf} (from 4. 4-26a):

$$A_s = L_{bsr} - L_{bf} \text{ dB}. \qquad (4.4\text{-}59)$$

Terrain parameters required for calculation of L_{bsr} or As are included in the listing of section 4.4. 16; additionally, the minimum monthly mean value of surface refractivity, $\overline{N}_s$, is required, as discussed in section 4.4.3. Specifically, the following parameters- addition to $\overline{N}_s$ are used:

Carrier frequency, f, in megahertz, and the wavelength, λ in km

Path distance, d, in kilommeters

The angles α_o and β_o from (4.4-10)

The scatter angle θ from (4.4-11)

The ratio s from (4.4-13)

The parameter h_0 from (4.4-12)

Estimates of the effective antenna heights h_{e1} and h_{e2} as explained in section 4.4.17 (m).

4.4.23.2 The reference value, L_{bsr}, of basic transmission loss in decibels due to forward scatter is giver. by

$$L_{bsr} = 30 \log f - 20 \log d + F(\theta d) + H_o \text{ db}$$

where the frequencty, f, is in megahertz, the path distance, d, is in kilometers, and the function F(od) is plotted in figure 4.4-21 as a function of the procucty od of the path length d in kilometers times the scatter angle o in radians. The function H_o will be given below. Equation (4.4-60)for the scatter loss is applicable to all except exceptionally long scattter links. However, the simplified procedures used here to obrtain the terms F(od) and Ho in (4.4-60) are sttrictly applicable only for $0.7<s<1$, and with the effective heights h_{e1} and h_{e2}, approximately equal(unless ho is negligible). For other cases, these procedures generally overestimate the scatter loss. More complete methods with additional formulas, graphs, and correction terms can be found in Rice et al. [16, sec. 9).

4.4.23.3 F(od) is read from. figure 4.4-21 as a function of the product θd and of the surface refractivity, $\overline{N}_s$. Visual interpolation between the various curves will be stifficintly accurate. Since Ns is a minimum.

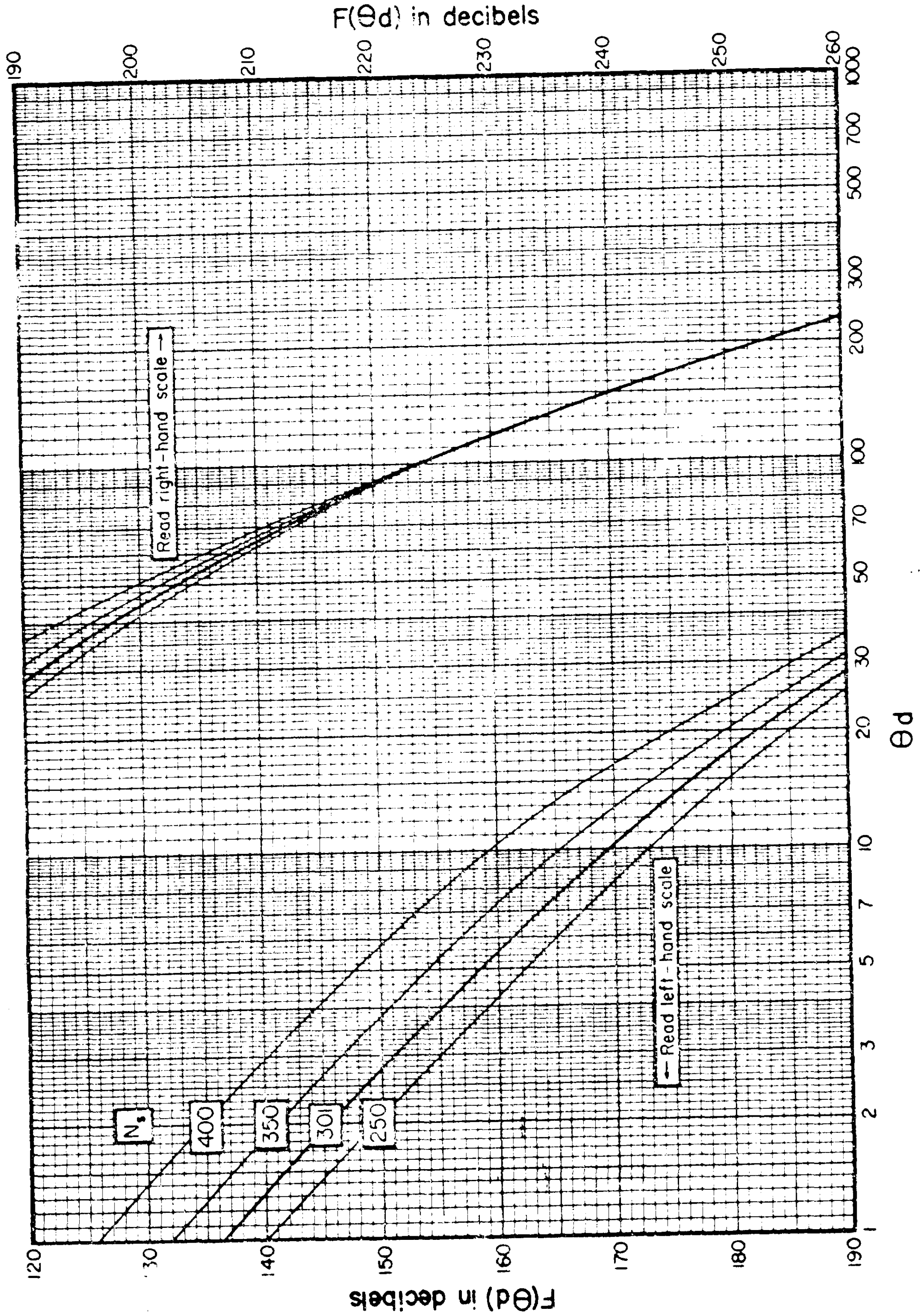

Figure 4.4-21 The Attenuation Function F(θd) for d in kilometers, θ in radians, and 0.7 ≤ s ≤ 1

monthly mean value, its range given here should be adequate for all applications. For od < 1, and 250 N_s < 400, the following approximate expression has been developed and may be used:

$$F(\theta d) \cong 30 \log (\theta d) + 139.5$$

$$- \left[0.06(N_s - 250) + 0.00025(\overline{N}_s - 250)^2 \right]. \qquad (4.4\text{-}61)$$

4.4.23.4 In the formulation of the forward scatter theory, it was assumed that the antennas are sufficiently high above reflecting surfaces so that the available power is doubled by reflections near both path terminals. However, for low effective antenna heights in terms of the wavelength, the reflected energy tends to become more phase-coherent with phase opposition and to cancel energy from the direct ray in the lower part of the common scattering volume where scattering efficiency is greatest. Hence, the available total energy is,aecreas~d, and the frequency gain function, H_0 is a measure of this decrease in energy and corresponding increase in path loss. H_0 depends on the parameters r_1 and r_2 which are functions of the effective antenna heghts in terms of wavelength, and η_s which is dependent on atmospheric and terrain , parameters. Determine first:

$$r_1 = \begin{cases} 4\pi \theta h_{e1}/\lambda & \text{if } \alpha_o \le \beta_o \\ 4\pi \theta h_{e2}/\lambda & \text{otherwise} \end{cases} \qquad (4.4\text{-}62a)$$

$$r_2 = \begin{cases} 4\pi \theta h_{e2}/\lambda & \text{if } \alpha_o \le \beta_o \\ 4\pi \theta h_{e1}/\lambda & \text{otherwise} \end{cases} \qquad (4.4\text{-}62b)$$

Where a_0 and So are from (4.4-10). In (4-62a, b) the scatter angle, 6, is in radian, and the effective antenna heights, $h_{e1,2}$, and the wavelength, λ, must be in the same units. The wavelength, may be determined using (4.4-27a)

4.4.23.5 If r_1 and r_2, in (4.4-62), are greater than 20, the frequency gain function, H_0, is negligible. If this is not the case, the parameter η_S must first be determined from figure 4.4-22, as a function of h_o from (4.4-12). Ho is then determined from figure 4.4-23 as a function OF $r_{1,2}$ and η_S using the following rules:

(a) Averaging: if $r_1 = r_2$, either one can be used to enter figure 4.4-23, to determine Ho. If $r_1 \neq r_2$, determine $H_{o1,2}$ for r_1 separately from the graph and use the average of the two values to obtain Ho.

(b) Interpolation: for $1 \le \eta_s \le 5$, visual interpolation between the appropriate curves on figure 4.4-23 is adequate. For $0 < \eta_s < 1$, read Ho for $Ho_S = 0$ and $\eta_s = 1$ separately, and use the following interpolation formula to obtain Ho corresponding to the actual value

$$H_o(\eta_s < 1) = H_o(\eta_s = 0) + \eta_s[H_o(\eta_s = 1) - H_o(\eta_s = 0)] \text{ dB.} \qquad (4.4\text{-}63)$$

4.4.23.6 As already noted, the estimates for Ho given above apply strictly to, the case where s = 1 and $h_{el} = h_{e2}$; i. e., symmetrical paths with equal effective antenna heights. However, it is not likely that serious errors are introduced by the use of this procedure except at frequencies less than about 500 MhZ, or for very unsymmetrical paths with s<0.1 or > 10. In such rare cases, the methods by Rice, et al . [16] should be used, although they are more complex.

4.4.23.7 The reference value, L_{bcr} , of basic transmission loss for the scatter mechanism is obtained by adding the median atmosphere c attenuation, A_a to the scatter losss, lbSr, resulting from (4.4-60). The scatter attenuation, As, for comparison with diffraction attenuation values, A_k, A_{rd}, or A_{id}, is obtained by subtracting the free- space loss, L_{bf} from L_{bsr}.

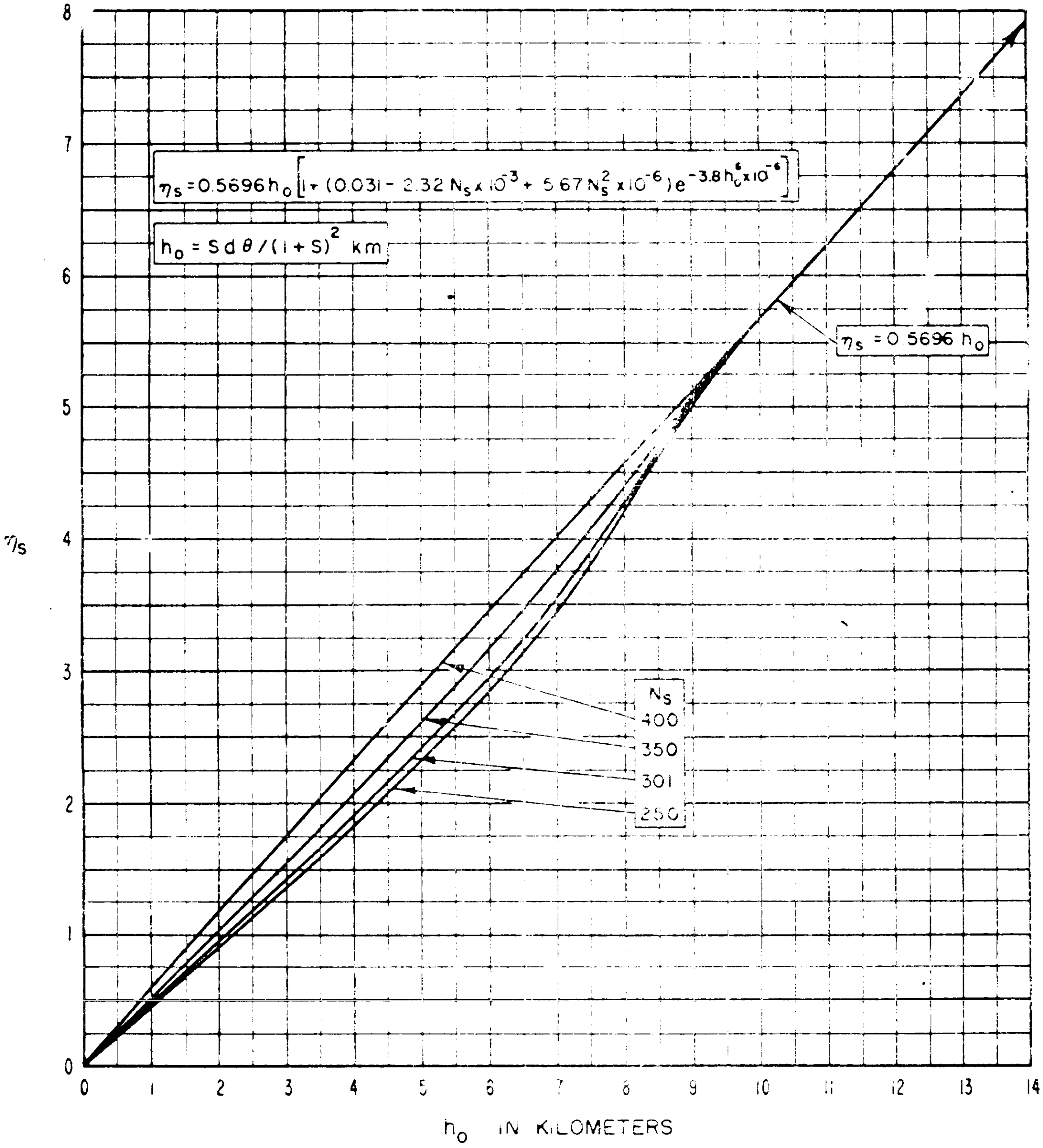

Figure 4.4-22 The Parameter n_s in Tropospheric Scatter Propagation

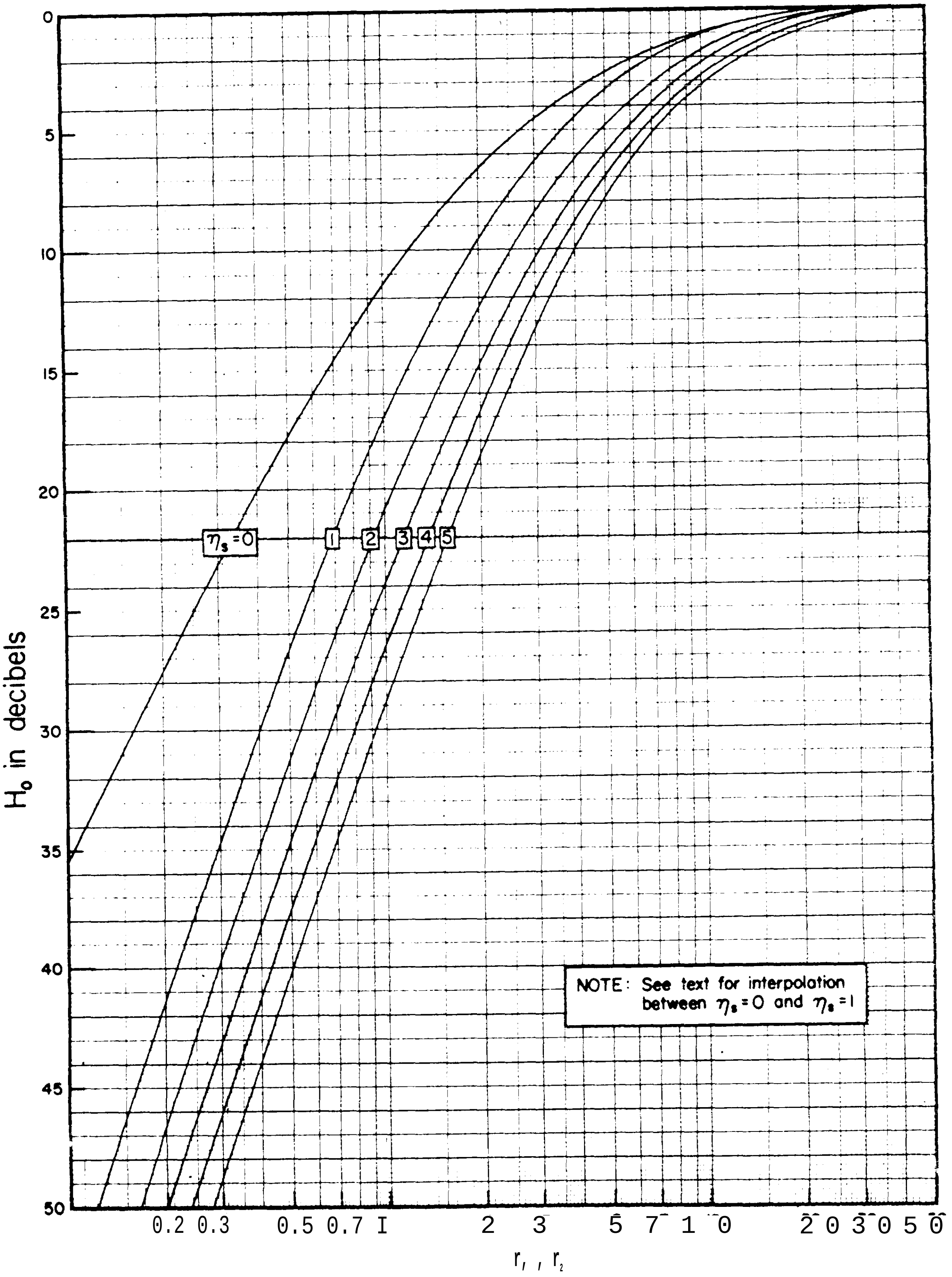

Figure 4.4-23 The Frequency Gain Function Ho

4.4.24 Combining Diffraction and Scatter Loss

4.4.24.1 In cases where diffraction and scatter attenuation values for a given path are within 15db of each other, the actual attenuation will be some what less than either of the two. Figure 4.4-24 can be used in such cases to determine the attenuation due to the two mechanisms as a function of their difference in decibels. The curve shown in figure 4.4-24 is denoted R(0.5). For any specific case, determine the difference between the diffraction attenuation, $A_{diff} = A_k$, A_{rd}, or A_{id}, and the scatter attenuation, A_s, in decibcis, determine the corresponding value of R(0. 5) from the figure, and the resulting attenuation, A_{ds}, is then given by:

$$A_{ds} = A_{diffr} - R(0.5) \text{ dB.} \qquad (4.4\text{-}64)$$

4.4.24.2 Reference basic transmission loss values can be substituted for the attenuation values, if desirected, but note than L_{bcr} been defined to include the median atmospheric attenuatioan A_a, whereas L_{bsr} does not.

4.4.24.3 If diffraction and scatter attenation differ by about 15 dB or more, the above combination method may be omitted and the final value of L_{bcr} is the smaller one of those corresponding to the two mechanisms. The sign (plus or minus) of the difference between diffraction and scatter attenuation is important in the determination of R(0.5) and must not be overlooked.

4.4.24.4 To summarize the results of ihe preceding. steps, the reference value of basic transmission loss is obtained in accordance with (4.4-24b) by adding to the free-space loss, L_{bf}, the average atmospheric attenuation, A_a, and the calculated attenuation relative to free space, A_{cr}, The latter is the smallest of the values A_k, A_{rd}, A_{id}, A_s, or A_{ds}, whichever is applicable to the specific link in accordance with the methods discussed above.

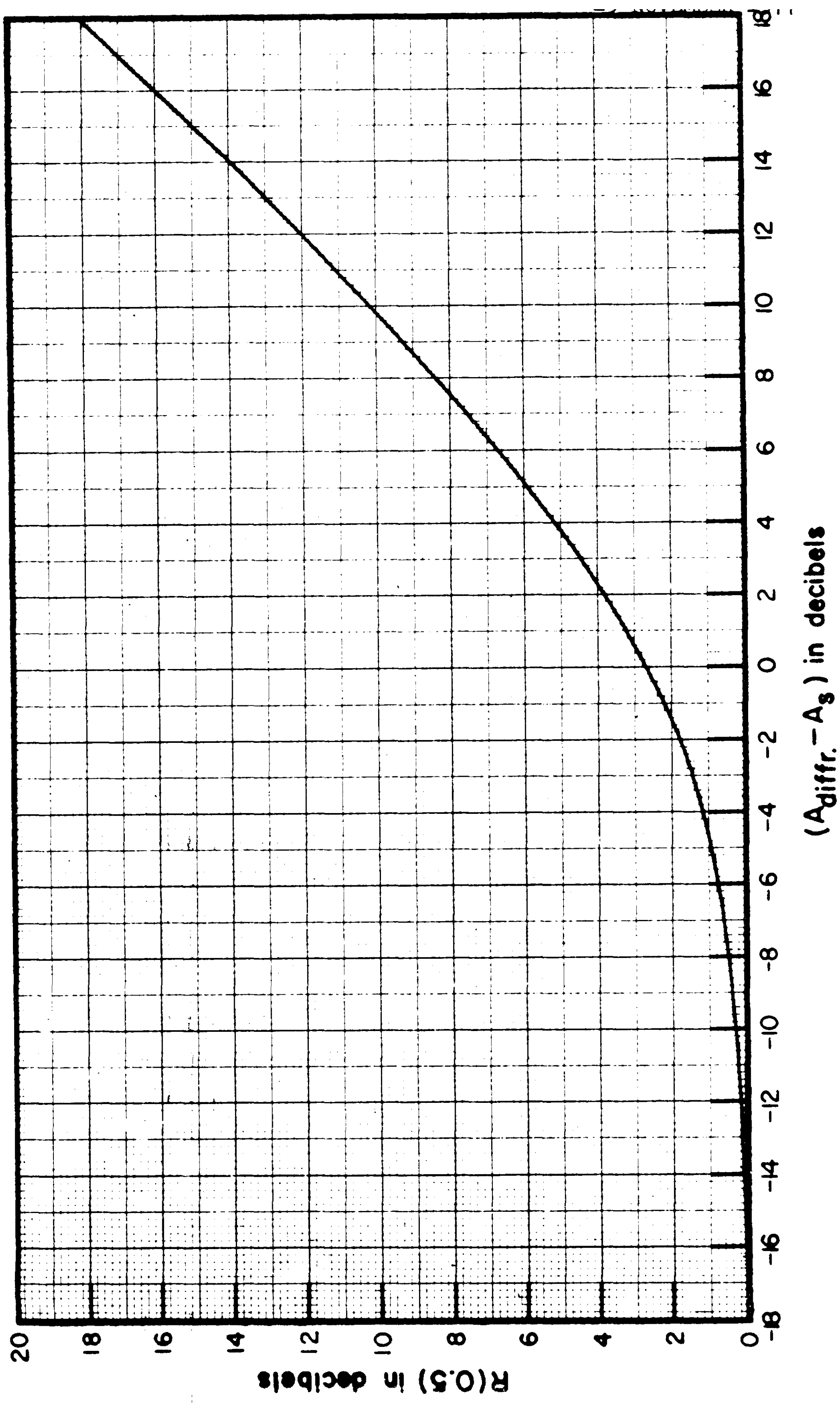

Figure 4.4-24 · The Function R(0.5) for Combining Diffraction and Scatter Losses

4.4.25 Long-Term Variability

4.4.25.1 The previous sections provided methods for calculating a reference value of basic transmission loss as a function of terrain parameters and median atmospheric parameter ; i. e., those which - correspond to average propagation. conditions over a specific link. The next step is the estimation of the basic transmission loss variability with time as a function of the time-varying atmospheric parameters. The methods presented here are largely empirical, having been derived from observations and measure measurements [1] (16, sec. 10]. Thus, their general application is subject to uncertainties, which will be discussed subsequently in section 4.4.26.

4.4.25.2 For the purpose of assessing the effects of transmission loss variability over transhorizon links, it has been found expedient to distinguish between short-term and long-term. phenomena. Short-term, fading over transhorizon links is associated with a time irterval for which the average received power level remains constant, and the fading results from the changing phase relation. Of various multipath components received by the system. Such multipath cOmpOnents are largely caused by atmospheric irregularities (the "scatter" mechanisms), but can, in some cases, also be attributed to multiple specular reflections from atmospheric layers Or terrain features (72). The time interval over which the average received power level remains cinstant may vary between several minutes and approximately one hour and is generally shortest for frequencies above 2000 MHz. The original data on which transmission loss variability analyses are based were organized In terms of hourly median values and within- the-hour distributions for convenience and uniformity. Thus, it is still useful to define long-term variability as the variability of hourly transmission loss medians and short-term variability as the variability of the instantaneous received power levels relative to the hourly median value. It has been generally accepted that the time distribution of hourly median transmission loss values is not significantly different from the distribution of half-hourly or even 5-minute medians at the higher frequencies considered here.

4.4.25.3 Since short-term variability over transhorizan links is essentially a phase-interference phenomenon? its effects can be accounted for by appropriate diversity design, and are implicitly included in the specification of the required hourly median predetection carrier-to-noise ratio expected to provide the desired grade of service Thus, the time availability of the desired grade of service is given by the time distribution of the hourly medians of the required ratic, which can be directly related to the time distribution of hourly basic transmis sian loss medians (see sec. 4.4.26).

4.4.25.4 The time variability of basic transmission loss is expressed by empirical functions V(q) in decibels, where q denotes a fraction of all hours of an average year, such as 0.999, or the corresponding percentage such as 99.9%. Since there are 8760 hours in. 2 year of 365 days, q = O. 999 corresponds to all but approximately 9 hours of the year, and q = 0.9999 may be taken to represent all but hour, the function V(q) is a function of climate, path parameters, and carrier frequency, as will be shown below, and defined such that:

$$L_b(q) = L_{bcr} - V(q) \text{ dB.} \qquad (4.4\text{-}65a)$$

Here, L_{bcr} is the reference value of basic transmission loss as defined earlier, and $L_b(q)$ is the basic transmission loss not exceeded for a fraction q (or for q%} of all hours, or exceeded for a fraction (1- q) Or a percentage (100 - q%) of all hours. This notation has been chosen because field strength, received power levels, or available carrier-to-noise ratios exceeded correspond to transmission loss not exceeded, and the distribution graphs are more logically oriented with the abscissa denoting field strength or received power levels increasing upward.

4.4.25.5 The variability function V(q) is expressed as the sum of a yearly median value, V(0.5), and a component Y(q), with all quantities in decibels. Available graphs and formulas facilitate calculation of a yearly basic transmission loss median without the necessity of obtaining the entire distribution. Thus:

$$L_b(0.5) = L_{bcr} - V(0.5)\ \text{dB}. \qquad (4.4\text{-}65b)$$

From (4.4-65a) and (4.4-65b) it follows that:

$$L_b(q) = L_{bcr} - V(0.5) - Y(q) \qquad (4.4\text{-}66)$$

$$= L_b(0.5) - Y(q)\ \text{dB}$$

and:

$$V(q) = V(0.5) + Y(q)\ \text{dB}. \qquad (4.4\text{-}67)$$

4*4, 25.6 V(0.5) and Y(q) are functions of the effective distance, d_e, which is obtained from carrier frequency and path parameters by calculating two auxiliary parameters d_{sl} and d_{Lo} The first of these; d_{S1}, is a function of frequency:

$$d_{sl} = 65(100/f)^{1/3}\ \text{km} \qquad (4.4\text{-}68)$$

where the frequency f is in megahertz. The efective antenna heights, h_{e1} and h_{e2}, were defined in section 4.4.17 where it was also discussed how they can be estimated from inspection of the path profiles. They are used to calculate the parmeter d_{Lo}:

$$d_{Lo} = 134\left(\sqrt{h_{e1}} + \sqrt{h_{e2}}\right)\text{km}, \qquad (4.4\text{-}69)$$

where h_{el}, h_{e2}, and d_{Lo} are in kilometers. Then the effecive distance, d_e, in kilometers, is obtained as follows as a function of the path distance, d, in kilometers, and d_{S1} and d_{LO} :

$$d_e = \begin{Bmatrix} 130\ d/(d_{Lo} + d_{sl}) & \text{for } d \le (d_{Lo} + d_{sl}) \\ 130 + d - (d_{Lo} + d_{sl}) & \text{otherwise} \end{Bmatrix} \text{km.} \qquad (4.4\text{-}70)$$

4.4.25.7 Estimates given here for V(0.5) in figure 4.4-25 and for Ye(q) in figures 4.4-26 to 4.4-32 are largely based on the information in CCIR Report 244-2 [1]. However, the curves in [1] have been modified by ITS workers for use in computer programs. * Algebraic expressions were fitted to the various curves in [1], and the information given here is based on these expressions which so far have not been formally published. In addition, it was felt that some of the CCIR estimates for climate types 3 (maritime subtropical), 7a (maritime temperate, overland), and 7b {maritime temperate) oversea) are not realistic for the longer distances and small values of the time availability q (0.01, 0.001, and 0.0001). These have been more substantially modified. * Thus, the curves in this handbook differ somewhat from the applicable CCIR recommendations and reports, but they are thought to be more up-to-date estimates. The subscript in $Y_0(q)$ means that the curves in figures 4.4-25 to 4.4-32 have been drawn for a single standard frequency (1000 MHz). Values of Y(q) for other frequencies are in some cases obtained by using correction factors which will be explained below.

4.4.25.8 The various climate types are listed in table 4. 4-2 including supplementary data to aid in the selection of the appropriate type for a specific radio link, and table 4.4-3 lists the applicable figure (4.4-26 to 4.4-32) for each climate type. Table 4. 4-2 is based primarily on the annex to CCIR Report 244-2 1], and is presented here as the best available information in lieu of maps. If a path is near a border

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*Informal communication from A. G. Longley.

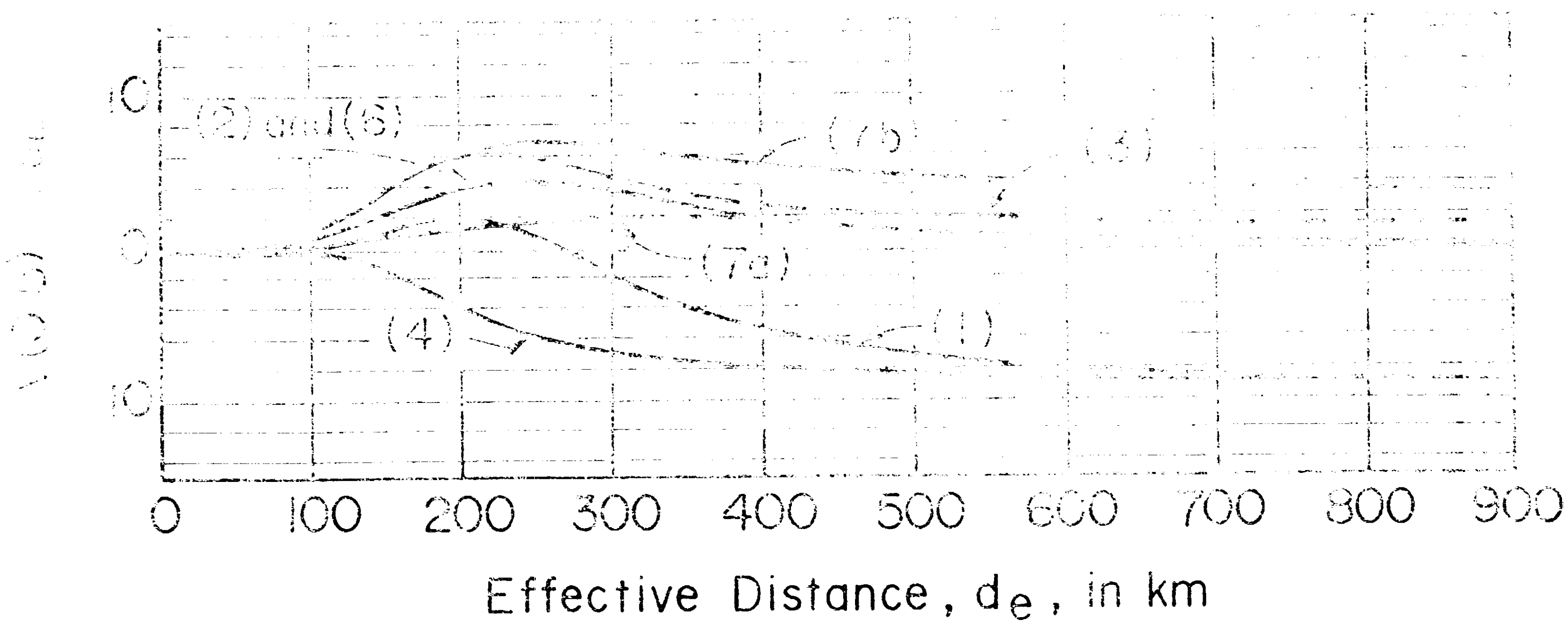

Figure 4.4-25 Variability Function V(0.5) as a Function of Effective Distance and Climate Type (as indicated by the code numbers, see table 4.4-3)

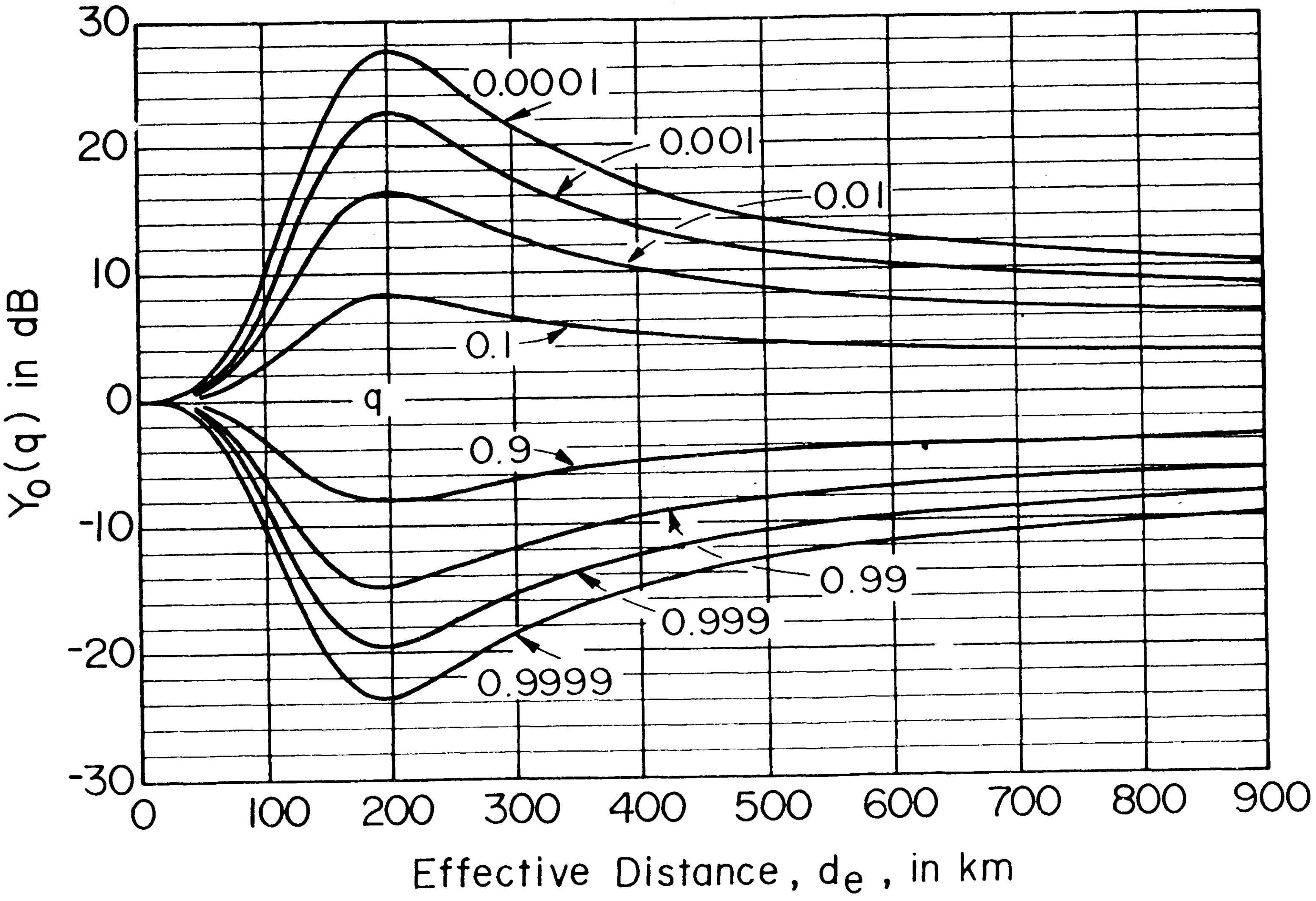

Figure 4.4-26 Variability Function $Y_o(q)$ for Climate 1, Equatorial

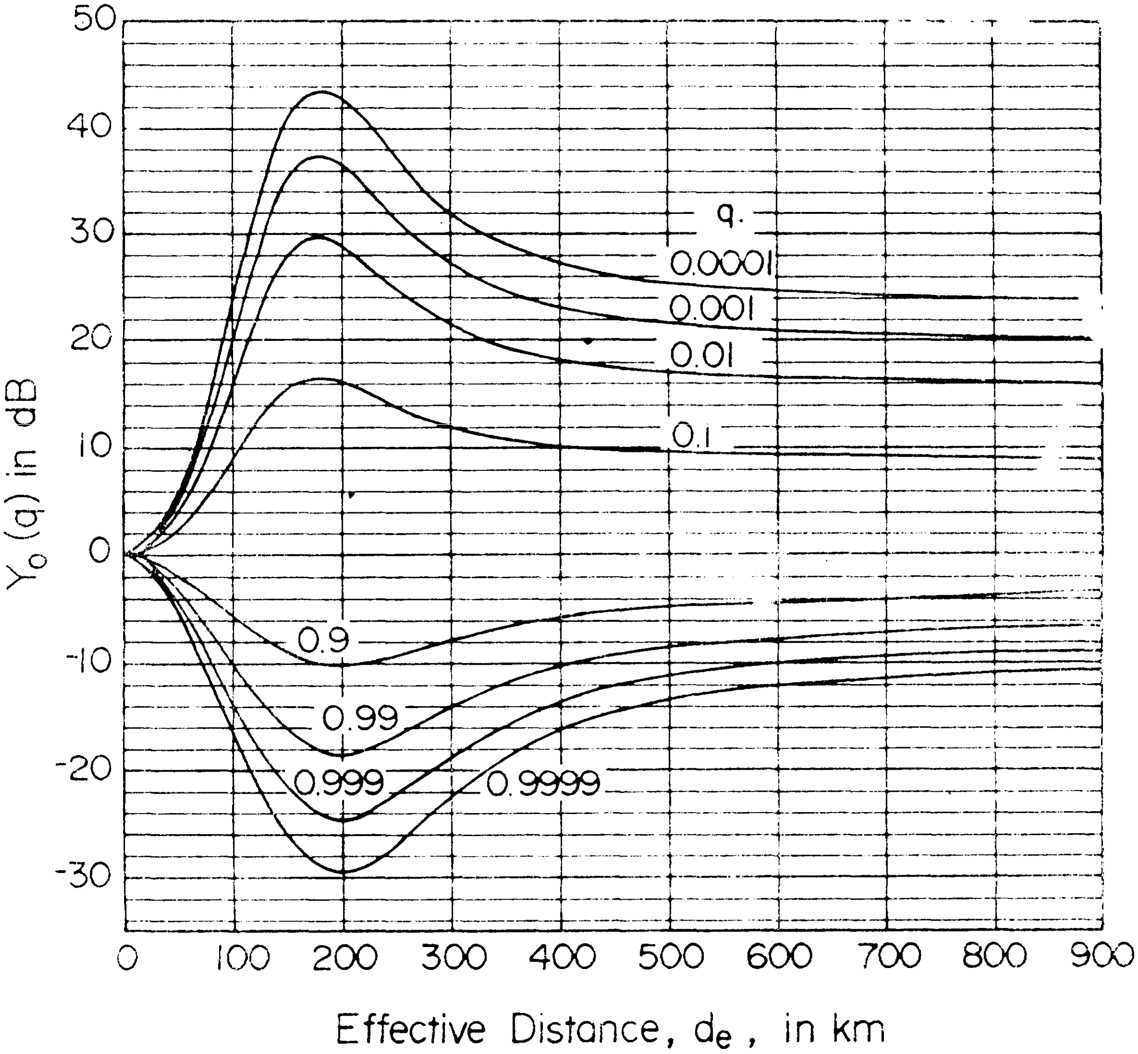

FIGURE 4.4-27 VARIABILITY FUNCTION Yo (q) for Climate 2, Continental Subtropical

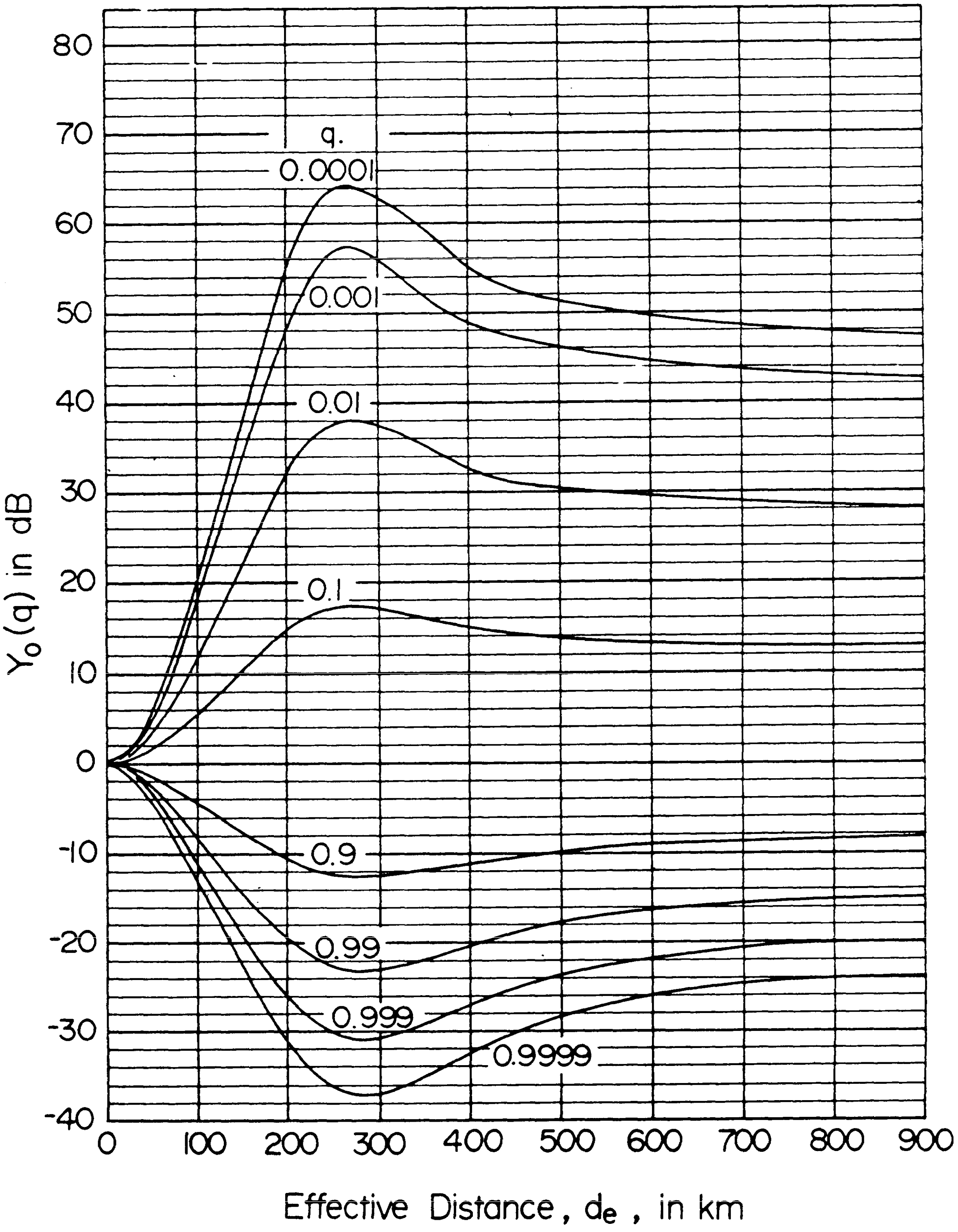

Figure 4.4-28 Variability Function Y_o (q) for Climate 3 Maritime Subtropical

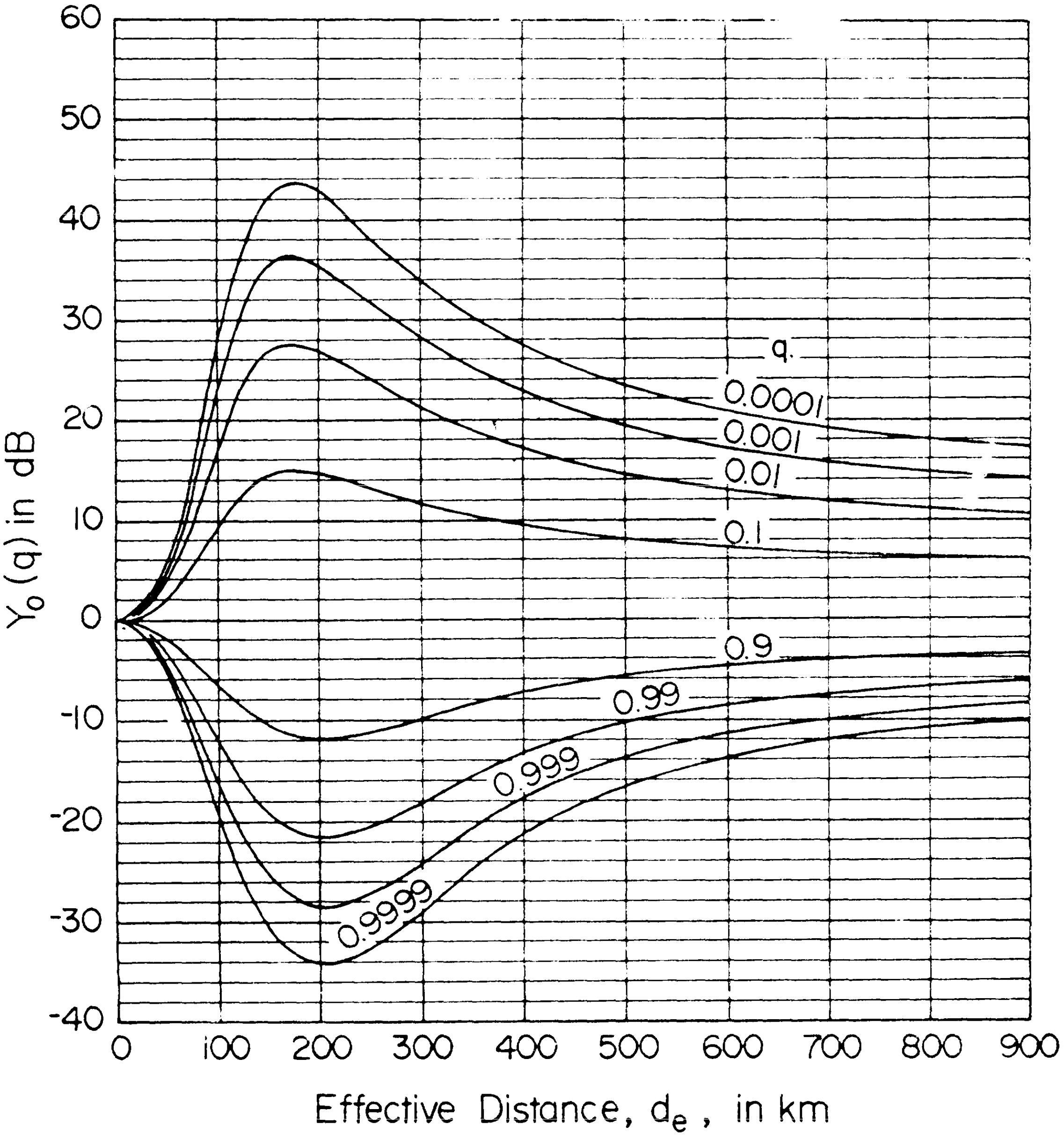

FIGURE 4.4-29 Variability Function $Y_0(q)$ for Climate4 Desert (Sahara)

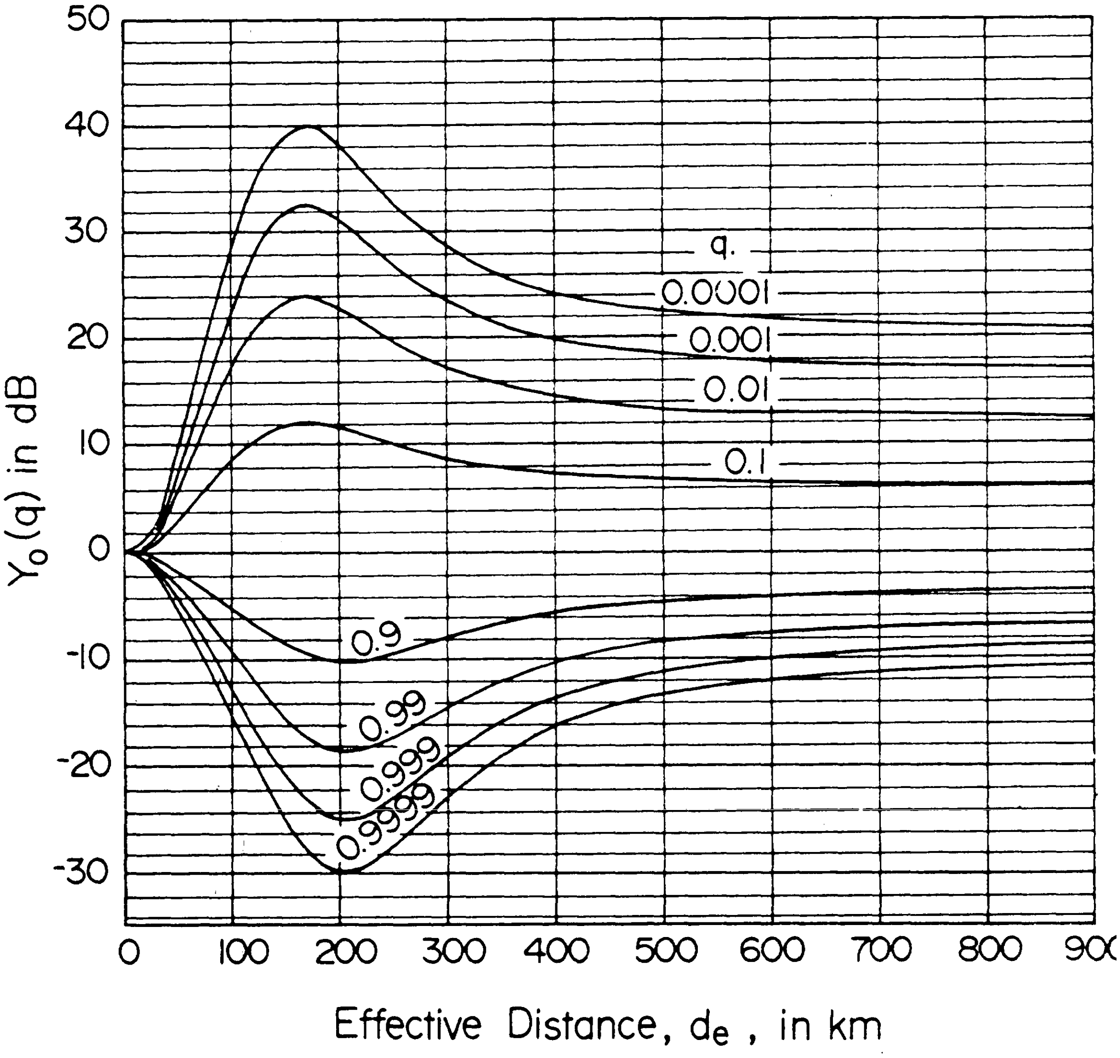

Figure 4.4-30 Variability Function $Y_o(q)$ for Climate 6, Continental Temperate (May also be used to provide estimates for Climate 8, Polar)

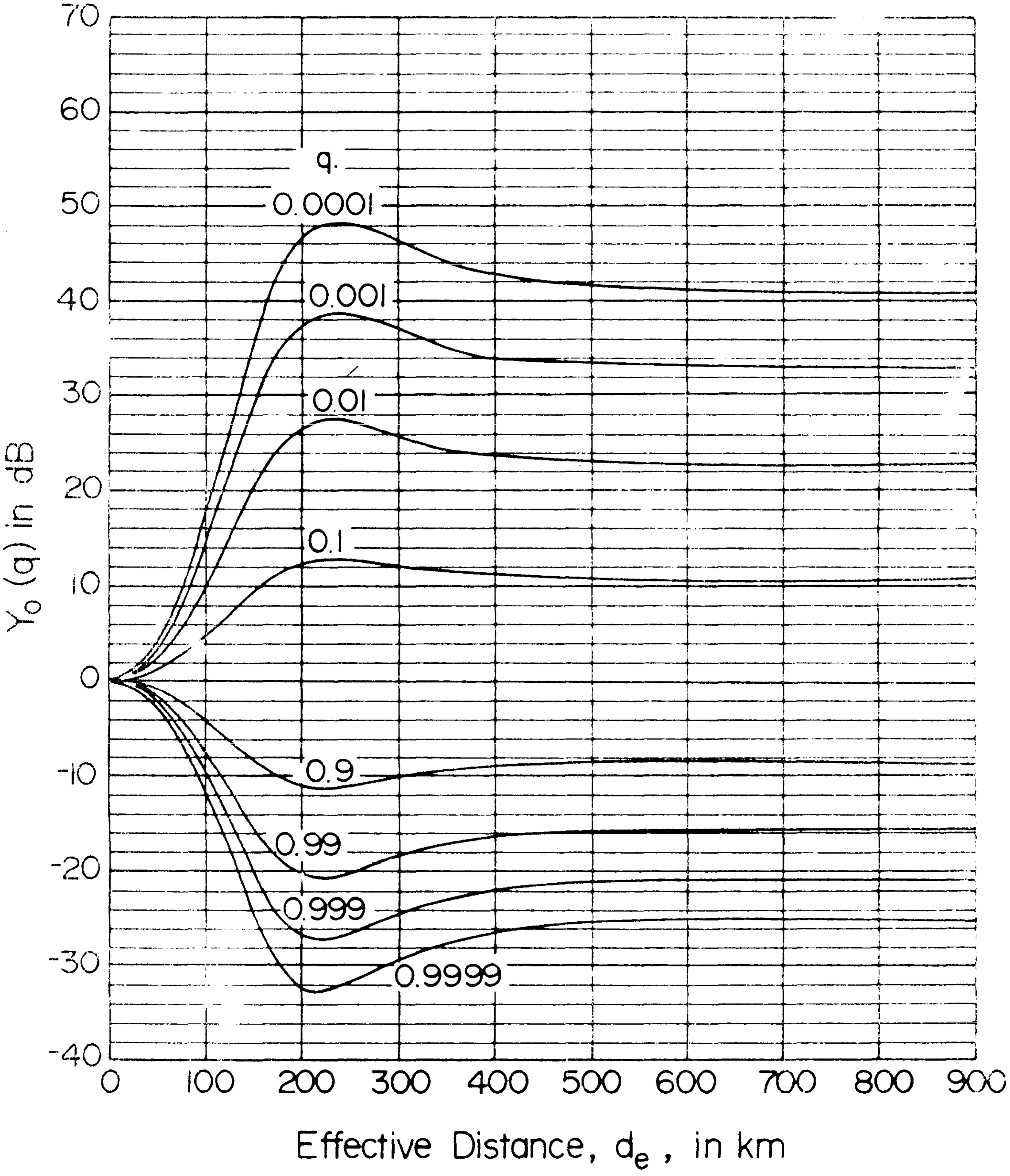

FIGURE 4.4-31 Variability Function $Y_o(q)$ for Climate 7a, Maritime Temperate, Overland

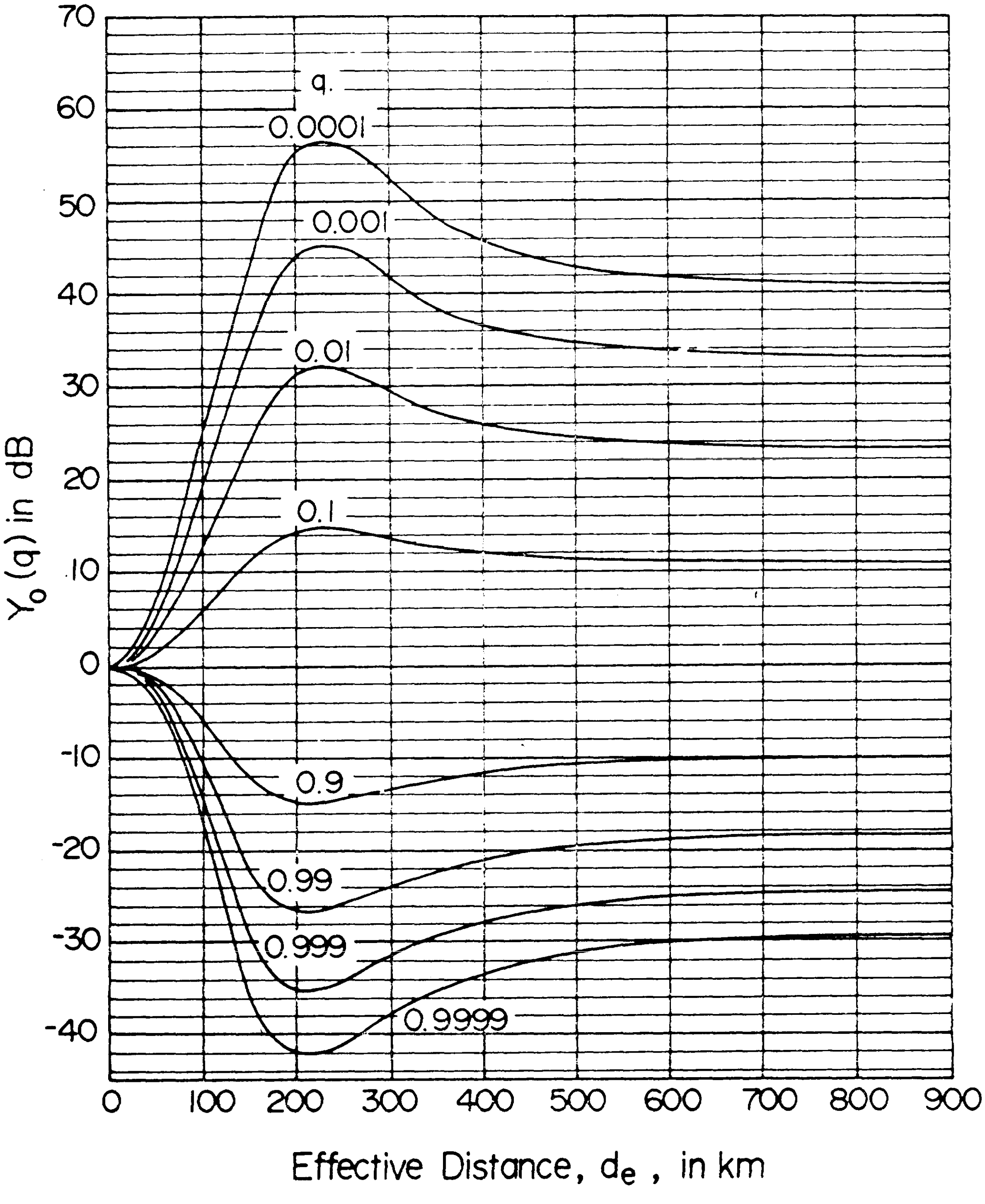

Figure 4.4-32 Variability Function $Y_o(q)$ for Climate 7b, Maritime Temperate, Oversea

TABLE 4.4-2 Climate Types and Characteristics

CCIR Climate	Radio-Climate Designator	Approximate Latitude Range	Seasonal Temperature (°F) Variation	Absolute Humidity (Surface)	Annual Precipitation (Inches)	Seasonal Variation in Precipitation	Wind	Typical Mean Annual N_s Near sea-level (N-units)	Annual Range of Monthly Mean N_s	Remarks
1	Equatorial	10°N - 10°S	Small	High all seasons	60 - 100	Maxima near equinoxes (Mar. 21 - Sept. 23); no completely dry season	Prevailing easterlies; frequent calms	370	0 - 30	Shower type rain predominates, any anomalous propagation occurs in stable periods between showers.
2	Continental sub-tropical	10° - 20°	Moderate	Winter: moderate to high Summer: high	10 - 100	Dry winter, rainy summer	Monsoonal shift in direction	320	60 - 100	Where land is dry, ducts may form at times most of year
3	Maritime sub-tropical	10° - 20°	Moderate	High	10 - 100	Dry winter, rainy summer	Monsoonal shift in direction	370	30 - 60	Usually lowlands near sea
4	Desert	20° - 35°	Very large	Very low	< 10	Dry all seasons, large year to-year variations		280	20 - 80	Scatter propagation poor, especially in summer
5	Mediterranean	30° - 40°	Moderate (mild winters and hot summers	Moderate to high	15 - 25	Very dry summer; most rain in winter	Variable	320	10 - 30	These regions close to the sea; many are subject to elevated ducting in dry season.
6	Continental temperate	30° - 60°	Very large	Varies greatly with air mass changes; highest in summer	15 - 45	Spring and summer thunder-showers, winter snow. Prevailing winds offshore (land to sea), shielded by mountains from on-shore moist winds.	Variable	320	40 - 40	Affected by moving storms, fronts, and pressure systems. Sheltered from sea or large lake influences. N_s in plateau areas may be 250-280.
7a	Maritime Temperate, Overland	30° - 60°	Moderate	Moderate to high (varies with wind direction & air mass charges)	25 - 100	Driest season tends to be spring or summer; high rainfall coastal mountains.	Prevailing winds off sea & unobstructed by mountains; flow off land mass brings lowest humidity. May be significant land-sea breeze effects	320	20 - 30	Typical areas are west coasts of continents or large islands in latitudes of westerlies (United Kingdom, west Europe, west coast N. America) Japan more nearly climate 6.
7b	Maritime Temperate, Oversea	30° - 60°	Moderate	High	25 - 60			320	20 - 30	Applies to coastal & oversea areas where both horizons of path are on sea. Ducts may occur frequently.
8	Polar	60° - 90°	Very large	Low	5 - 15	Winter snow very dry; most precipitation in summer showers.		300	10 - 40	

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between two different climate types, it is recommended that calculations be made for both climates in order to assess possible differences in the resulting variability functions.

4.4.25.9 At the present time, no curves are available for climate types 5 and 8; it is recommended that an average between Type 3 (maritime subtropical) and 7b (maritime temperate, overland) be substituted for Type 5 (Mediterranean). Similarly, Type 6 (continental temperate) should be substituted for Type 8 (polar) unless more definite information is available from other sources.

Table 4. 4-3 Location of Ye(q) Graphs for the Various Climate Types

Climate No.	Designation -	Fig. No.
1	Equatorial	4.4-26
2	Continenal Subtropical	4.4-27
3	Maritime Subtropical	4.4-28
4	Desert (Sahara)	4.4-29
5	Mediterranean	Not available
6	Continental Temperate	4.4-30
7a	Maritime Temperate, overland	4.4-31
7b	Maritime Temperate, oversea	4.4-32
8	Polar (use continental temperate)	4.4-30

4.4.25.10 Since the fraction q is based on the total of 8760 hours within one year, the graphs in figures 4.4-25 to 4.4-32 are for all hours of the year, and are not representative of specific seasons or time blocks. Except for Climates 2, 4, and 6, the curves should be used directly for all frequencies; i. e. $Y_o(q)$ as read from the appropriate graphs equals Y(q) l For climates 2, 4, and 6, sufficient information is available to define frequency correction factors g(q,f) and on which have been identified in conjunction with the computers program described earlier They are shown in figures 4.4-33 and 4.4-34. The factor g(q, f) is a function of frequency and appies only to the time fractions q = 0.l (for climates 2, 4, and 6) and q = 0.9 (for climate 6 only) . The c-factor in. figure 4.4-34 is then used to arrive at other values of the time availability, q. Thus, for climates 2, 4, and 6:

$$Y(0.1) = Y_0(0.1)\ g(o.i,f), \qquad (4.4\text{-}71a)$$

for climate 6 only, $Y(0.9)= Y_0(0.9)\ g(0.9, f),$ (4.4-71b)

and for all climates, $Y(q) = cY(0.1)$ for $q<0.5$ (4.4-71C)

$Y(q) = cY(0.9)$ for $q >0.5$ (4.4-71d)

4.4.25.11 The factor c is plotted in figure 4.4-34 as a function of the time fraction q for all climates and can therefore also be used to interpolate between the curves for fixed values of q (figures 4.4-26 through 4.4-32). For values of q beyond the range of figure 4.4-34 ($q >0.9$) which are frequently of interest, the values for c in table 4.4-4 may 'be used since within this range the long-term variability follows a log-normal distribution.

Table 4.4-4 The Factor c for q >0.9 to be used in (4.4 -71d)

q	C
0.95	1.28
0.99	1.82
0.995	2.01
0.999	2.41
0.9995	2.57
0.9999	2.90

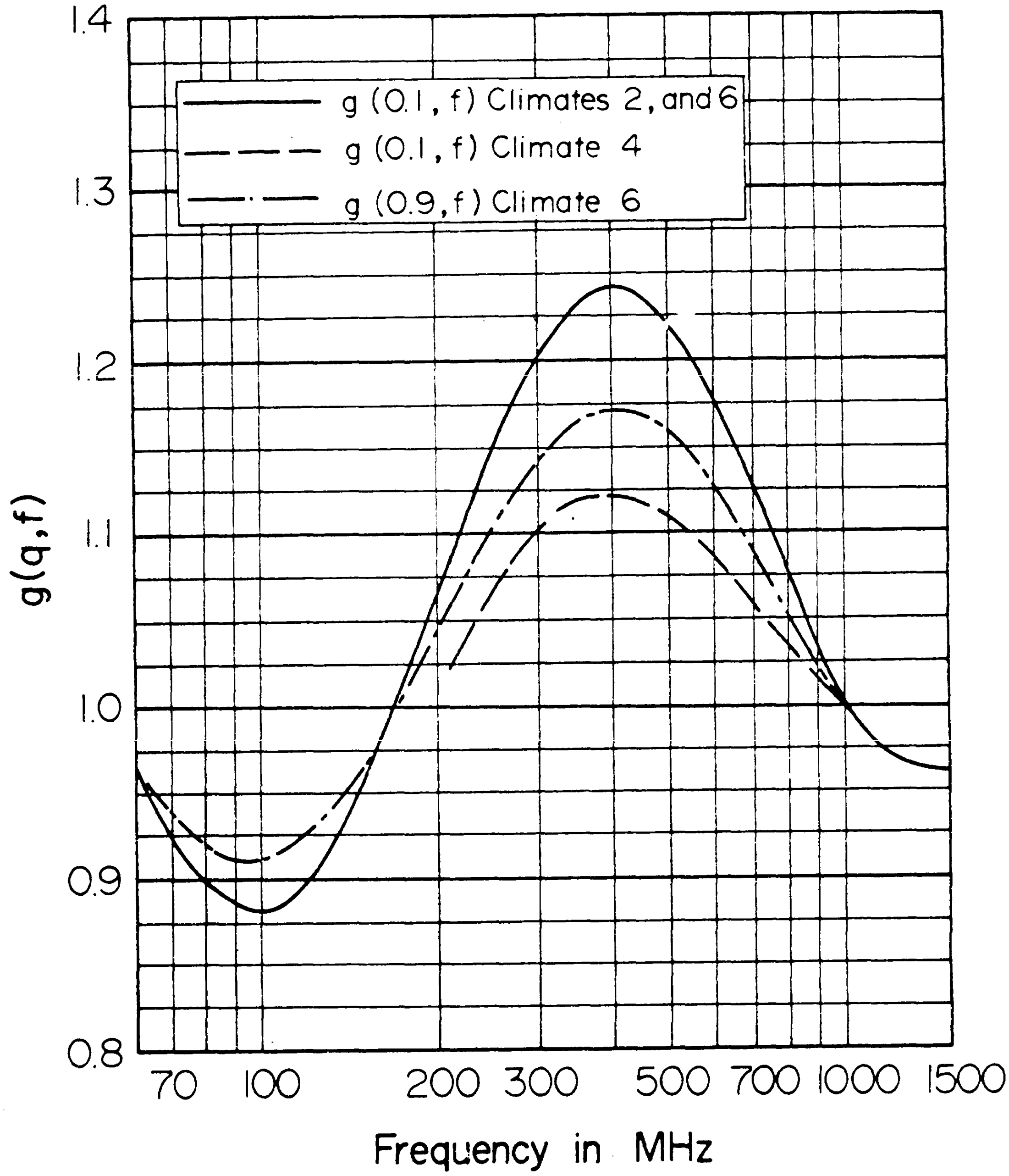

Figure 4.4-33 The Frequency Frequency Fractor g(q,f)

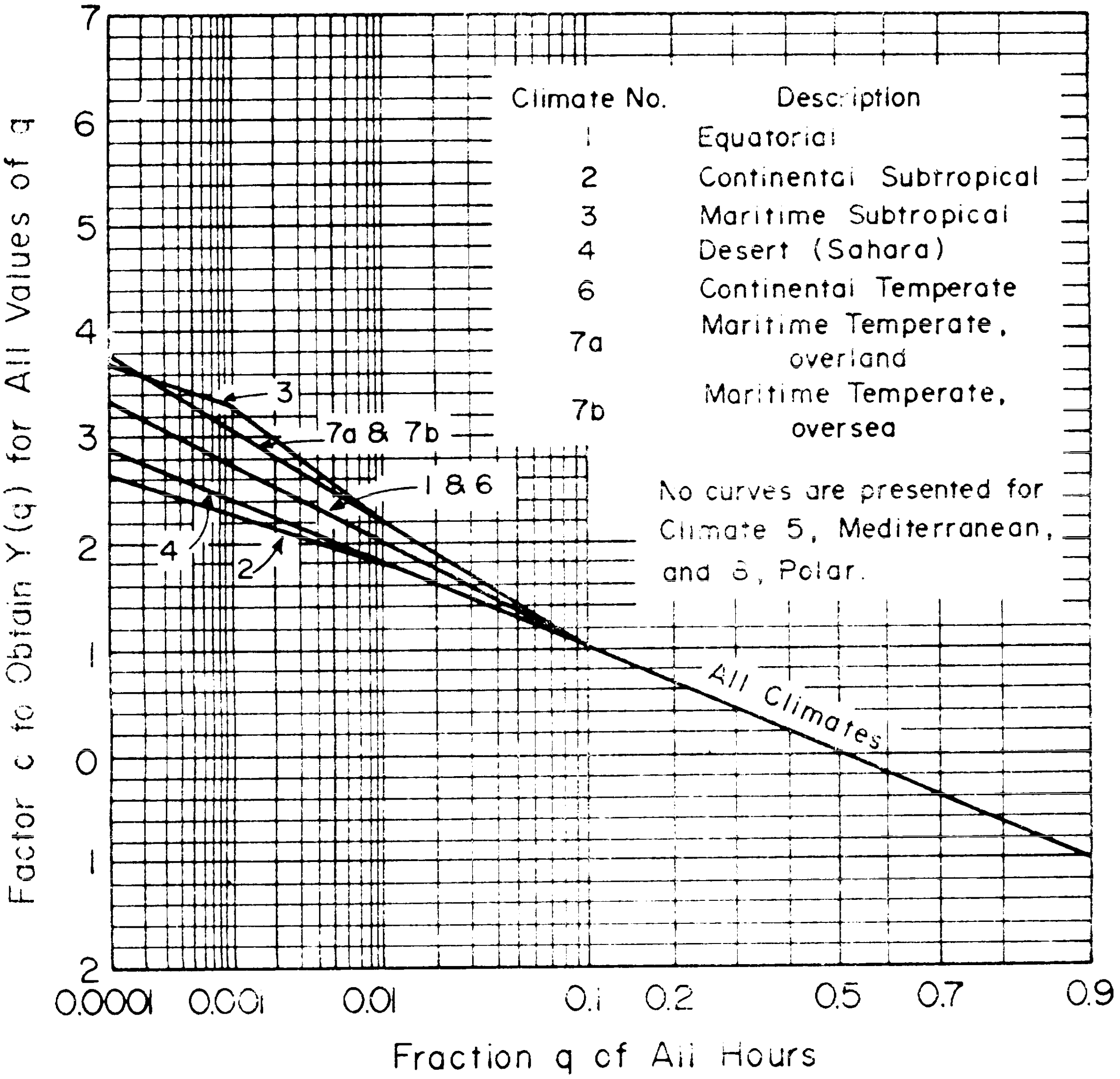

Figure 4.4-34 the Factor c as a Function of the Fraction q

4.4.25.12 As an example, consider a path in Climate 6 with an effective distance d_e = 300 km, and at a frequency f = 500 MHz. From figure 4.4-30 Y_o(O. 1) is read as 8.6 dB as a function Of d_e and q. For climate 6, g(o. 1, f) = 1.22 (from figure 4.4-33). Using (4.4 -71a) we obtain therefore Y(O. 1) = 10.5 db. If we now desire values of Y corresponding to the fractions 0.005 or 0.001 of all hours figure 4.4-34 gives for climate 6 the values of c = 2.2 for q = 0.005 and 2.7 for q = 0.001. Substituting now into (4.4-71a), the results are Y(0.005) = 23.1 dB and Y(0.001) = 28.4 dB.

4.4.25.13 It will usually be sufficient to read or calculate the values of Y only to the nearest one-half decibel since they are in most cases relatively crude estimates.

4.4.25.14 At frequencies above 1500 MHz the limiting value for the g(o. 1 f) and g(O. 9, f) functions in figure 4.4-33 is approximately O. 97. The factor g represents the effects of several parameters which are at least partially related to frequency, but cannot be defined more precisely at the present time.

4.4.25.15 It should be noted again that the g- and c-factors are only required when the g-factor is assumed to be different from 1 (climates 2, 4, and 6), or where interpolation between the curves on figures 4.4-26 to 4.4-32 is necessary. Otherwise, the curves in these figures can be used directly to obtain the required distributions of Y(q), V(q), or Lb(q) since in these cases Y(q) = Y_o(q).

4.4.25.16 Additionally, the following rules should be observed:

a) For transhorizon links the received power levels are rarely greater than those corresponding to free-space propagation; therefore, assume that a minimum value for Lb(q) calculated from (4.4-65) or (4.4-66) is the free-space level, L_{bf}.

b) For single-horizon diffraction- links the procedure given above may overestimate the long-term variability but provide a reasonable upper bound. Rice, et al. [16, sec. 10.8) have suggested a method fcr obtaining the cumulative transmission loss distribution for such a link as the convolution of the transmission loss distributions for its two sections. However, this method cumbersome, and requires the use of a computer. Recent comparisons of available data with prediction methods suggest that the use of such a complex method is not really justified for the purpose of this handbook.

c) Although this handbook is not intended to be used for line-of-sight microwave link design, utilization of passive repeaters (see section 4.4.56) may require estimates of time variability for the individual line -of- sight hops that make up a passive repeater system, and for the total links over which passive repeaters are used. Long-term variability for line-of-sight links can be estimated in the same manner as for transhorizon links, although for conventional microwave links at frequencies above above 6 GHz and up to 50 km long other fading mechanisms such as short-term phase interfereace are of greater importance. Comparisons of predicted and measured long-term variability for several line-of-sight links are included in a a report by Longley, et al., [76]

d) For passive repeater systems, one may estimate long-term variability by considering each system as a single path similar to the considerations applicable to knife-edge diffraction links (see b above) .

4.4.25.17 In summary, long-term variability for transhorizon links is expressed by determiniing the cumulative distribution curve of basic transmission loss S using the variability functions V(0.5) and Y(q). k most cases, values for these functions can be read directly from figures 4. 4-25 to 4.4-32, as a function of the effective distance, de, and of the climate type. Cases where modifications of these procedures are required have also been discussed in this section.

4.26 System Parameters, Confidence Limits, and Service Probability

4.4.27 Prediction Uncertainty Concepts

4.4.27.1 In the previous sections of this chapter, methods were provided to calculate basic transmission loss and its time variability as a function of terrain and atmospheric parameters using several different models in accordance with the assumed or expected propagation mechanism over a specific link. It has been repeatedly pointed out during these discussions that most models and methods are based at least in part on empirical data; i. e., some of the mathematical parameters in the models are derived from the analysis of applicable measurement results. Since most measurement data are limited in scope, time of record, and accuracy, their use implies a certain degree of uncertainty. ALso such data may sometimes be applied to paths with different terrain or atmospheric characteristics than represented by the conditions under which they were obtained. The processes in tropospheric transhorizon propagation are extremely complex, and it is neither possible nor practical to provide numerical values of all possible parameters and their effects on the time distribution of transmission loss. Consequently, the specific values calculated in accordance with the material in the previous sections must be considered as mean values resulting from an ensemble of propagation paths for which the parameters used in the transmission loss calculations are exactly identical, but which differ from each other in additional respects which cannot be included in the formulation of the models and methods used. It is reasonable to assume that long-term measurements over such an ensemble of paths or links would produce a random (or Gaussian) distribution of transmission loss values for each percentile of time with the mean of such a distribution identical to the calculated value. The standard deviation of this distribution would then characterize the uncertainty inherent in the prediction or modeling process.

4.4.27.2 Subsequent subsections will provide methods for estimating prediction uncertainty and establishing confidence limits about calculated system performance parameters. It will be useful, however, to relate basic transmission loss values first to several other parameters of the system by which its performance can be evaluated.

4.4.28 The System Equation

4.4.28.1 The separation of time varations into short term and long-term together with the available data on long-term variability suggest the definition of a convenient parameter whicn can be easily related to propagation and overall system parameters on one hand and to equipment performance specifications and the required grade of service on the other hand. Such a parameter is the hourly median pre-detection signal-to-noise ratio (identified by R in decibels). For FDM-FM systems, R is simply the hourly median carrier-to-noise ratio. It can be easily related to the desired grade of service in terms of bit- or character-error rate or voice channel noise as a function of the equipment parameters including diversity configuration. This will be shown in section 4.5.20. The parameter R is utilized in the system equation as will be shown later.

4.4.28.2 The relation between the radio frequency power available from a transmitter at one terminal and that reaching the receiver input at the other terminal of a link may be simply expressed in decibels as the algebraic summation (addition and subtraction) of power levels. Power is gained because it is concentrated into relatively narrow beams by the transmitting and receiving anternnas. Power is lost primarily through the transmission medium, but also in the transmission lines or waveguides which connect the antennas to the trarsmitter and receiver terminal, respectively. The power flow in such a system can be expressed in the followlling manner:

$$P_r = P_t + G_p - L_b - l -_{l} \text{ d BW.} \qquad (4.4\text{-}72)$$

Here, P_r is the power available at the receiver input in dbw, P_t is the transmitter power, also in dBW, G_p is the effective antenna gain for the system in dB (see section 4.4.29), L_b is the basic transmission loss over the link in dB, and L_{fl} is the sum of the losses in the transmission lines or waveguides, the duplexers, and other circuit elements in the system, and is also in dB. P_t and P_r must be in the same units relative to a reference power level (usually decibels relative to 1 watt), whereas the other quantities represent ratios and are therefore simply expressed in decibels.

4.4.28.3 In (4.4-72) it is assumed that all impedances are matched so that no additional power loss occurs through reflections or other phenomena. This is a reasonable assumption for systems in the frequency range above about 200 MHz, and for the type of antennas used in such applications.

4.4.28.4 The received power level may also be related to the receiver noise figure, the receiver noise bandwidth, the carrier- (or predetection signal) -to-noise ratio, and the absolute noise threshold:

$$P_r = -204 + B + F + R \text{ dBW}. \qquad (4.4\text{-}73)$$

Here, the constant -204 is the Johnson noise power per hertz of radio frequency bandwidth in decibels relative to 1 watt of power. The value of this constant is determined by the expression (-10 log kT) where k is Boltzman's constant and T is the reference temperature usually taken as 288.5 degrees Kelvin corresponding to ambient conditions [33]. The other terms in (4.4-73) are as follows:

B = the pre-detection noise bandwidth b in hertz, but expressed in decibels (B = 10 log b). In many cases B may be assumed equal to the intermediate frequency bandwidth. Skolnik [73] provides ratios of the effective noise bandwidth to the 3-dB bandwidth for several types of receiver circuits, and his data may be used for more accurate determination of noise bandwidth as required.

F = the receiver noise figure in decibels. Antenna circuit losses and external noise effects can usually be neglected for tropospheric transhorizon systems so that the receiver noise figure can replace a more complex system noise factor (see sec. 4.4.41 for additional discussion).

R = is the hourly median single-receiver carrier-to-thermal noise ratio discussed earlier, which is a measure of the desired grade of service.

4.4.28.5 Combining (4.4-72) and (4.4-73), and solving for P_t, the system equation defined by Norton [3] is obtained:

$$P_t = L_b - G_p + F + L_l + R + B - 204 \text{ dBW}. \qquad (4.4\text{-}74)$$

In this form it specifies the transmitter power P_t required to provide, for instance, the specified grade of service, R, with all the other parameters fixed. It may also be solved for any of the other terms, and applies to any time availability, q. For application to fixed transhorizon systems the time dependence may conveniently be included in the basic transmission loss terms. All other terms may thus be considered constants, and the required transmitter power, for this form of (4.4-74), varies in time as the basic transmission loss term, L_b. Similarly, a simple transposition of the terms in (4.4-74) results in an expression for R, as an example, which then again varies as L_b with the transmitter power P_t and all other terms considered constant.

4.4.28.6 Note that (4. 4-73) does not involve propagation parameters. The power level P_r may be interpreted as the required receiver input level in dBW as a function of bandwidth, noise figure, and the desired carrier-to-noise ratio.

4.4.29 The Effective Path Antenna Gain, C_p

4.4.29.1 In tropospheric transhorizon propagation, the antenna gains G are usually expressed in decibels relative to an ideal isotropic antenna. Cross polarization effects need not be considered in transhorizon link design; i. e.) one considers only transmission between antennas having the same polarization - either horizontal or vertical. At frequencies above about 400 MHz parabolic reflectors fed by dipoles or horns located at or near the focus of the parabola are almost universally employed. The gain of such an antenna is a function of the relation between antenna diameter and wavelength, and of the efficiency of the aperture [34] . For the commonly used aperture efficiency Of 56%, the gain G in free space relative to an isotropic radiator is given by:

$$G = 20\log D + 20\log f - 42.1 \text{ dB} \qquad (4.4\text{-}75a)$$

where the diameter D is in meters and the frequency f is in megahertz. If the diameter is expressed in feet, the equation becomes:

$$G = 20\log D + 20\log f - 52.4 \text{ dB (for D in } \underline{\text{feet}}\text{).} \qquad (4.4\text{-}75b)$$

4.4.29.2 As already noted in section 4.2.119 the effective Path antenna gain in (4.4-72), G_P , can be expressed by the sum of the free-space antenna gains G_1 and G_2 of the terminal antennas less a multipath coupling loss L_{gP} which is caused by the incoherency of the wave front arriving at the antenna due *to* the scatter mechanism and other atmospheric effects. L_{gP} may be neglected for knife-edge or smooth-earth diffraction, since the wave-front in these cases may be assumed to be uniform over the receiving antenna aperture. Thus the effective path antenna gain, G_P, is expressed by:

$$G_P = G_1 + G_2 - L_{gP} \text{ dB} \qquad (4.4\text{-}76)$$

where L_{gp} is negligible for knife-edge or smooth-earth diffraction paths.

4.4.29.3 Formulas to determine G_P for transhorizon links given by the CCIR [1, p. 90] as a function of the free-space antenna gains G_1 and G_2 tend to overestimate L_{gP} for large antennas. A recent analysis of available and applicable data*suggests the following approximate expressions for L_{gP}:

$$L_{gp} \cong \left\{ \begin{array}{ll} 0, \text{ if } G_1 + G_2 \leq 40 \text{ dB}, & \text{or path is knife-edge or smooth earth diffraction;} \\ 5.8 - 0.29\,(G_1 + G_2) + 0.0036\,(G_1 + G_2)^2, & \text{otherwise} \end{array} \right\}. \quad (4.4\text{-}77)$$

A graph of L_{gP} versus $G + G_2$ was shown in figure 4.2-3. The sum of $G_1 + G_2$ will seldom exceed 100 db in practice, since large antennas with corresponding small beamwidth may be subject to excessive fading problems because of changes in the angle of arrival of the incoming energy, and should be avoided.

4.4.29.4 The estimates of G_p and L_{gp} obtained in the manner must be considered to be long-term average or median values;time variations in these quantities are absorbed in the time variability of transmission loss and the related prediction uncertainties.

4.4.29.5 In case of two-horizin diffraction over irregular terrain,. or where the resulting reference value orf value of basic transmission loss is Obtained by combining diffraction and scatter losses (see sec. 4.4.24). L_{gP} should not be neglected, But calculated in accordance with (4.4-77

4.4.30 Time Availability and System Parameters

4.4.30.1 The system equations (4.4-72) and (4.4-74) and (4.4-74) are applicable to any instant in time; consequently they modified to include the concept of long-term variabilty as discused in section 4.4.25. Recall that the expected variability of the median transmission loss values is expressed by empirical functions V(q) . These are

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* Informal communication from. Mrs. A . G .Longley of OT/ITS. of OT/ITS.

combined with the reference value. L_{bcr}, in order to provide the value of basic transmission loss. Lb(q) not exceeded* during a fraction, q, of all hours within the time period considered, for the paths characterized by distance and other parameters [16]. The fraction of hours, q, is the time availability, and may also be expressed in percent. Equation (4.4-65a) from section 4.4.25 is repeated here for convenience:

$$L_b(q) = L_{bcr} - V(q) \quad B. \qquad (4.4\text{-}65a)$$

All quantities are expressed in decibels, and the reference transmission loss values, $L_b(q)=L_{bcr}-B$" are calculated in accordance with the material presented in the previous sections. Usually, values of Lb(q) are calculated for q = 0.01, 0.1, 0.5, 0.9, 0.99, 0.999, and 0.9999, and the completed distribution of $L_b(q)$ is obtained by drawing a smooth curve through the calculated points, using normal probability graph paper.

4.4.30.2 Calculation of the path antenna gain G_p has been discussed in the preceding sub-section. In most point-to-point applications, it is convenient to establish a relationship between reference values using (4.4-7.4), by replacing L_b with L_{bcr}, P_t with P_{tcr}, R with R_r, and collecting all terms except P_{tcr} and R_r into an auxiliary constant, M_0, where

$$P_{tcr} = M_o + R_r \ \text{dBW} \qquad (4.4\text{-}78)$$

$$M_o = L_{bcr} - G_p - 204 + F + B + L_l \, \text{dB}. \qquad (4.4.79)$$

Here, R_r is defined as a specified hourly median predetection RMS carrier-to-RMS thermal in-band noise ratio chosen by the designer on the basis of the required grade of service. Equation (4.4-78) establishes a generally applicable relation for the fixed system constants contained

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*This terminology is used because a value of transmission loss not exceeded during a time fractions q, is equivalent to a field strength or received power level value exceeded during the same time fraction q.

in M_0, the reference transmitter power, P_{tcr} ard R_r without any consideration of time variability. However, a number of terms in M_0 are frequency dependent; thus, (4.4-79) and (4.4-78) are useful to estimate the optimum frequency range (i. e. , that for which the required transmitter power is a minimum) for various systems as a function of antenna size, noise figure, line losses etc. , ard can save as a basis to obtain suitable frequency assignments. This will be demonstrated by an example in section 4.4.32.

4.4.30.3 Time availability is included by establishing a relation between the reference transmitter power value, P_{tcr} and t he transmitter power, $P_t(q)$, required to provide the desired grade of service, R_r, during at least a fraction q of all hours. This is analogous to the corresponding transmission loss relation in (4 4.-. 55a), and may be obtained by direct substitution:

$$P_t(q) = P_{tcr} - V(q) \text{ dBW}. \qquad (4.4\text{-}80)$$

4.4.30.4 Equations (4. 4-78) and (4.4-80) can be combined to obtain the required transmitter power to provide the desired service during the time fraction, q, as a function of system constant including a fixed, specified value R_r identifying the grade of service:

$$P_t(q) = M_0 + R_r V(q) \text{ dBW}. \qquad (4.4\text{-}81a)$$

Similarly, the transmitter power can be fixcd at a constant value P_{to}, and the system equation solved for the pre-detection hourly median RMS signal-to-R.MS thermal in-band noise ratio R(q) exceeded during a fraction q of all hours R(q):

$$R(q) = P_{to} - M_o + V(q) \text{ dB}. \qquad (4.4\text{-}81b)$$

4.4.30.5 In most practical applications, a compromise has to be found between the optimum frequency range deter-mined from (4. 4-78) and (4.4-79), and available frequency allocations and equipment.

Once a frequency has been selected, the system constant M_o can be determined for the other applicable equipment parameters such as antenna size, order of diversity, number of communication channels, and modulation requirements. From (4.4-81a) the transmitter power, $P_t(q)$, can be determined which would provide for the system the grade of service specified by R_r, or better during a fraction, q, of all hours. The form (4.4-81b) is based on a fixed value of transmitter power, P_{to}, and its use results in the hourly median predetection RMS carrier-to-RMS thermal in-band noise ratio, now designated R(q), which would be exceeded during a fraction, q, of all hours. In some cases it may be desirable to exclude the bandwidth term, B, from the system constant M. and combine it with R_r. The resulting new parameter is directly proportional to the required carrier power. This can be shown by expressing the system equation (4.4-74) in units of power rather than in decibels.

4.4.31 Service Probability

4.4.31.1 The procedures used in the preceding subsections would provide the complete solution to the design problem if the prediction formula were comprehensive enough to give exact answers. This is related to the prediction uncertainty concept already discussed in section 4.4.27: any formula or method used for predicting conditions in the “real world” (as opposed to idealized models) has some probability of prediction error associated with it. In the case of calculation methods for transmission loss and its variability, it is impractical to allow in more detail for all the characteristics of the terrain and the atmosphere even if known. Furthermore, there is some uncertainty in the estimate of equipment performance parameters such as the relation of the predetection carrier-to-noise ratio to the grade of service and other terms in the system equation. All these considerations are somtimes taken into account by arbitrarily specifing and equipment margin" or a "design margin" in system calculation i. e., a safety factor which may amount to as much as a additional 10 dB in transmitter power above the calculated values

4.4.31.2 The service probability concept used here is a more fundamental method of taking design and equipment uncertainies into account than arbitrary specification of a "design margin". It should be noted, however, that its use can result in "over- engineering" a path or a system, or in excessive spectrum requirements . Consider a number of tropospheric propagation paths which have ideritical geometrical and meteorological parameters entering the prediction formula as well as identical equipment specifications. The predicted cumulative distributtion of basic transmission loss, $L_b(q)$ from (4.4-65a), and of other derived parameters in dB, as a function of the fraction of all hours, as an example, would then be a single curve applicable to all such paths or systems. If, however, it were possible to perform measurerments of such parameters over all of these paths over a long period of time, the result would be a great number of distribution curves, living different medians and different ranges. This is due to parameter -which may differ randomly from path to path, but are not taken into account in the prediction method. Figure 4.4-35 demonstrates the concept of the resulting family of distribution curves. In the limit (representing a very large number of paths, each measured over a very long time period) any abscissa or ordinate value can be characterized by a normal distribution of measured values with the calculated value taken as its mean. Thus, any calculated value, or the calculated distribution as shown in figure 4.4-35 by the broken line, is taken as a statistically expected* result. Since all paths with identical prediction parameters

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*The reader is cautioned to note that the term "statistically expected" should not be confused with the everday use of the word "expected".

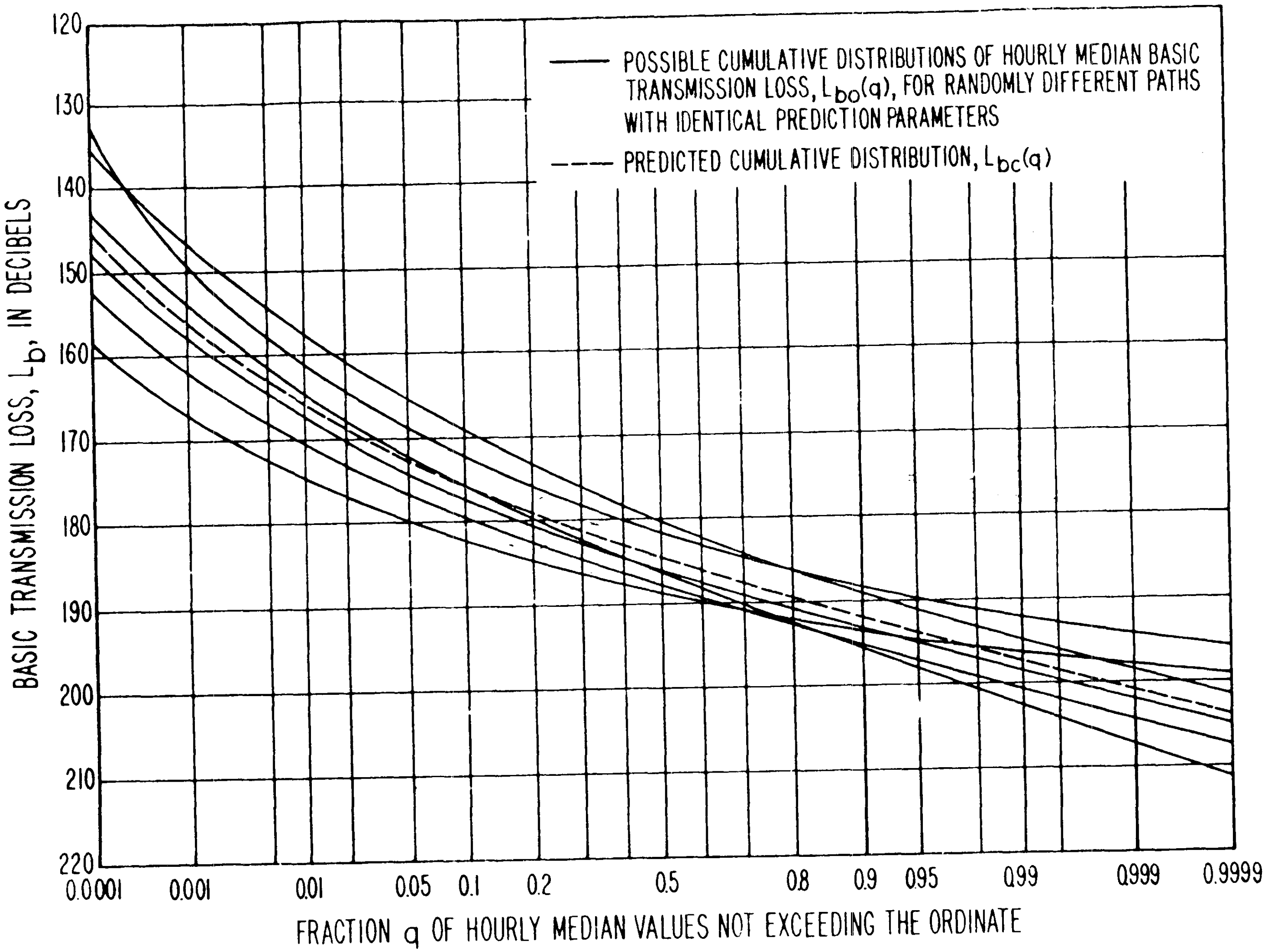

Figure 4.4-35 Illustrative path-to-path Variation of Long-duration Distributions for Randomly Different Paths with Identical Prediction Parameters

are observed not to perform identically, we introduced the concept of "prediction uncertainty" to estimate the probable deviation on of individual path performance from the " statistically expected" distribution. Service probability may then be defined as the probability of obtaining a specified guide of service, R_r, or better, during a given fraction of the hours, q.

4.4.31.3 Numerical estimates of the prediction uncertainty are based on comparison of calculated and measured transmission loss data obtained from long-term measurements over many propagation paths [17]. The uncertainty in a calculated hourly median transmission loss value $L_b(q)$ (or corresponding values of $P_r(q)$ or R(q)) is proportional to the departure Of its value from the long-term median Lb (O. 5) Of all I b(q)'s. Thus the prediction uncertainty associated with a value Lb(q) exceeded during a fraction (l-q) of all hours is measured by a standard deviation $o_c(q)$ expressed by:

$$\sigma_c^2(q) = \sigma_c^2(0.5) + r^2 Y^2(q) \qquad dB^2 \qquad (4.4\text{-}82)$$

where the function has been defined in (4.4-66) and (4.4-67) in conjunction with the time availability function V(q), and r is a constant related to climate-. Best generally applicable estimates at this time are $\sigma_c^2(0.5) = 25$ dB,^{2} and $r^2 = 0.12$[16]. These numbers may be revised as more data from various climatic areas become available and can be evaluated. For climate 6 (continental temperate) in the U. S. , where more data are available and have been analyzed, $\sigma_c^2(0.5)$ = 12.7dB2 can be used; for this case, r^2 is also 0.12[16].

4.4.31.4 The standard deviation at(q) thus defined applies only to the uncertainty in determining basic transmission loss and related quantities such as median path antenna gain. The uncertainty in estimating equipment parameters (pre-detection signal-to-noise ratio, circulator losses, noise figures, etc.) can be represented by a constant standard deviation, σ_r, usually estimated to be 2 dB in the absence of sufficient test data.* Both standard deviations can be combined as shown:

$$\sigma_{rc}^2(q) = \sigma_c^2(q) + \sigma_r^2 \ dB^2. \qquad (4.4\text{-}83)$$

This is simply the addition of variances (squared standard deviations) under the reasonable assumption that the prediction uncertainty values represented by at(q) due to propagation and by σ_r due to equipment are uncorrelated. The resulting function $\sigma_{rc}(q)$ denotes the standard deviation $\sigma_{rc}(q)$ as a function of time availability.

4.4.31.5 Service probability Q(z) can be defined in the following manner: The calculated (or statistically expected) value of a system parameter, for instance, the hourly median predetection RMS signal-to-RMS noise ratio, is designated R(q, 0. 5) as a function of the time availability q, and other system parameters. The 0. 5 in the parenthesis indicates that it is a statistically expected value (as explained above) with the service probability Q = 0.5 assigned to Then the value of R which would be exceeded with a probability given by Q(z) during the fraction of hours, q, is obtained by subtracting from R(q, 0. 5) the product $zo_{rc}(q)$; where z is the standard normal deviate used to relate the standard deviation (for which z = 1) to other probability values:

$$R[q, Q(z)] = R(q, 0.5) - za_{rc}(q) \ dB. \qquad (4.4\text{-}84)$$

The standard deviation of prediction uncertainty in (4. 4-84) has been defined by (4.4-82) and (4.4-83). The relation between the standard normal deviates z and the service probability, Q(z) is given by the normal probability integral:

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} \exp(-x^2/2) \ dx. \qquad (4.4\text{-}85)$$

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*No distinction can be made at this time between characteristics of new and old equipment.

The variable x under the integral is the dummy variable of integration and has no further significance. Probability tables in most statistical text books list values of the service probability, Q(z), versus the standard normal deviate, z; see, for instance, [35, pp. 689 -693], where s service probability corresponds to the tabulated values of F(t), and the standard normal deviate is designated by t. A simple graph of Q(z) versus z is shown in figure 4.4-36.

4.4.31.6 For service probability values less than 0. 5, values of z are negative, and

$$Q(-z) = i - Q(z). \qquad (4.4\text{-}86)$$

For a service probability value Q = 0.5, which is the statistically expected value, the standard normal deviate z is zero, the second term in (4.4-84) drops out, and the equation is reduced to an identity.

4.4.31.7 Equations (4.4-81a) and (4.4 -81bj can now be modified by inclusion of the service probability term $z\sigma_{rc}(q)$:

$$P_t[q, Q(z)] = M_o + R_r - V(q) + z\sigma_{rc}(q) \quad \text{dBW} \qquad (4.4\text{-}87a)$$

and

$$R[q, Q(z)] = P_{to} - M_o + V(q) - z\sigma_{rc}(q) \quad \text{dB}. \qquad (4.4\text{-}87b)$$

These are now the complete expressions for either the transmitter power $P_t[q, Q(z)]$ which would provide a given pre-detection signal-to-noise ratio R_V or better during a fraction q of all hours with the probability Q(z), or the pre-detection signal-to-noise ratio R[q, Q(z)~ resulting during areas east a fraction q of all hours with a service probability value Q(z), when a fixed value P_{to} of transmitter power is used. Since transmitter power is usually limited by practical considerations, (4.4-87b) may be a more useful form.

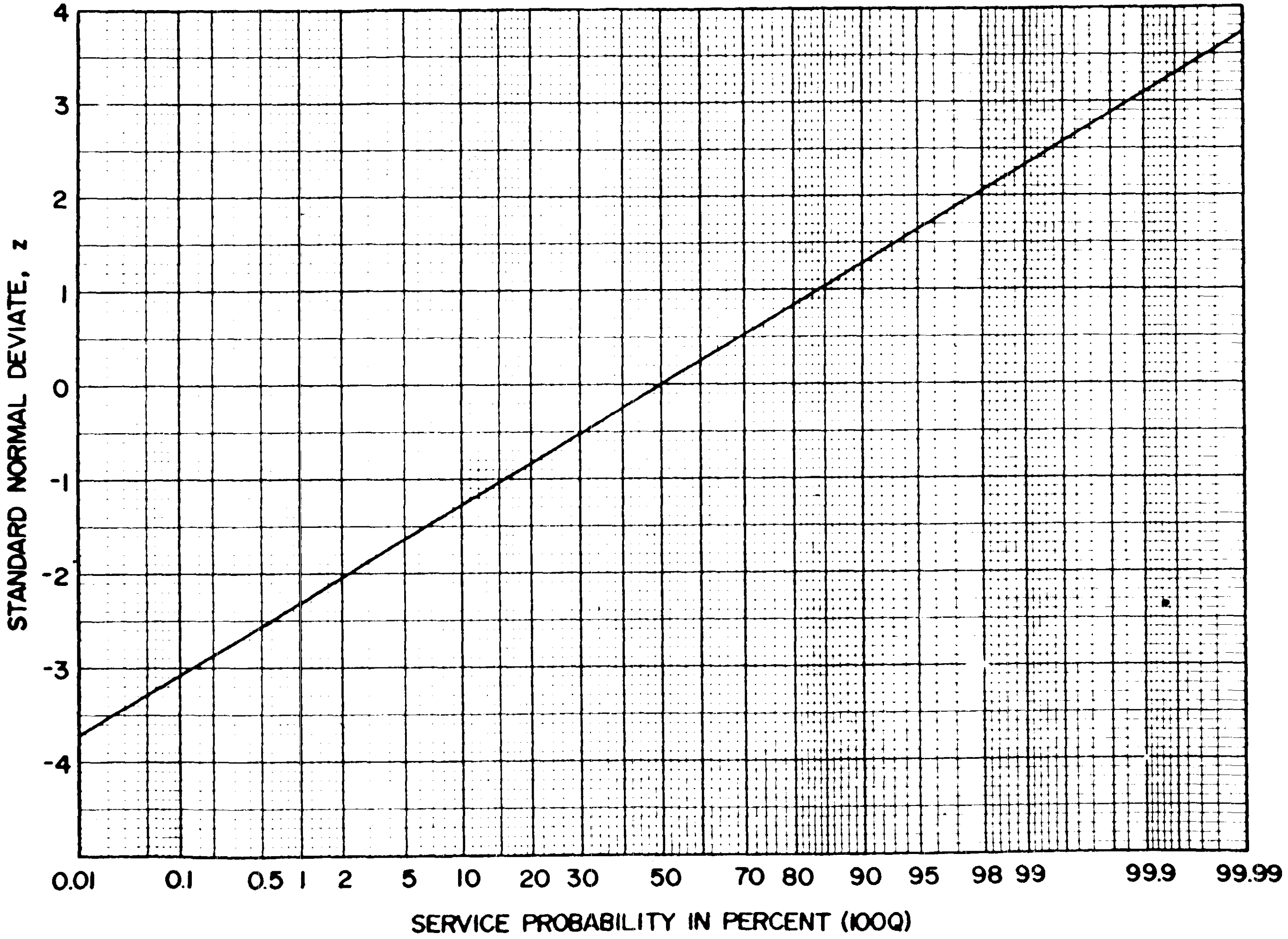

Figure 4.4-36 Graph of Q(z) Versus the Standard Normal Deviate, z

4.4.32 An Example of Perforrmance and *Service* Probability Calculations

4.4.32.1 The procedures described in the preceding subsections can be further illustrated using design data from an operating link in Europe. This is a 198-km path almost entirely over water. One of the terminals is in England near the North Sea coast, and the other terminal is in Holland at the coast. Path loss and system performance tests were performed in 1972, * and the results of these tests permitted a comparison of predicted with actual measured values of transmission loss. Initial performance estimates for this path are based on appropriate assumptions of the various equipment parameters, although there is actually no choice in operating frequency. Values can be substituted into (4.4-78) and (4.4-79) for frequencies between 200 and 5000 MHz in order to determine an optimun. frequency where the required transmitter power would be a minimum. From the results plotted in figure 4.4-37 this is around 1600 Mhz for 10-m (nominally 30-ft) dishes, and between 800 and 1000 mHz for 20-m (nominally 60-ft) dishes. The shape of these curves is determnined by the frequency dependence of the various parameters in the system equation (4.4-74). The ordinate scale of the required transmitter power level P_t in dBW corresponds to the reference value of basic transmission loss, L_{bcr}, and does not include the effects of long-term variablity. The value of the requied carrier-to-noise ratio $R_A(g)$ used here is based on the 3 pWO/km requirements for allowable long - term median thermal noise in a voice channel (see sec. 4.5.18),

4.4.32.2 The optimum frequency for this link with 10-m dishes is about 1600 MHz, but is not available for assignment. Therefore the 4500 - 5000 MHz range must be considered. Similar compromises.

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* Discussed in an unpublished report to the sponsoring agency,

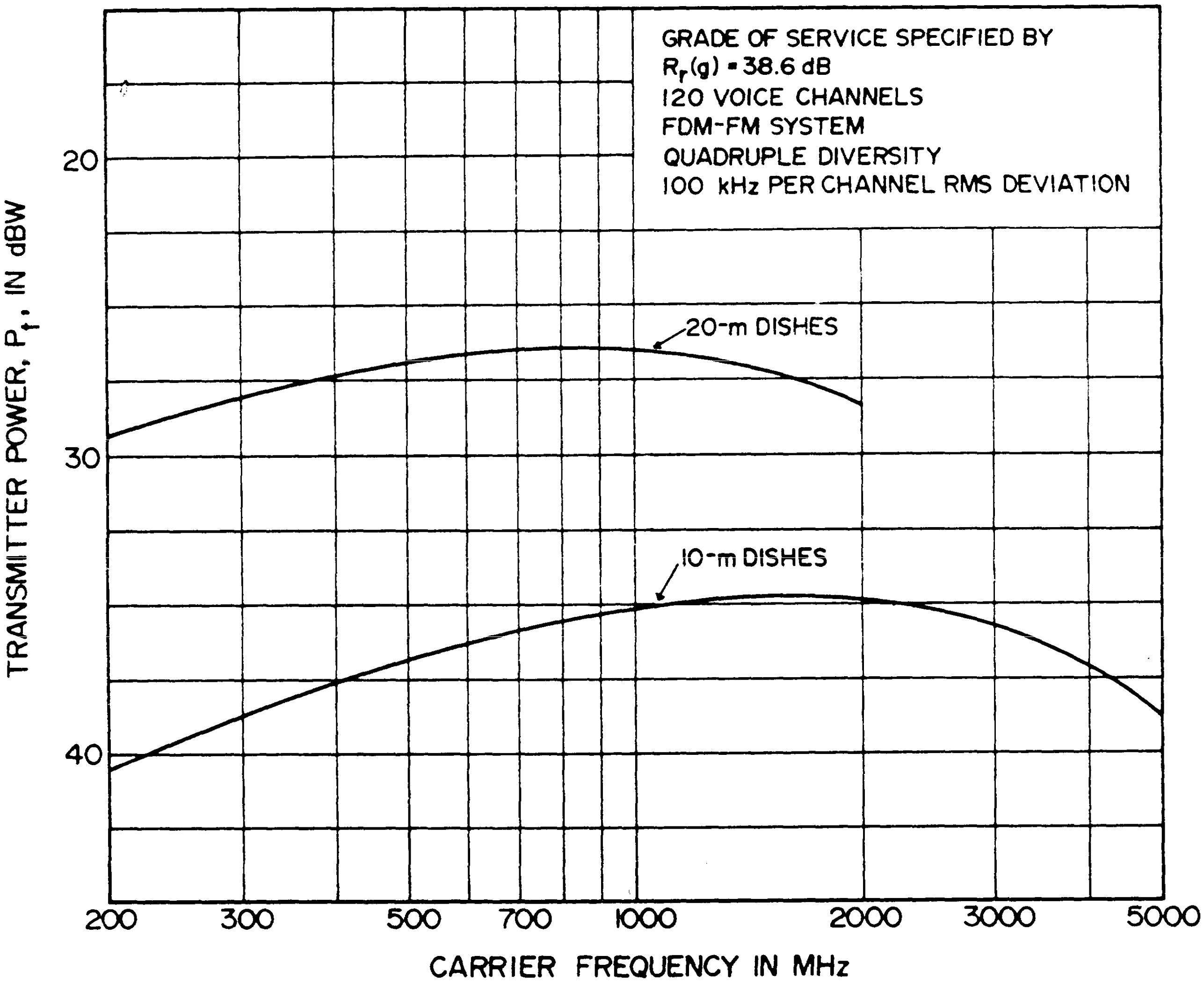

Figure 4.4-37 Required Transmitter Power as a Function of Frequency for 198-km Transhorizon Link

may have to be made in almost all design problems, but the procedure suggested above provides the designer and customer with an indication of what assignments would be desirable, and how many decibeis of achievable system gain are lost by non-optimized assignments. For the present example, 4700 MHz has been selected as the operating fre- frequency with 30-ft dishes. A final value for the system constant M_o can then be determined from these assurmptions and using other equipment. parameters reflected in the terms of {4.4-79). The results of the transmission loss and long-term variability] calculations from section 4.4.25 can then be used in (4.4-81a) and (4.4-81b) in order to obtain the cumulative distribution of the required trarnsmitter power, $P_t(q)$ as a function of the percentage of hours for a fixed value of the carrier-to-noise ratio $R_r(q)$. Alternativey, the cumulative distributions of the available carrier-to-noise ratios $R(q)_s$ or the received carrier level, $P_r(q)$, may be obtained for a fixed value of transmitter power, P_{to}" These alternative forms are usually preferred since in an actual design problem the transmitter power P_{to} is restricted to a few nominal values such a 1 kW or 10 kW. For the example, figure 4.4-38 shows one curve of the statistical distribution of basic transmission loss with ordinate scales added for the hourly media:. carrier-to-noise ratio, $R(q)$, and the received carrier level $P_r(q)$. These are based on the link and equipment parameters which will be further discussed in section 4.5.2.2

4.4.32.3 In addition to the statistically cxpected performance of the system shown by the solid line in figure 4.4-38 (as explained in sections 4.4.27 and 4.4.32), the procedures in section 4.4.32 are then used to establish confidence limits about this *curve.* Confidence levels for values of Q of 0.05 and 0.95 are also shown in figure 4.4-38. They include a 0.9 confidence band which. defines the limits for long-term

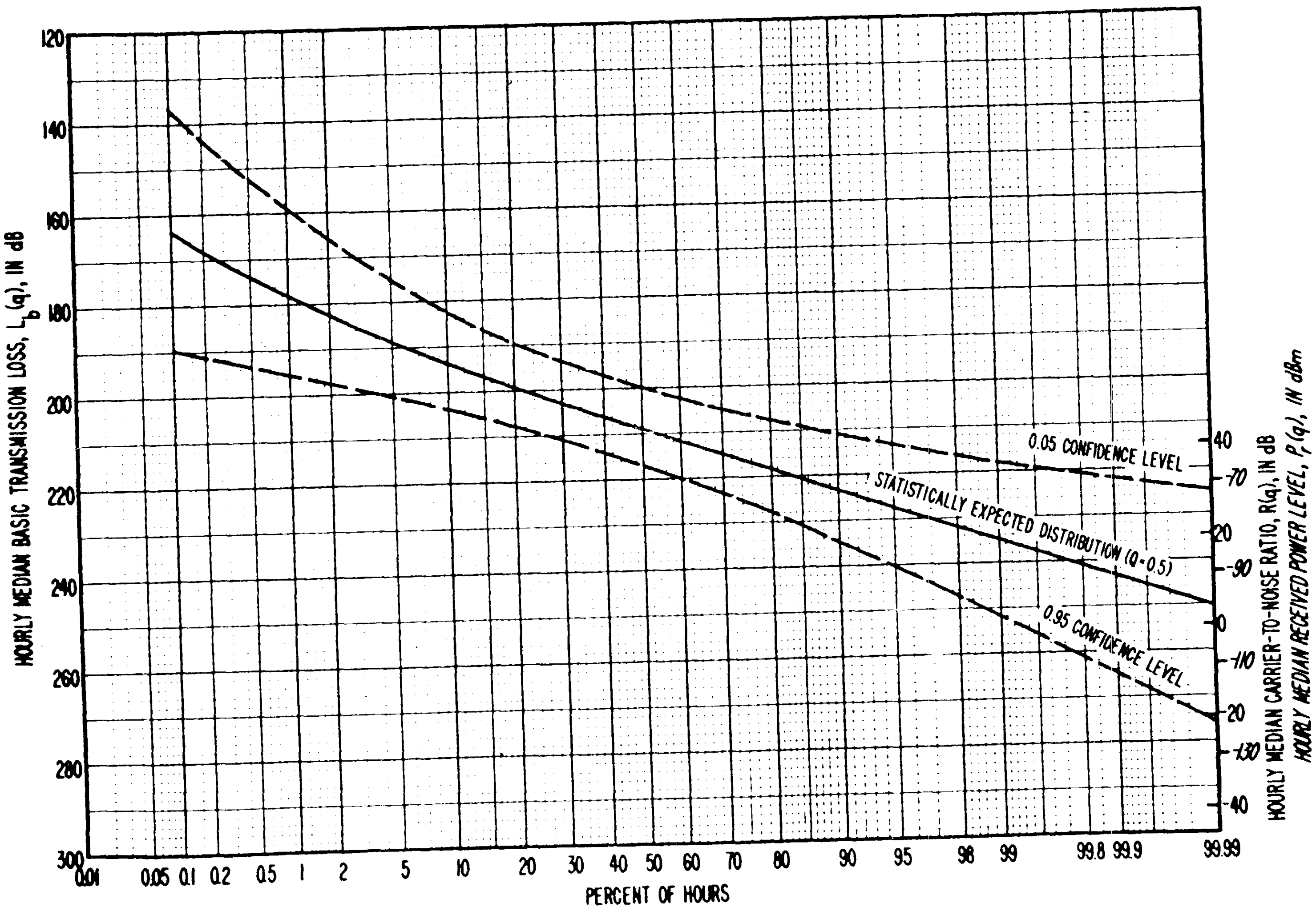

Figure 4.4-38 Example of Statistical Distribution of Basic Transmission Loss and Related Parameters

distributions of hourly medians for systems with the same path and equipment parameters. These confidence levels are based on $\sigma_c^2(q) = 25\ \mathrm{dB}^2$, $r^2 = 0.12$, and $\sigma_r^2 = 4\ \mathrm{dB}^2$.

4.4.32.4 If higher service probability values are of interest for a given set of equipment parameters, figure 4.4-38 shows that a smaller value of R(q) results during the same fraction of hours than for the statistically expected value corresponding to Q = 0. 5. This corresponds to requiring a greater probability of success. As an example, the specified 10 kw transmitter power (see 4.5.21 .2) results in an hourly median predetection signal-to-noise ratio of approximately 19.5 dB during q = 99% of all hours with a probability Q = 0.5 (equivalent to an even chance of success or failure). However, the requirement of a service probability value Q = 0.95 reduces this value of R $_{LO}$ approximately 2.5 dB, i. e., below noise threshold (from the lower broken curve in figure 4. 4-38) Although this represents substantially less chance of failure (one out of twenty) during the same percentage of all hours, it applies only to a reduced value of R which in this case is operationally useless. If we say that this path will work with an hourly median pre-detection carrier-to-noise ratio of 10 dB, figure 4.4-38 shows that one-half of a large number of hypothetical identical paths will "work" during 99.937% of all hours. But if we require 19 out of 20 such paths (0.95) to "work", this can be expected only during 97.7% of all hours.

4.4.32.5 Defferences such as the one between the values of 11 dB and -6 dB, corresponding to 0.5 and 0.95 service probability values in this example, can be termed " safety margins". There is, however, another way to include time availability and service probability considerations in the system equation, so that performance estimates can be obtained which take into account all variables. Let the transmitter power as well as the pre-detection signal-to-noise ratio be fixed for a given system by specifying both P_{to} and R_r. Then, either one of the complete system equations (4.4-87a) or (4.4-87b) can be solved for the standard normal deviate as a function of the time availability) q. The corresponding service probability values, Q(z), are then determined from probability tables or from figure 4.4-36. As an example, fix PtP[Q(z),q] in (4.4-87a) to denote a specified transmitter power value, P_{to}:

$$P_{to} = M_o + R_r - V(q) + z\sigma_{rc}(q). \qquad (4.4\text{-}88)$$

Then, recall that (4. 4-8la) applies to the statistically expected value, Q (z) = 0.5, so that for z = 0:

$$P_t[0.5,\ q] = M_o + R_r - V(q). \qquad (4.4\text{-}89)$$

Subtracting (4.4-89) from (4.4-88) and solving for z, the following relation is obtained:

$$z = \frac{P_{to} - P_t(0.5,\ q)}{\sigma_{rc}(q)} . \qquad (4.4\text{-}90)$$

4.4.32.6 For each z determined by (4. 4-90), the corresponding service probability Q(z) is obtained from Probability tables or from figure 4. 4-36, and curves of time availility, q, versus Q(z) can be determined for specific assumptions of values for P_{to} and R_r. Such curves are conveniently plotted on a double-probability display, as shown in figure 4.4- 39, and the performance of the various systems can now be compared. For the example, two curves are shown; both for a fixed R_r = 10 dB, but for transmitter power values P_{to} of 30 dBW (1 kW) and 40 dBW (10 kW), respectively. Each of these curves represents specific systems with attached price tags in dollars. Thus, one may estimate additional costs for increased service probability. In the example, a system with 1 kW transmitter power would provide the required grade of service (given by R_r= 10 dB) during 99% of all

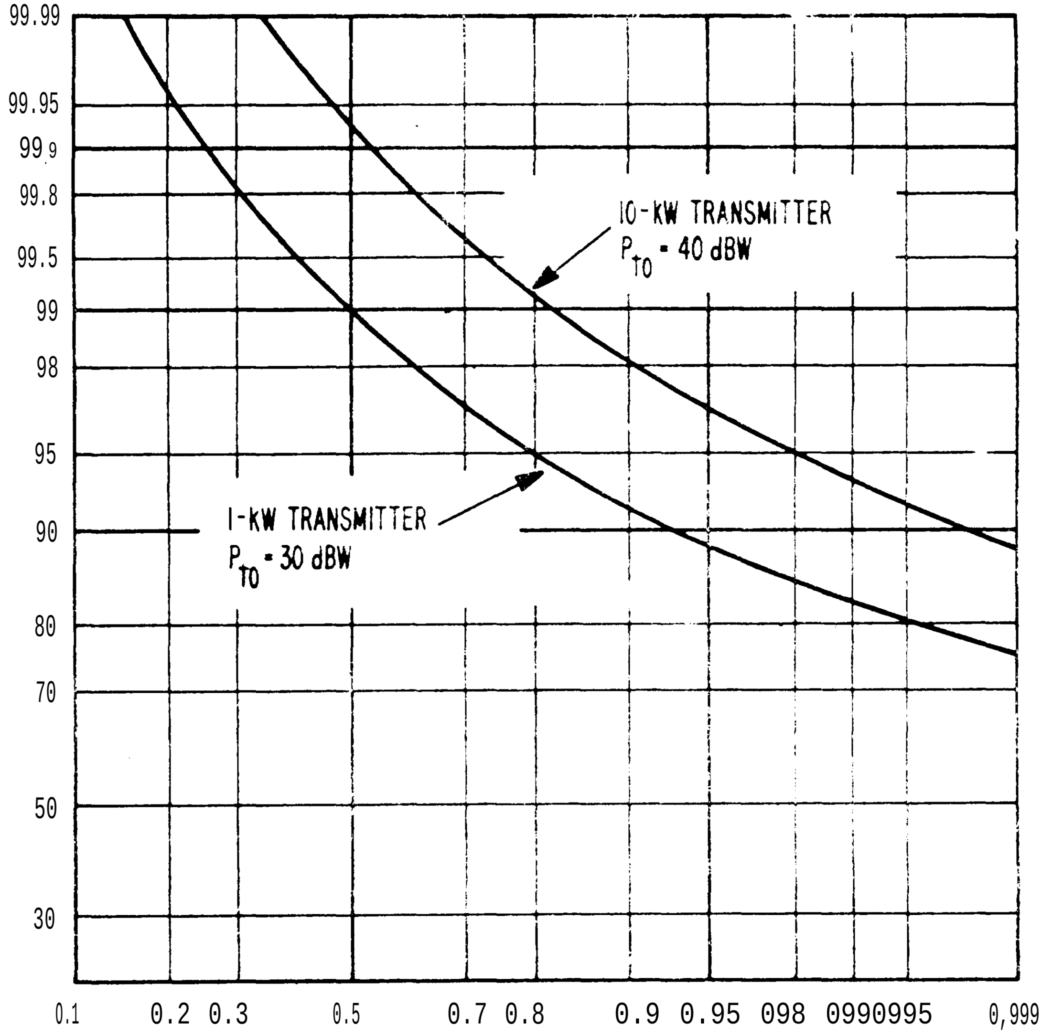

Figure 4.4-39 Graph of Service Probability Versus Time Avaiability for Sample Link

hours with a probability of only 0.50 corresponding to one chance out of two of failure. An increase in transmitter power to 10 kW would provide the same time availability with a service probability of 0.82, which reduces the chance of failure to approximately one out of five, but is obtainable only at a higher installation and operating cost because of the higher transmitter power. It is then up to the designer, or perhaps the user, to decide whether the increased probability of success justifies the higher cost and the possibly increased complexity of the installation.

4.4.33 An Alternative Appreach to Variability Calculations

4.4.33.1 We have already noted in earlier parts of section 4.4 that the long-term variability of transmission loss over a given link is derived from empirical data. The uncertainty associated with this approach can be evaluated by the use of confidence intervals and service probability, as explained in sections 4.4.31 and 4.4.32. A somewhat more direct approach would be to describe in statistical terms the variability of those atmospheric parameters which affect path losses, and calculate path loss for the expected range of values of such parameters.

4.4.33.2 The surface refractivity, Ns, is not well correlated with hour-to-hour or day-to-day variations in transmission loss [37, 38, 39]. The use of n_s in the methods discussed in section 4.4 is based on the correlation between long-term median values of Ns (monthly or seasonal) with transhorizon path loss [18? sec.7]. On the other hand, the initial refractivity gradient AN/Ah, defined as the mean value over 1 km, as discussed in section 4.4.3. can be directly related to the effective earth radius, a, which affects path geometry and particularly the scatter or diffraction angle 0. Consequently, the time distribution of the initial gradient could be used to establish a time distribution of transmission loss by (1) determining corresponding effective earth radius values (from fig. 4.4-1 and by calculating basic transmission loss values for each effective earth radius. Such results can than be plotted at the time fractions ,applicable to each value (from the distribution of the gradient) and compared with the empirical time distribution with its confidence limits obtained from section 4,4.2b, 4.4. 32, and 4.4.33.

4.4.33.3 There are several precautions which must be taken if such calculation methods are used:

1. It will usually be of greater interest to determine potentially large values of transmission loss as a funcion of <u>positi</u>ve refractivity gradients corresponding to smaller effective earth radius values. Large negative gradients which sent to decrease transmission loss are frequently associated with ducts. The high field strength (low transmission loss values) occurring in such Cases cannot be easily calculated using the methods described in this Chapter.

2. Tropospheric scatter theory is based on <u>average monthly</u> mean surface refractivity values. The relatlonship between refractivity gradient and surface refractivity given in (4.4-2b) in section 4.4.3 is not applicable to positive gradients; therefore results of scatter calculations for the corresponding effective earth radius factors, k < 1, are questionable. Estimates can be obtained by using the n_s = 250 curve in figure 4.4-21 for F(θd), and 4.4-22 for [illegible].

3. Time distributions of refractive index gradients are usually based only on short time instance \ascents of radiosondes once or twice per day), and the results are applicable primarily to the im mediate area of the weather station. It is questionable whether such results can be applied to long paths over continous periods periods of time. Boithias and Battesti [40] have derived a relationship between "point" values of the effective earth radius factor k, and k-values which may be applicable to lIne-of-sight links of a given length. An applicable curve

from their report is shown in Report 338-1 of [1l. However, additional data are required before such methods can be confidently applied to long transhorizon links. Alternative methods are given in Report 244-2 of [1]; a method proposed by the French admistration is based on refractivity gradient statistics.

4.4.33.4 At this time, however, it may not be useful in most cases to calculate transmission loss directly as a function of k. Such results may represent extremes which may occur only rarely, and whose principal purpose is comparison with the results using the empirical time distributions. Further analysis work is required before statistics of atmospheric data can be used more directly and with confidence in transhorizon link design.

4.4.34 Diversity on Transhorizon Links

4.4.35 General Considerations for Space, Frequency, and Quadruple Diversity

4.4.35.1 Transhorizon links usually utilize tropospheric scatter mechanisms where the received electromagnetic energy is composed of many individual components which are scattered or reflected from irregularities or inhomogeneities in the upper atmosphere. The phase relations between these components changes constantly because of the changing spatial relations between scattering or reflecting elements due to turbulence, wind, and other effects in the atmosphere. Consequently, the received power level, by summation of individual "multipath" components changing in relative phase, fluctuates at a rate which is related to the relative motion of the atmospheric irregularities, the wind velocity, and the carrier frequency of the transmitted energy. This is commonly termed fading, and the rate of fading, or of the power level fluctuations, may vary typically from a few fades per minute to possibly tens or hundreds per second. Similar fading phenomena, although at relatively slow rates, may be observed over mountain diffraction links, where a numbers of components of varying phase can be present because the many terrain feature"seen" by the antennas at the path terminals can act as separate diffracting obstacles.

4.4.35.2 If several distinct "paths" can be provided for a radio signal, the observed fading is usually uncorrelated; i.e. , the field strength variations for each individual path will generally not show maxima or minima simultaneously. Thus a summation of the individual field stength value in their proper phase relations with produce less variation in the available power level than those resuliting from a sigle path, and particularly it will avoid the effects of large drops in signal levels (deep fades) since it is not likely such deep fades would occur simultaneously on all paths. The distance or different paths mentioned here are usually obtrained either by separating antennas in space, by employing different frequencies on a path between the same antennas, or by a combination Of both methods. These techniques are grouped under the term "diversity reception".

4.4.35.3 The simplest forms of diversity are dual space and frequency diversity configurations where only two individual paths are involved. Basic block diagrams are shown in figures 4.4-40 and 4.4-41. The dual frequency diversity System uses two transmitters which modulate the baseband signal two different carrier frequencies which are transmitted by a single antenna. The received signals (also by a single antenna) are separated by proper circuitry, detected in two receivers, and combined by a simple switch by which the arger of the two signals is selected for further processing. In the dual space diversity system,only one transmitter and one transmitting antenna is used, but the signal is received by two antennas which are separated in space. After detection, the same type of switch

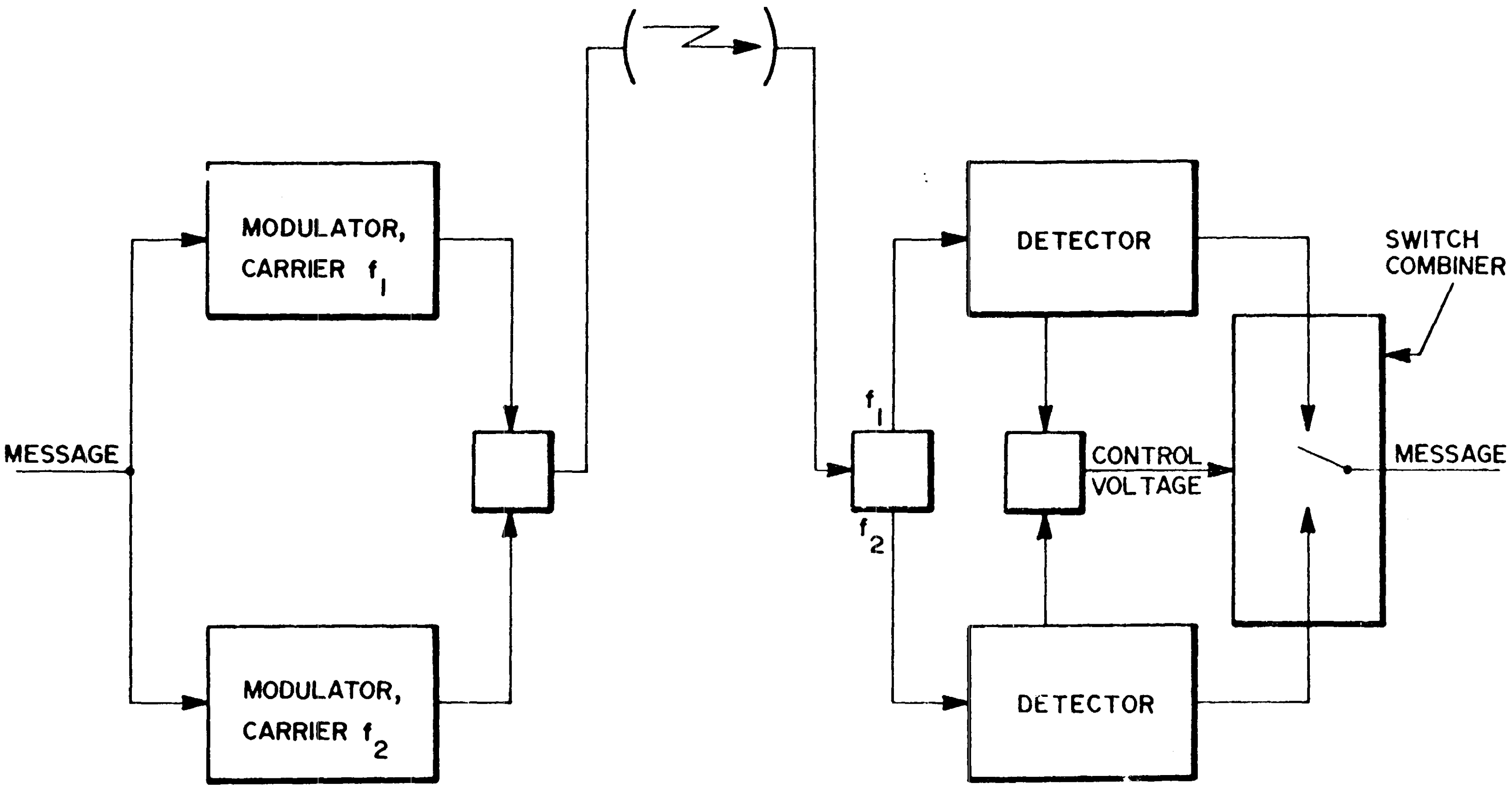

Figure 4.4-40 Simplified Block Diagram of a Frequency Diversity System

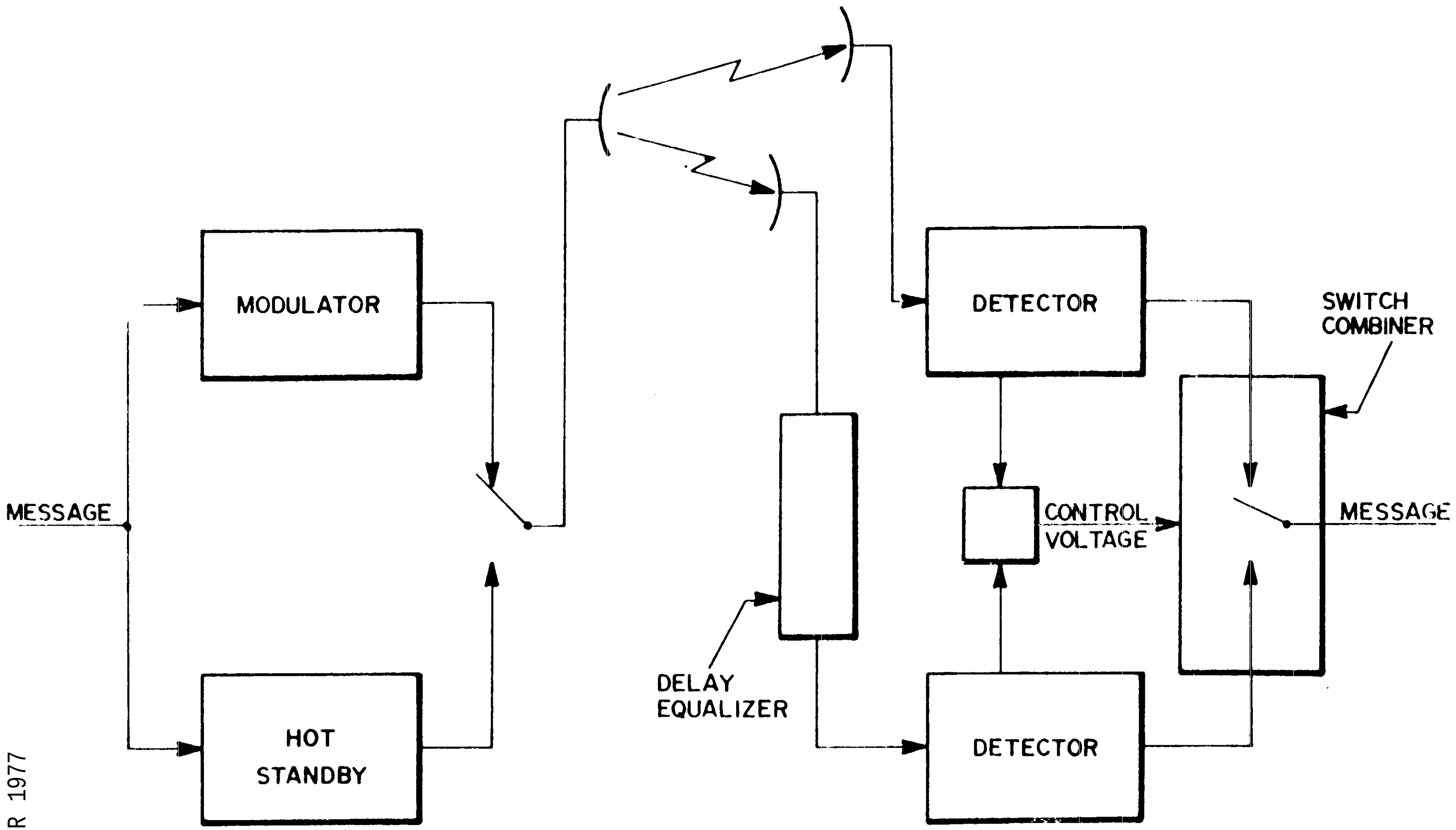

Figure 4.4-41 Simplified Block Diagram of a Space Diversity System

combiner can be used to provide the larger of the two received signals for further processing.

4.4.35.4 The simple forms of dual diversity shown in figure 4.4-40 and 4.4-41 are satisfactory only on line-of-sight or some knife-edge diffraction links; for transhorizon links, higher-order configurations such as quadruple diversity are recommended. Commonly used quadruple (space-frequency) diversity systems are illustrated in figures 4.4-42 and 4.4-43, where electrical separation between the various transmitting and receiving frequencies is aided by the use of different polarizations and various circuit elements such as diplexers and duplexers. Similar techniques can also be applied to quadruple space diversity systems when the number of frequencies required for a frequency diversity scheme cannot be assigned. A typical quadruple space diversity configuration with orthogonal poharizations is shown in figure 4.4-44. Quadruple diversity systems are most commonly used for transhorizon links with two antennas at each terminal with the signals having different polarizations and/or different frequencies separated in the antenna circuits.

4.4.35.5 In some applications angle diversity may be used. Here signals arriving at different angles of incidence are utilized by proper design of the antenna feed system.

4.4.35.6 Various methods for combining signal components are used, which range from simple selection combiners (which select the strongest signal of those available) to more sophisticated techniques which assure that all available signals are combined in a phase-coherent manner so that voltages always add.

4.4.35.7 Diversity techniques would be unnecessary for ideal smooth-earth or knife-edge diffraction links. However, no actual

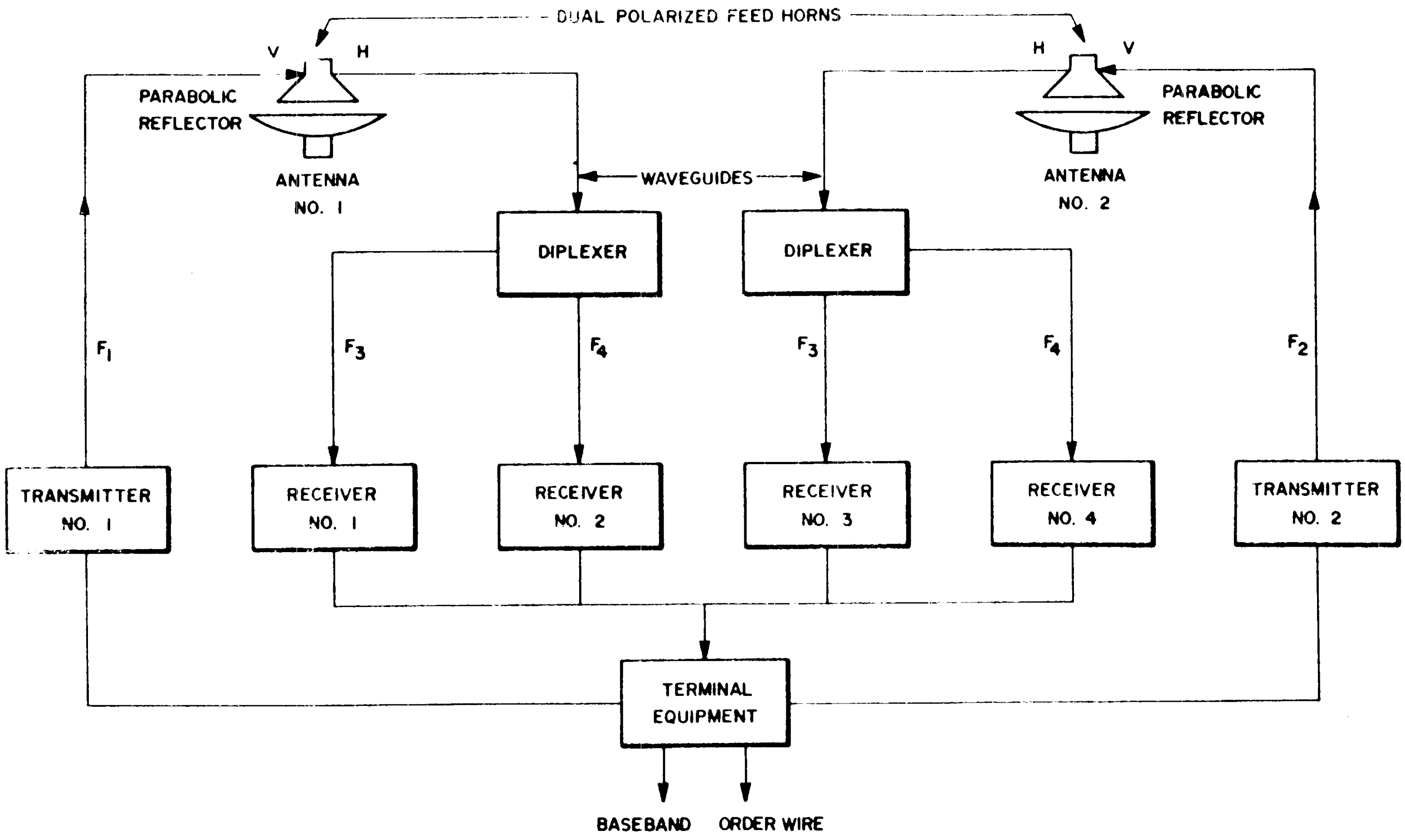

Figure 4.4-42 Quadruple Diversity Configuration (Frequency and Space)

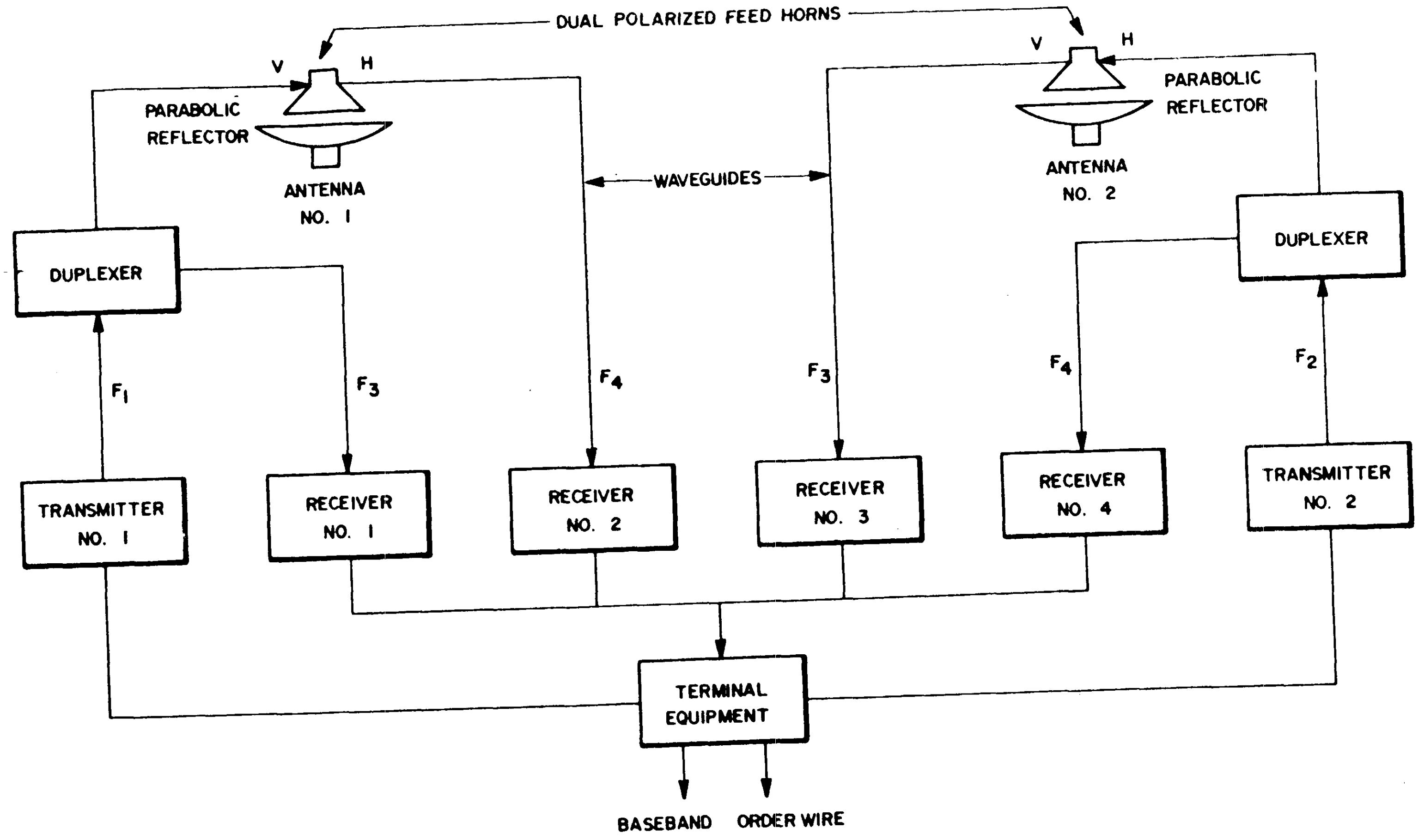

Figure 4.4-43 Alternative Quadruple Diversity Configuration (Frequency and Space)

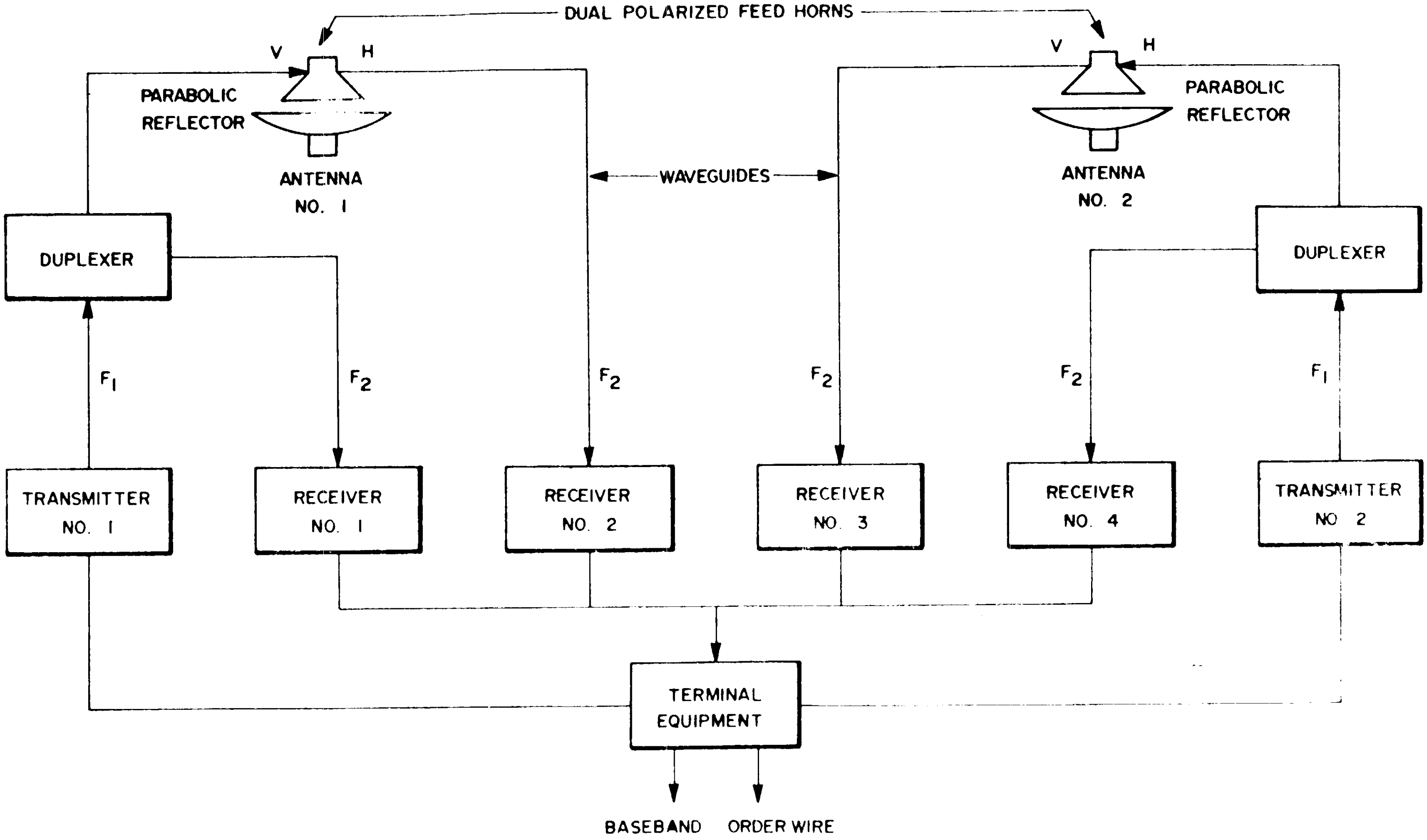

Figure 4.4-44 Space Quadruple Diversity Configuration Using Polarization to Separate Signal Paths

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path resembles ideal conditions, and some multipath components will always be present because of the variations in atmospheric structure 4.435.8 Diversity systems also provide automaticallyt some degree of redundancy by uttilizing several transmitters and receivers over a specific link. Thus, thefailure of one equipment completly such as a transmitter will not completely disable the system, since operations (perhaps with reduced reliability) can still be carried on with the other transmitter.

4.4.35.9 Since frequency diversity requires additional spectrum space, its use may requires special justification in terms of the desired system reliability, as recognized by the CCIR in its Recommendation 302[4,p.33]. Thus quadruple space diversity systems (as shown in fig.4.4-44) have been utilied in many cases with the electrical isolation between the various pathe provided by using orthogonal polarization as already note.

4.4.36.1 Spacing and Frequency Separation

4.4.36.1 The effectiveness of a diversity system in transhorizon propagatioon depends on the degree to which time variations of the fields received by the individual antennas (or at the individual frequencies)are uncorrelated., Expeerience has shown that for space diversity separations of 100 wavelengths or larger between antenna centers should be used if these are arranged perpendicalar to the propagation path. This amounts to about 15 m at 2000 MHz or 7.5m at 4000 MHz, as examples., Since the antennas utilized tin such applications are usually quite large (nominal 60ft or about 20 min diameter at 2000 MHz and30 ft (10m) at 4500 MHz), this is not excessive.

4.4.36.2 In most application the antennas are spaced horizontally There are a few cases where vertical spacings have been utilized in transhorizon propagation, but the results have not been uniformly good.

It has been observed that when the general signal level is depressed, the signal from the lower antenna may suffer even more attenuation (due, possibly, to a foreground obstacle which under low signal conditions becomes dominant) and contributes almost nothing to diversity performance. In general, vertical space diversity should be used on a transhorizon path only when no other alternative is available.

4.4.36.3 Frequency spacing should be larger than approximately 5% of the nominal carrier frequency, if possible. However, availability of frequencies, possibility of interference, or other considerations may dictate the specific frequencies which can be used in a transhorizon diversity system. Since frequency diversity in such systems will usually be a component of a quadruple diversity space-frequency arrangement, the choice of frequencies may not be too critical. Considerations of the required electric. ! isolation between frequencies in a diversity system may be more important.

4.4.36.4 A more complete discussion of diversity techniques is given in CCLR Report 376-1 [4; p. 169].

4.4.37 Horizontal Space Diver sity for Single Obstacle Diffraction Paths

4.4.37.1 The nonuniform transverse profile of the diffracting edge of natural obstacles and reflections on the transmission paths on each side of the diffracting edge may result in multipath transmissions causing variations in received signal level as a function of frequency, space, and time (as already noted in section 4.4.35). The amplitude of such variations may be reduced by both horizontal and vertical space diversity, frequency diversity, and by the use of narrow-beamwidth antennas. Optimum horizontal spacing of antennas can be obtained from path testing of horizontal interference patterns at the proposed antenna sites and perpendicular to the path [41].

4.4.38 Combiners

4.4.38.1 A second important part of diversity system design is the choice of combining techniqes One may assume a switch combiner whose output is merely the better of two signals. But there ar adder combiners, ratio combiners, and others which attempt to make more efficient use of the two signals. If adjusted correctly, they should make the diversity performance even better.

4.4.38.2 Another way to classify combineres is to describe the point at which combining takes place. Infigures 4.4.-40 and we have implied that this is done only after both signals have passed through complete receivers, been detected, and brough down to baseband frequency. This method is called postdetection combining. It is widely used as the simplest and most reliable methodm But the signals may also be combined at the IF output. This is called predetection combining. In principle , the earlier the signals are combined the better is the ulitimate performance. Another advantage of predetection combiners is that for repeater stations without channel breadout detection is unnecessary and may be eliminated. Predetection combiners must have the ability to adjust the phases of the two to four individual signals so that the signal voltages always add in phase. This is a difficult task; thus, predetection combineers in use today are expensive, and their degree of reliability is uncertain. Newer techniques are available, although as yet untested in operational systems.

4.4.39 Radio Frepuency Interference

4.4.40 General

4.4.40.1 Interference ahould be consideered tn the link design to insure that noise contributions from exeternal sources and from sources within the system will remain well below tolerance levels. Section 4.5.8 contains consideration of co-channel and adjacent channel interference from other links in the system. Noise associated with modulation, demodulation, and the linearity or delay in electronic modules is considered as part of equipment characteristics and requirements. Noise generated by sources external to the system is considered part of the ambient radio frequency environment which must be determined by an electromagnetic compatibility study (see sec. 4.2.29). An. the following two sub-sections noise types and sources external to the system are identified and site modification and equipment techniques which can be used to minimize interference are discussed.

4.4.41 Additive Radio Noise

4.4.41.1 We have implied in section 4.4.28 that the receiver noise figure F in decibels is usually the most significant noise component which must be considered in trans horizon system design. As a parameter in the system equation, it is used to evaluate the relations between received carrier level, basic transmission loss, bandwidth and system performance in terms of the carrier-to-noise ratio. However, there may be cases where external noise sources produce additional degradation of system. performance, and their effects must be quantitatively evaluated or at least estimated.

4.4.41.2 External noise sources may be either natural or man-made, and some important sources are listed below as examples. They are termed "additive", since their effects are independent of the presence or absence of a desired signal.

1. Natural additive noise sources
   a. Atmospheric noise (usually negligible at frequencies above 1000 MHz)
   b. Sky noise
   c. Galactic noise
   d. Solar noise (when antenna points at the sun)

2. Man-made additive radio noise sources
    a. Power lines or power supplies
    b. Automotive ignition systems
    c. Fluorescent lights
    d. Switching transients
    e. Electric razors
    f. Door bell buzzers
    g. Electric motors.

4.4.41.3 Radio noise from such sources has spectral energy distributions which vary more or less uniformly over wide bandwidths throughout the frequency spectrum. Typical values for various types of sources are shown in figure 4.4-45 for the 1 - 100 GHz frequency range, and are compared with threshold values for commercially available receiving equipment. This graph was assembled from material in several references and is in terms of the median operating noise factor F_{am} in dB relative to the thermal noise threshold kT_o per hertz of bandwidth, where T_o is the reference temperature and k is Boltzman's constant (see sec. 4.4.28). The reference temperature is fixed so that $10 \log kT_o = -204$ dBW /Hz.

4.4.41.4 In order to utilize the values in figure 4.4-45, the noise factors must be referred to the receiving antenna terminals for addition of noise power values. Based on the original work by Friis [33], the following expression was given by Norton [3] for the effective noise factor F (in dB) of a receiving system including all internal and additive noise sources where

$$F = 10 \log f \text{ dB}^* \qquad (4.4\text{-}91a)$$

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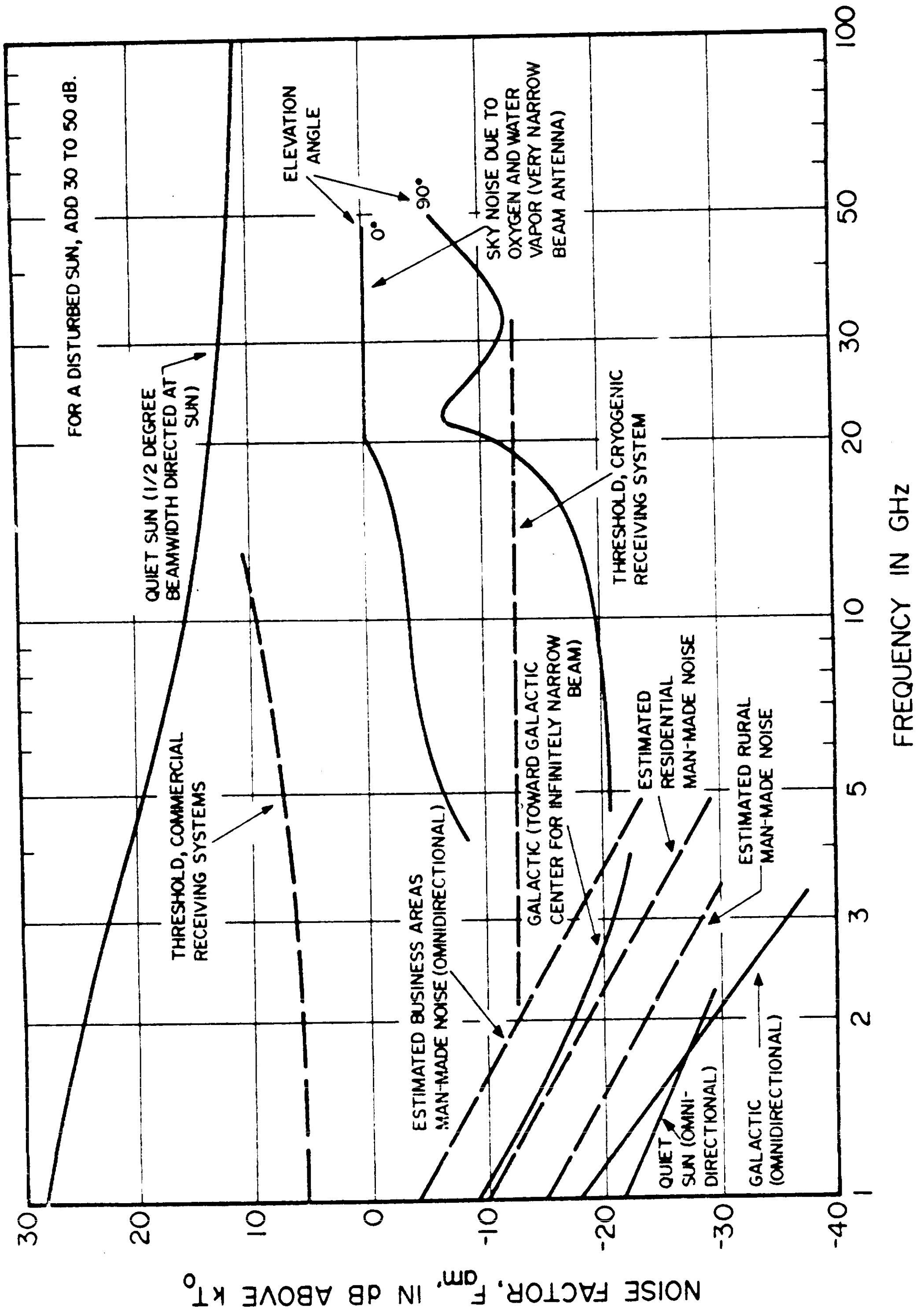
*For the purposes of section 4.4.28 it was assumed that external and antenna circuit noise contributions can be neglected. Since line losses were treated separately, the receiver noise figure was considered to be equivalent to the effective noise factor F.


FOR A DISTURBED SUN, ADD 30 TO 50 dB.
QUIET SUN (1/2 DEGREE BEAMWIDTH DIRECTED AT SUN)
ELEVATION ANGLE
0°
90°
SKY NOISE DUE TO OXYGEN AND WATER VAPOR (VERY NARROW BEAM ANTENNA)
THRESHOLD, CRYOGENIC RECEIVING SYSTEM
THRESHOLD, COMMERCIAL RECEIVING SYSTEMS
GALACTIC (TOWARD GALACTIC CENTER FOR INFINITELY NARROW BEAM)
ESTIMATED RESIDENTIAL MAN-MADE NOISE
ESTIMATED BUSINESS AREAS MAN-MADE NOISE (OMNIDIRECTIONAL)
ESTIMATED RURAL MAN-MADE NOISE
QUIET SUN (OMNI-DIRECTIONAL)
GALACTIC (OMNIDIRECTIONAL)
30
20
10
0
-10
-20
-30
-40
NOISE FACTOR, F_{am}, IN dB ABOVE kT_o
1
2
3
5
10
20
30
50
100
FREQUENCY IN GHz

$$f = f_{am} - 1 + \ell_c \ell_\ell f_r \qquad (4.4\text{-}91b)$$

The terms in (4.4-91) are all in units of power or power density ratios, and

$F_r = 10 \log f_r$ . . . . receiver noise figure previously denoted by F)

$f_r = 10^{F_r/10}$

$L_\ell = 10 \log \ell_\ell$ . . . . Transmission line and associated losses in db

$\ell_\ell = 10^{L_\ell/10}$

$L_c = 10 \log \ell_c$ . . . . antenna circuit losses in db (ususlly negligible above 500 MHz)

$\ell_c = 10^{L_c/10}$

$F_{am} = 10 \log f_{am}$ . . . . external noise factor in db as shown in figure 4.4-44

$f_{am} = 10^{f_{am}/10}$

The values F_{am} plotted in figure 4.4-45 are median values. As an example, consider the effect of the quiet sun on system performance if a narrow-beam antenna is oriented such that the sun passes through its beam at certain certain of the day or the year. Let the receiver noise figure F_r = 12 dE, the transmission line losses 1_2 = 2 db, and the antenna circuit Losses L_c be negligible (L= 0 dB or L_C = 1). At a Frequency of 2 GHZ, F_{am} = 25 db from figure 4.4-45. Converting F_r, L_L, and F_{am} "into the corresponding ratio and substiting in into (4.4-91b) we obtain f = 340.3, and the corresponding effective noise factor of the system becomes F = 10 log f = 25.3 dB; i. e., the system performance relative to the receiver noise figure is degradeded by 25.3-12=13.3dB.

4.4.41.5 Note that the F_{am} values in figure 4.4-45 are medians over relatively broad bandwidths. Although atmospheric noise at the median level is insignificant at frequencies above 30 MHz, local thunderstorms may create a great deal of interference throughout the VHF and UHF bands.

4.4.41.6 The galactic (omnidirectional) noise curve with a +2 dB allowance for temporal variations indicates the upper limit for this source for antennas not directed toward the galactic center. However, in any given situation the galactic noise levels should be calculated considering critical frequencies and any directional properties of the antenna. With a very narrow beam, the galactic center is about 10 dB "hotter" than the median background. Note also that the curve in figure 4.4-45 is based on a beamwidth of 0. 5 degrees or less pointing at the quiet sun. The disturbed sun can cause these quiet sun values to increase by 30 to 50 dB.

4.4.41.7 Sky noise due to absorption by water vapor and oxygen is of importance when low noise-factor receivers are used with narrow beam antennas directed at low elevation angles but away from the surface of the earth as for satellite communications.

4.4.41.8 The man-made noise levels in figure 4.4-45 *are* derived from measurements as explained in Supplement 9 to the JTAC report on spectrum engineering [74; see p. 59 - 13 and fig. 3]. The "urban" data include measurements from such locations as the business areas of New York, Baltimore, Washington, D. C. , Denver, Melbourne, Tel Aviv, Haifa, and Jerusalem. The “suburban” curve was obtained from data taken at Boulder, a location near Washington, D. C. , Melbourne, Tel Aviv, Haifa, and some locations in England. The “rural" measurements *were* made at locations as free as possible from man-made noise.

4.4.41.9 Man-made noise in urban locations can represent the primary limitation to reception at frequencies up to 2 MHz. At present there is insufficient knowledge regarding its dependence on angle-of -

quate engineering analyses of levels likely to be available at the receiving antenna terminals. Statistical descriptions of noise need also to be related to its interference potential relative to the information being received.

4.4.42 Frequency Selective Interference

4.4.42.1 For point-to-point trarishorizon systems the major potential interference sources are undesired signals radiating from transmitters on the same or adjacent channels to the one desired. These sources include satellites, satellite ground stations, radar stations, and other point-to-point relay systcm in the same area. In addition to these sources, reflections from aircraft and precipitation act as secondary sources. Such sources when operative with respect to the desired path can cause frequency selective fading and the therefore distort the wanted signal. Quantitative information for estimating the outages due to these various source will often be impractical to obtain but the following considerations should be Kept in mind designing a particular link:

a. Consider the effect of antenna pathern, gain and polarization on unwanted signal sources.

b. Avoid main beam intersections with undesired sources.

c. Site shielding may be effective when a site must be shared with a source of unwanted signal. Shielding may be accomplishe by advantageously locating on the brow of a hill, placing the antenna at a location such that the unwanted source is screened by evergreens, or by actually making a cut in a hill [43].

d. Transmission line connections, cable, and cormponet shielding must be designed to prevent radiation leakage. Mechanical RF switches, shutters and probes should be avoided or, where necessary) carefully designed to prevent radiating or picking up unwanted signals.

4.4.43 Sharing of Frequency Bands Between Communication-Satellite Systems and Transhorizon Terrestrial Radio-Relay Systems

4.4.43.1 Special interference problems may exist on frequencies which are shared between transhorizon terrestrial and satellite communication systems. Pertinent considerations are outlined in the Annex to CCIR Report 209 - 2 [4; p. 291].

4.4.44 Equipment Considerations

4.4.44.1 This section provides information on available equipment for transhorizon links with some of the advantages and limitations of using it in the design. Items are discussed in terms of function, options, flexibility, environmental characteristics space requirements susceptibility to interferences gains dynamic ranges bandwidth, reliability, primary power requirements, and other applicable characteristics.

4.4.44.2 Diversity equipment combinations and combiners were already discussed in section 4.4.35. The equipments which will be considered here are antennas, passive repeaters, RF transmission lines, separating and combining elements, transmitters, receivers, and active repeaters.

4.4.45 Antennas

4.4.46 Antenna Types and Parameters

4.4.46.1 Transhorizon radio links are almost always equipped with large parabolic antennas since such antennas are the only practical ones available which provide the high gains. In the past, large planar dipole arrays have been used in the 300-MHz frequency band particularly in Europe, but at higher frequencies , such arrays are economically impractical bercause of the problems of feeding the multiple radiating elements. The following discussion will therefore be limited to large parabolic reflector-type antennas.

4.4.46.2 The essential requirements imposed on the antenna relate to the following characteristics:

a. antenna gain in the direction of the main beam; on transhorizon links antnna gains of more than 45 dB may sometimes be required.

b. half-power beamwidth; since such antennas have small half-power beamwith (<1°,) great stability and rigidity are required in the antenna and mount.

c. attenation of sideiobes; important for prevention of interference with other systems working at the same or at adjacent frequencies;

d. reflection factor at the antenna terminals; this must be kept small particlariy in broadband systems (<5%), in order to prevent intermodulation distortion of the signal.

4.4.46.3 The parablic antennas used for most transhorizon applications may either be mounted on low towers or similar structures, or, particlarly for large sizes, are actully bill-board type paraboloid sections at ground level. Their side lobe and back lobe attenuation is adequate for transhorizon links.

4.4.47 Isotuopic Antennas and Cain.

4.4.47.1 The background material in the following subsections on antennas was taken largely from section B.IV.4 of [54]. Antenna gain values previously given in this handbook (sec. 4.2.11 and 4.4.29) are useful estimates for system design.

4.4.47.2 The propagation of radio waves requires the use of antennas to launch the electromagnetic energy from the transmission line into the atmosphere, and collect it again at the receiving end. Antenna "gain" is a measure of the efficiency of this energy transfer. Other important parameters of an antenna are its bandwidth, impedance and radiation pattern. A convenient reference for gain and radiation pattern comparisons is the hypothetical isotropic antenna which, by definition, radiates its energy equally in all directions, so that its "gain" is defined as unity. Other antennas increase the effective radiated power by concentrating more power in a desired direction. Hence, they are directional and are characterized by gain factors with respect to the isotropic antenna.

4.4.47.3 The power radiated from, or received by, an antenna can be related to a concept of "effective area". For an isotropic antenna, the power is distributed evenly over the surface of a unit sphere surrounding the antenna. The power gain g of an antenna over the area A relative to an isotropic antenna can be expressed by:

$$g = \frac{4\pi\eta A}{\lambda^2}, \qquad (4.4\text{-}92a)$$

where

A = actual antenna area in the same units as ^{2}

η = efficiency of antenna aperture (usually taken as 0.55 or 0.56)

λ = wavelength at the operating frequency.

The antenna gain, G, in decibels is:

$$G = 10 \log g = 10 \text{ LOG } \frac{4\pi\eta A}{\lambda^2}. \qquad (4.4.92b)$$

4.4.48 Directivity and Radiation Patterns

4.4.48.1 The directivity, normally lobe pattern, is Also a measure of the antenna gain. An antenna may radiate in any direction, but it usually suffices to know the directivity in the horizontal and vertical planes which are the planes of the principal polarizations. The beamwidth of an antenna is defined from the main (largest) lobe of its radiation pattern which is usually plotted in the form shown in figure 4.4-46. The center of the graph represents the location of the antenna, and relative field strength is plotted along radial lines outward from the center. The line at 0° shows the direction of maximum radiation, while in this example at 30° from the maximum, the field strength e has declined to 0.707 of the maximum. The decibel ratio of this value to the maximum is:

$$20 \log \frac{e_{max}}{e} = 20 \quad \frac{1}{0.707} = 3 \qquad (4.4\text{-}93)$$

These “3-dB points” are considered to be a measure of the antenna directivity; for this example, the antenna has a beamwidth of

$e_u = 2 X 30^\circ = 60^\circ$.

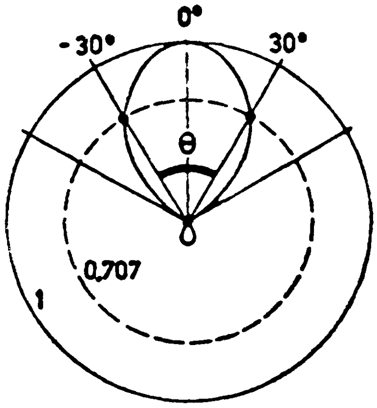


Figure 4.4-46. Example of antenna radiation pattern.

4.4.48.2 Such diagrams are frequently plotted directly in decibels rather than in terms of field strength or power. In radio-relay engineering it is customary to present the patterns in Cartesian coordinates (abscissa = angle, ordinate = gain).

4.4.49 Impedance Matching

4.4.49.1 Each antenna is connected to the transmitter or receiver via a transmission line or "feeder"; its input impedance establishes the load on the line as well as on the transmitter or receiver by the transfer characteristics of the line. To have the RF energy produced by the transmitter radiated with minimum loss or the energy picked up by the antenna passed to the receiver with minimum loss, the input impedance of the antenna must be matched to the characteristic impedance of the feeder, and the impedance of the feeder must also be matched to the impedance of the transmitter output or receiver input,

4.4.49.2 Mismatch gives rise to relected waves on the feeder line. They are characterized by alternating voltage maxima V_{max} and minima V_{min} at intervals of one quarter wavelength on the line. The voltage standing wave ratio $VSWR = V_{max} / V_{min}$ or the reflection coefficient magnitude, ρ, which is the ratio of the amplitude of the reflected wave to that of the incident wave are measures of the effectiveness of the power transfer. They are related by:

$$\rho = \frac{(VSWR) - I}{(VSWR) + 1} \qquad (4.4\text{-}94)$$

In the case of wideband FM radio-relay systems the maximum permissible reflection coefficient p ranges from 0.01 to 0.05; in the case of low capacity radio-relays it may range up to 0. 15 and for single -channel links up to 0.2.

4.4.49.3 Mismatch is also frequently expressed by return loss which is the decibel difference between the power incident upon a mismatch discontinuity and power reflected from the discontinuity. Both quantities have to be in the same units; i. e. dBW or dBm. The relation between return loss, RL, in dB and the reflection coefficient, ρ, is given by:

$$RL = 20 \log (1/\rho) \text{ dB.} \qquad (4.4\text{-}94a)$$

Related discussions will be found in eection 4.5.25.

4.4.50 Relative Bandwidth

4.4.50.1 Matching of the input impedance of the antenna to the characteristic impedance of the feeder is always possible for a certain fixed frequency. When, however, the antenna is to work over a wide frequency band or, without returning, within a relative large range of carrier frequencies, its electrical parameters must remain uniform within such ranges. The bandwidth of an antenna is the continuous frequency range over which the desired match is achieved, and ranges between 1.05 to 1.7 to 1 in the case of radio relays. The bandwidth and the desired VSWR (or match) are important specification parameters.

4.4.51 Front-to-back Ratio

4.4.51.1 Another measure of antenna performance is the ratio of power radiated from the maximum (front lobe) to that radiated from the back lobe of the antenna. This is illustrated in figure 4.4-46, where there is a small lobe extending from the back of the antenna. The ratio is expressed in dB. As an example, if an antenna radiates 10 times the signal power forward than back, its front-to-back ratio is 10 dB. Parabolic reflector antennas attain front-co-back ratios of 50 to 60 dB. The front-to-back ratio of the antennas is important because it is one factor which contributes to the susceptibility to and the likelihood of creating RF interference.

4.4.52 Reciprocity Principle

4.4.52.1 In free space, any two identical antennas may be used for transmitting or receiving interchangeably. In practice, this means that the gain and directivity of an antenna are the same whether it is used for transmitting or receiving.

4.4.53 Reflector-type Antennas

4.4.53.1 Antennas for application to transhorizon radio-relay systems require high gain and good directivity. The desired radiation patterns and other characteristics are obtained by using parabolic reflectors. The basic function of the reflector is to intercept energy radiated by the feed and reradiate it in the desired direction. In this process some of the energy is scattered in unwanted directions by irregularities in the reflector surface, lost by transmission through the surface, or diffracted around the edge of the reflector. Surface irregularities must be small in comparison with the wavelength in order to minimize such losses. In practice, they should be less than one-eighth of a wavelength (w8).

4.4.53.2 The gain of a parabolic antenna is given by substituting the cross-sectional area $\frac{D^2}{4}$ into (4.4-92a):

$$g = \frac{4\pi\eta A}{\lambda^2} = \eta\left(\frac{\pi D}{\lambda}\right)^2 \tag{4.4-95}$$

where

η = aperture efficiency (usually taken as 0. 55 or 0. 56),

A = true cross-sectional area $\pi\frac{D^2}{4}$.

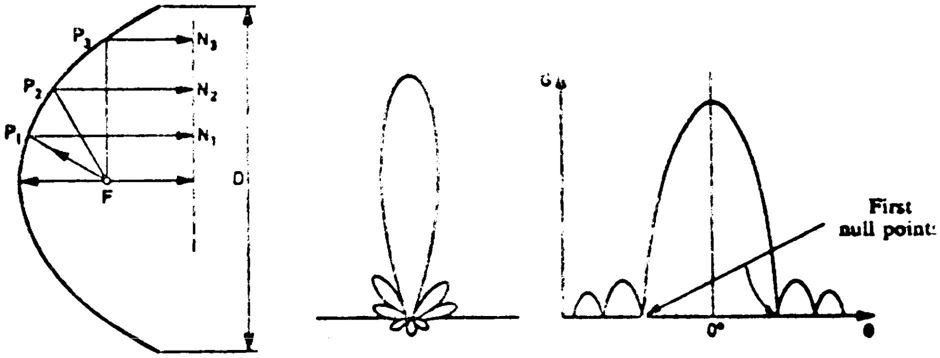
D = diameter, x = wavelength (in the same units).

A graph of representative parabolic antenna gains in dB above isotropic for various frequencies and diameters was shown in figure 4.2-4 (sec. 4.2. 11), and (4.4-95) expressed in dB was given as (4.4-75a) or (4.4-75b) in section 4.4.29 as a function of antenna diameter in meters or feet, and of frequency in MHz.

4.4.53.3 The operation of a parabolic reflector is illustrated in figure 4.4-47 where the feed point is located at the focus, F, of the parabola. Actually, the drawing represents a cross-section through a paraboloid of revolution about its axis. For large circular apertures (i. e., those whose diameter is large compared to the wavelength) with uniform illumination, the beamwidth between half-power (3 dB) point for n = 0.55 is given by [34; p. 12 12] :

$$\theta_u = 70/D_A \text{ degrees.} \tag{4.4-96}$$

From the information in [54] onemay estimate the ratio of the beamwidth width between first null points (see fig. 4. 4-47) and half- power beamwidth as approximately 2.4.



a) Ray paths

b) Directivity in polar co-ordinates

c) Directivity in rectangular co-ordinates

Figure 4.4-47. Direccivity of parabolic antennas.

4.4.53.4 Figure 4.4-48 is a graph of circular parabolic antenna beamwidth versus antenna gain based on the material in section 2.2 of [16]; it also corresponds closerLy to Jasik's resuits [34, p. 12 - 12]. because of power fading due to variations in vertical angle of arrival, antennas with vertical bearmwidth less than 0.5^0 should not be used unless some form of angle diversity as employde. In practice this means a maximum antenna diameter of apprximatlel 20 m (60 ft) for the 2000 MHz band . . . and 10 m (30 ft) for the 4500 .MHZ band. A useful relationship, also based on [16. sec,.2.2] for the antenna diameter D in meters corresponding to a half-power beamwidth O_u=0.50 is:

$$D = \frac{41,700}{f} \text{ meters} \qquad (4.4\text{-}97)$$

where f is the frequency in MHz.

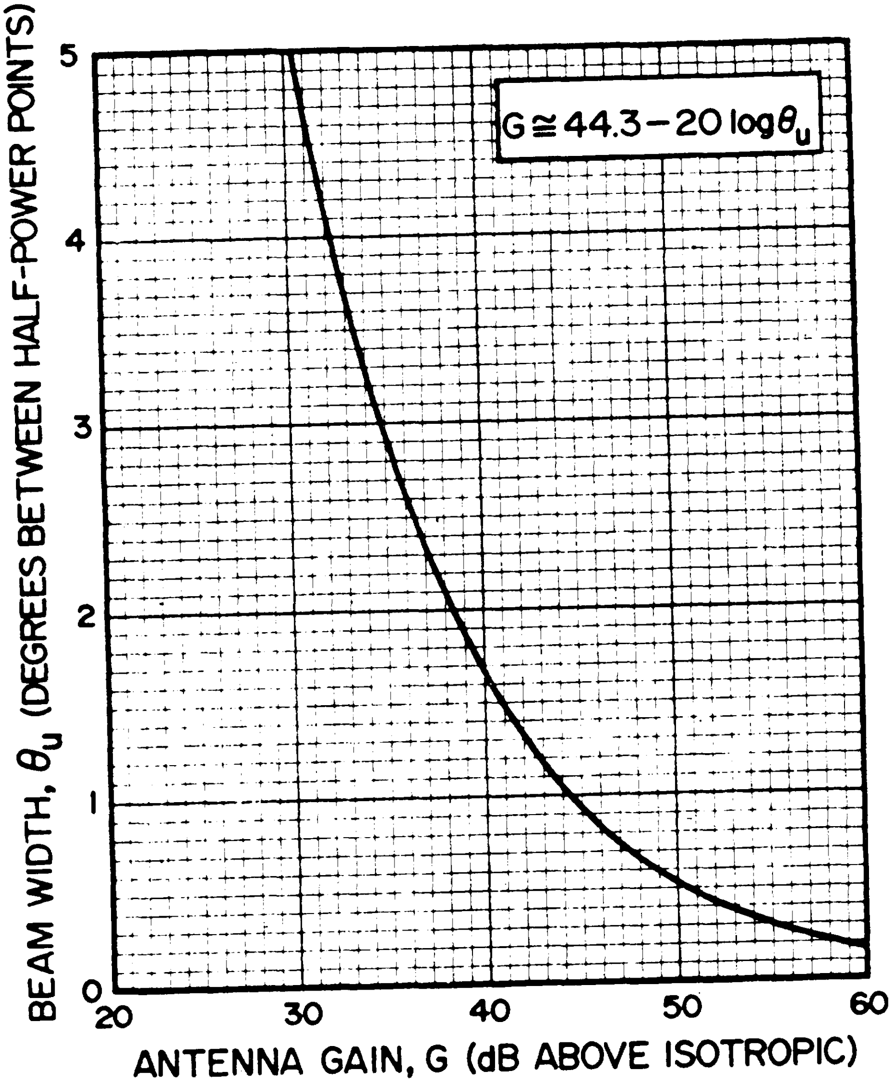
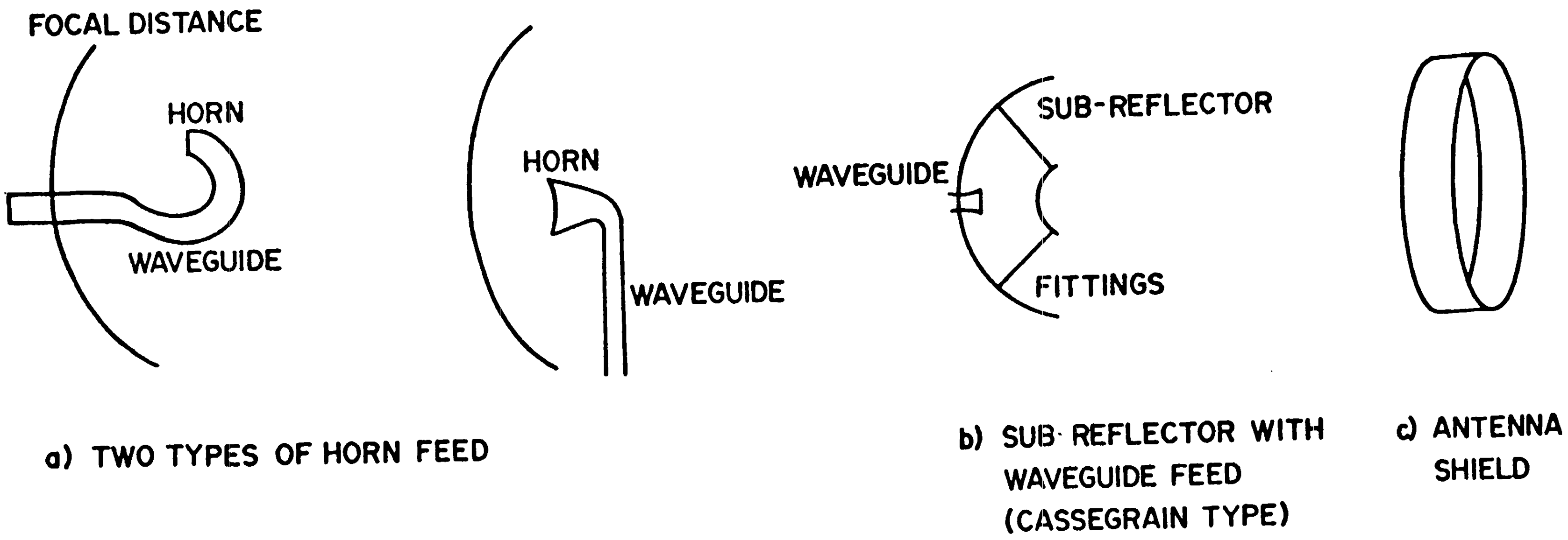


Figure 4.4-48 Nominal Antenna Beam Width as a FUnction of Gain

4.4.53.5 Because feed horn aperture blockage there is a minimum size of parabolic antenna normally manufacture at any given frequency. In practice, the paraboloid is never illuminated uniformly, but the illumination tapers off towards the outer edge, so that the overall gain is reduced. However, the taper also dereases the sidelobes, thereby improving the front-to-back-ratio arid cutting down on interference. Typically, a 10 dB taper of illumination is used, that is, the energy density at the edges of the refiector AS 10 dB less than the energy density at the center of the dish. This taper is effected by the pattern of the primary feed and is the reason that the aperture efficiency n is only 0.55. A recent development is the scalar feed which p educes a much more uniform illumination of the parabolic reflector while maintaining the energy density at the edge of; the reflector 10 dB below the center level. Using such iced arrangements the aperture efficiency is increased to O. 7 or 0.75 which also provides 1.3 db increased antenna gain. While this improve sounds small, there have been cases where an additional 3 dB of system gain (from transmit and receive antennas) has considerably improved link time availability and is equivalent to doubling transmitter power. Also, a 1.3 dB increase in antenna gain obtained with the scalar feed is equivalent to a 17% increase in reflector diameter with a conventional feed.

4.4.53.6 Dipole elements are sometimes used as feeds from about 300 MHz to approximately 3 GHz, with resuiting antenna gains of 30 dB and more but in all bands, waveguide horn feeds are more commonly used. Some of the mechanical structures are illustrated in figure 4-49. In a), two types of feed horns are shown, the “button-hook" feed and the front-feed type. These antennas provide only one polarization when a rectangular waveguide feeder is used, and both horizontal and vertical polarization with a square waveguide feeder. The "Cassegrain” type of antenna shown in b) uses a sub-reflector at the focal



a) TWO TYPES OF HORN FEED

b) SUB·REFLECTOR WITH WAVEGUIDE FEED (CASSEGRAIN TYPE)

c) ANTENNA SHIELD

Figure 4.4-49 Typical Parabolic Antenna Configurations point to illuminate the parabola The sub-relect is itself illuminated from the waveguide feed, which may be circular or square in cross-section, thereby allowing ire use of both polarizations simultaneously. This type of antenna is uses mainly in satellite radio-relay applications from 2 to 10 GHz, with gains equal to those of horn-fed types, but is seldom used on transhorizon radio links. The shield, or "blinder" shown in c) is used to suppress sidelobes in parabolic antennas of both horn-fed and Cassegrain types, thereby reducing interference and noise. The inside surface of the shield is often lined with absorbing material to prevent reflections. This technique has not been e employed on transhorizon antennas since the mechanical support problems with large antennas are already serious enough.

4.4.54 Antenna Characteristics for Special Demands of Frequency Planning

4.4.54.1 Depending on the frequency range, the kind of the channel-pattern application, and the equipment properties, an economic utilization of the frequency spectrum by a suitable selection of the radio-frequencies calls for certain antenna properties and hence also for certain types to keep within permissible limits the interference between the radio channels used in the same geographical zone. Co-channel operation, for instance, calls for a high front-to-back ratio of the antennas. adjacent channel operation at nodal points calls for sufficient sidelobe attenuation under acute angles and, when several antennas of the same type are applied at a given places care must be taken to prevent electrical interactions between the antennas in their near field.

4.4.55 Mechanical Stability of Antennas

4.4.55.1 In order to obtain the required communication system reliability, the structure supporting the antenna must have a long-term mechanical stability compatible with the beam characteristics of the antenna. The structures involved in maintaining this mechanical stability are the antenna mount and/or the tower. The strength and cost of mounts and towers needed for supplying the required resistance to deformation will depend upon the wind velocities and ice loading conditions characteristic to the area where the antennas are being installed. The requirement for vertical angular stability is somewhat more stringent than for horizontal stability since in addition to mechanical deformation the vertical angle of arrival is also a function of atmospheric stratification characteristics.

4.4.55.2 There are two possible types of unwanted mechanical displacements of the antennas, elastic displacements such as torsional vibration and sways and inelastic displacement due. to such causes as back lash in antenna mounts, chnges in guy wire stress, foundation settling or the bending of structural members. The limit of elastic change in horizontal antenna orientation for an antenna mounted at the top of a tower should be less than +0. 2 of a degree during 9970 of the time. The estimate of wind loading forces should be based on the time distribution of estimated wind velocities for the geographic area in which the antennas will be mounted, and the antenna aperture area. It is important that peak wind gusts be considered, rather than average wind velocities; also the wind velocities on high terrain or mountain peaks tend to be considerably higher than on adjacent lowlands, where climatological stations are most frequently located.

4.4.55.3 The limit of horizontal inelastic movement of the tower and the antenna mount should be such that the horizontal change of antenna orientation will not exceed + 0. 1 degree during its operational life. This amount of change in orientation may not be allowable from any but an electrical beamwidth point of view since other mechanical considerations may necessitate a tighter tolerance.

4.4.55.4 The tower and mound should stiff enough that wind and ice loading do not change the vertical orientation of an antenna at the top of the tower either elasticaliy more than ±0.1 degee for more than one percent of the time, or inelastically more than of 1 degree during the operational life of the tower.

4.4.55.5 Service-wide specifications should be consulted when designing towers until appropriate and current DOD approved specifications are writen. Then these DOD approved specifications must be referred to.

4.4.56 Passive Repeaters

4.4.56.1 This material on passive repeaters is largely taken from section 7 of the Propagation Appendix to section B. IV. 3 of the CCITT/ CCIR Handbook [54]. Other useful references are [34; sec. 13] and [20; p.25-40] See paragraph 4.4.25.16 for a discussion of long-term transmission loss variability over links employing passive repeaters.

4.4. 56.2 Passive repeaters may occasionally be employed for transhorizon links when it is not possible to find a favorable location for the terminal or relay station antenna. To be effective, they must generally be line-of-sight to the active radio sites which they are connecting. They will be discussed here because they often provide an alternative to using a transhorizon link.

4.4. 56.3 The same beam stability considerations that affect the use of an antenna should be taken into account when using a passive repeater. The vertical dimension of the passive repeater should not exceed the diameter of a parabolic reflector used at the applicable frequency. For large reflectors, the horizontal width of a reflector should generally be at least twice the vertical dimension because the stability of the beam is much greater in the horizontal plane than in the vertical plane since changes in atmospheric refractive index affect the vertical angle of arrival most strongly. An additional reason for this minimum ratio of dimensions is that the beamwidth varies as a function of the projected width of the reflector perpendicular to the path and not the actual width.

4.4.57 Gain and Radiation Pattern of Flat Reflectors

4.4.57.1 The gain of a flat reflector is [54]:

$$G = 10 \log \frac{4\pi A \cos}{\lambda^2} \qquad (4.4\text{-}98)$$

where A = true area of reflector in the same units as the squared wave - length A^2

x = incident angle of the reflected ray (measured from a line perpendicular to the reflector).

4.4.57.1 A flat reflector is more effective as a passive repeater than a parabolic antenna, since the effective area of ' The latter is less than its true area. Furthermore, pardbolic antennas are more expensive and difficult to build than flat reflectors.

4.4.57.2 The radiation pattern of a flat reflector in terms of relative field strength is given by [54}:

$$E = \frac{\sin[(\pi d/\lambda) \sin \phi]}{(\pi d/\lambda) \sin \phi} \qquad (4.4\text{-}99)$$

where E = secondary field produced by a uniform primary illumination, in the main plane, parallel to side d

ϕ = the angle between the incident or reflected ray and the direction of interest on the pattern

d = the projected side dimension of the reflector, in the plane of the pattern desired, in the same units as the wavelength λ.

4.4.57.3 It is important to emphasize that the beamwidth of the reflector in the vertical plane can become a limiting factor on the size of the reflector just as in the case of active antennas This happens when the beamwidth in the vertical plane is so small that changes in angle-of-arrival exceed some fraction of the beamwidth of the reflector. A further disadvantage of too narrow beams is the need to make the structure stiffer and to resist deflection under wind and ice loads. Flat sheet reflectors are not sensitive to polarization but wire grating reflectors are.

4.4.58 Conditions of Planarity for Reflectors

4.4.58.1 Irregularities in the reflection surface result in the energy being scattered or defocused with a consequent reduction a in gain given by :

$$\alpha = 20 \log \left| \cos \left(\frac{p}{\lambda} 360^\circ \right) \right| \text{ dB} \qquad (4.4\text{-}100)$$

Where p is the height of the irregularity in the same units as the wavelength . Normal tolerance holds p to less than $\lambda/8$.

4.4.59 Radio Path with Since Flat Reflector

4.4.59.1 An example of a path employing a single flat reflector is illustrated in figure 4.4-50. In such cases a transhorizon link is replaced by two line-of-sight links, and may therefore utilize higher frequencies.

Let $d_1 = 1.62$ km,

$d_2 = 33.0$ km,

$f = 11{,}000$ MHz ($\lambda = 0.02725$ m),

$\theta = 48°$.

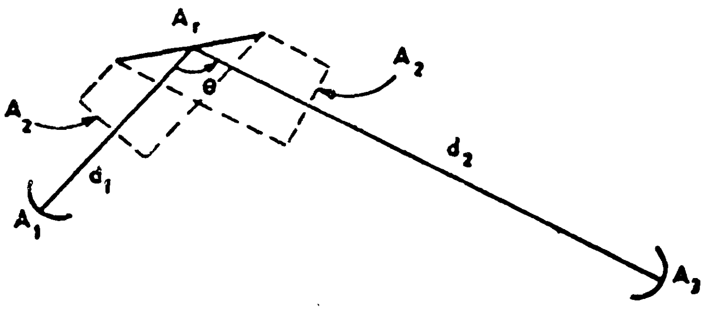


Figure 4.4-50. Path with one flat reflector.

The terminal antennas are 3-m paraboloids with 0.56 aperture efficiency, so that from the definitions following (4.4-95) their effective areas

$A_1 = A_3 = \frac{\eta \pi D^2}{4} = 3.96 m^2$. Let the dimensions of the flat reflectors be 6 x 3 m. From the geometry in figure 4.4-50 its effective area A_2 perpendiclar to the paths from A_1 Or A_3 is (6)(3) cos ($\theta/2$) = 16.5 m^2 for θ = 48°. The total loss L in dB is calculated as the sum of the dB loss for the individual paths d_1 and d_2 in figure 4.4-50 equivalent to-the calculation of free-space transmission loss:*

$$L = 10 \log \frac{\lambda^2 d_1^2}{A_1 A_2} + 10 \log \frac{\lambda^2 d_2^2}{A_2 A_3} \text{ dB} \qquad (404\text{-}101a)$$

$$= 10 \log \frac{(\lambda^2 d_1 d_2)^2}{A_1 A_2^2 A_3} \text{ dB.} \qquad (4.4\text{-}101b)$$

Since for this example $A_1 = A_3$, (4.4-10 lb) may be simplified to:

$$L = 20 \log \frac{\lambda^2 d_1 d_2}{A_1 A_2} \text{ dB.} \qquad (4.4\text{-}101C)$$

Substituting the numerical parameters, we obtain:

$$L = 20 \log \frac{(0.02725)^2 (1620)\ (33{,}000)}{(3.96)\ (16.5)} = 20 \log 608$$

$$= 55.7 \text{ dB.}$$

---

*Let, for the path d_1 (from A1 to A_2) the transmitted power be p_1 watts and the received power be p_2 watts. Then the basic transmission loss L is given by 10 log (P_1/p_2). But p_2 can be expressed by $\frac{p_1 G_1 A_2}{4\pi d_1^2}$ with $G_1 = \frac{4\pi A_1}{\lambda^2}$; thus $L = 10 \log \frac{\lambda^2 d_1^2}{A_1 A_2}$. The same reasoning applies to path d_2.

This value is obviously much less than a transhrizon transmission loss value directly between the terminals.

4.4.59.2 If we use the same example as above, but with the reflecfor at mid-path so that $d_1 = d_2 = 17.3$ km, the path loss will increase

by the ratio of $20 \log \left(\frac{17.3}{33.0} \cdot \frac{17.3}{1.62} \right) = 15$ dB. Hence, the size of the antenna or the reflector, or both must be increased to overcome the extra loss. Obviously, a reflector near one end of the path is much more efficient. When the loss in one of the paths is less than 6 dB, the reflector is likely to be in the near field of one antenna and the arrangement becomes a periscope antenna system, such as is frequently employed in line-of-sight links.

4.4.60 Two Flat Reflectors in One Path

4.4.60.1 Sometimes it may be advantage toto use two flat reflectors in one path, as shown in figure 4.4-51. In this case, where

and is:

$$L = 10 \log \frac{\left(\lambda^3 d_1 d_2 d_3\right)^2}{A_1 \left(A_2 A_3\right)^2 A_4} \text{ dB.} \qquad (4.4\text{-}102)$$

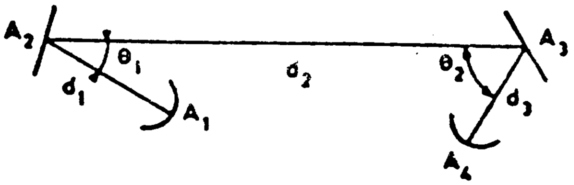


Figure 4.4-51. Two fiat reflectors in one path.

4.4.60.2 The double reflector system is used when the angle of transfer becomes less than about 40° since the longitudinal dimension of a single reflector would become excessive, The angles θ_1 and θ_2 should be kept as small as possible in order to reduce the loss.

4.4.60.3 Two flat reflectors can also be used to change the direction of a radio beam as illustrated in figure 4.4-52. The two reflectors are usually made equal in sizes so $A_2 = A_3$, and since in practice, A_1 is usually equal to A_4 the transmission, loss L for such an arrangement is given by:

$$L = 10 \log \left[\frac{(\lambda^2 d_1 d_2)^2}{A_1 A_2 A_3 A_4} \right] + L_r = 20 \log \left[\frac{\lambda^2 d_1 d_2}{A_1 A_2} \right] + L_r \text{ dB}, \quad (4.4\text{-}103)$$

where L_r = the loss caused by the distance d between the reflectors and will not exceed 3 dB if the reflectors are well into each others' near fields, i.e., $d_r < \frac{0.7A}{\lambda}$. This of system may be difficult to align.

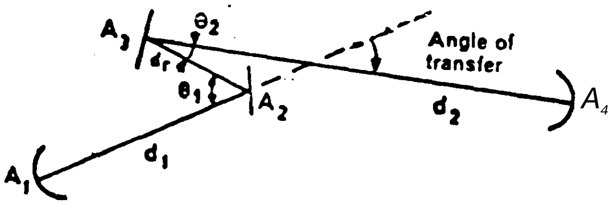


Figure 4.4-52. "Double" flat reflector geometry.

4.4.61 Parabolic Antennas Back-to-back

4.4.61.1 Instead of flat reflectors, it is possible to use parabolic antennas as passive repeaters back-to-back in a radio path with a waveguide or transmission line between them. Normal practice in such paths is to have $A_1 = A_4$ and $A_2 = A_3$, so that for the case illustrated in figure 4.4-53;

$$L = 10 \log \frac{(\lambda^2 d_1 d_2)^2}{A_1 A_2 A_3 A_4} = 20 \log \frac{\lambda^2 d_1 d_2}{A_1 A_2} \text{ dB.} \qquad (4.4\text{-}104)$$

The loss in the waveguide or transmission line between A_2 and A_3 must be added to the total path loss, This type of system has the advantage that correct initial pointing is easier and it also has less tendency to become misaligned than the double fkt reflector system. However, it is more expensive.

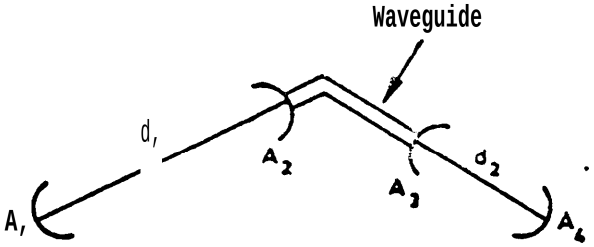


Figure 4.4-53. Parabolic antennas back-to-back.

4.4.62 Diffractors as Passive Repeaters

4.4.62.1 Performance on paths with a diffracting mountain obstacle can sometimes be improved by a diffraction grating or screen. Such a procedure is especially useful at higher frequencies (above 8 GHz) where large, truly flat refiecto:s are expesive and difficult to construct. The diffractor is a microwave version of the optical Fresnel lens, and there are two types -- the sc'reen type and the dielectric type. The screen type acts by blocking off those wave cnponents which would cancel the received field, while the dielectric type shifts their phase to add to the received field. Diffractors, as shown in figure 4.4-54, are placed or. the ridge forming the common horizon for a diffraction path, and may provide an effective gain over the natural obstacle [36].

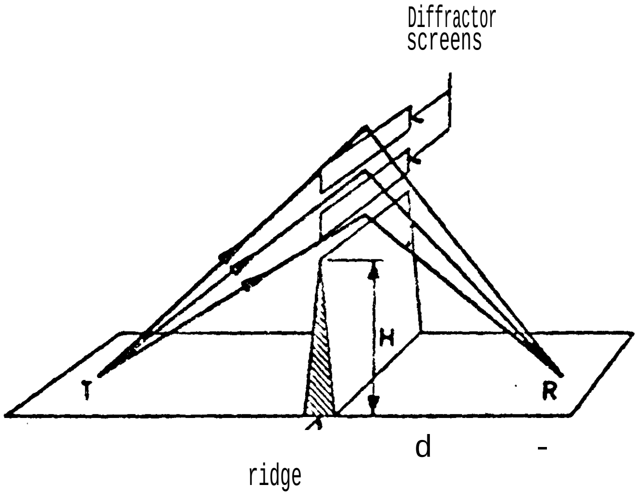


Figure 4.4-54. Microwave Diffractor.

4.4.62.2 The gains corresponding to aperture area associated with flat reflectors may be applied to the diffractor or lens type passive repeater.

4.4.63 R. F. Transmission Lines

4.4.63.1 There are two general classes of transmission lines which are used for transhorizon radio links, namely coaxial cable and waveguide. Other types such as two-wire lines and dielectric waveguide are never used. coaxial cable and waveguide will be discussed separately.

4.4.63.2 Pressurization of transmission lines is used except with solid or foam dielectric lines in order to keep moisture out of the line since water between the conductors and corrosion of the conductors will greatly increase line loss.

4.4.64 Coaxial Cable (see fig. 4.4-55)

4.4.64.1 As the s-ate-of-the-art of radio communication has advanced over the past several decades, numerous types of coaxial line have been developed to meet the requirements of system design.

The most important of these requirements for transhorizon radio links are minimum line loss, maximum power handling capacity, and ease of installation. The major types of interest are the air-dielectric rigid or flexible lines and solid-dielectric flexible lines. Due to the difficulty of installation, rigid lines which use dielectric beads to support the center conductor are seldom used except *near* 300 MHz when very high power is required.

4.4. 64.2 At moderate frequencies, say up to 1 or 2 GHz, flexible coaxial cables are used for both transmitter and receiver lines. The available separators for diameters of interest include a helical piss tic strip between inner and outer conductors, solid dielectric and foamed plastic dielectrics. These cables are easily installed in continuous runs from the RF equipment to the antennas and are available with factory-installed fittings. Field installation of fittings should be avoided where at all possible. Most field fittings are mechanical and electrical compromise solutions to a problem which is much more effectively handled in a factory where proper tools and materials and trained craftsmen are available.

4.4.64.3 Almost all flexible coaxial cables are covered with a thick sheath of tough plastic which is an important element in the mechanical structure of the line. This sheath may be removed from the line to provide an electrical ground connection but since this weakens the entire structure, it should be done only on straight sections. If this is done on bends, it may cause the line to kink where the sheath has been removed.

4.4. 64.4 Although coaxial lines are inherently broad-band devices, large diameter lines are unsuitable at high frequencies, since waveguide modes may be excited which extract power from and interfere with the desired mode. The frequency at which this becomes a problem corresponds to a wavelength in the coaxial line dielectric approximately equal to the average line circumference or

$$\lambda_c \approx 2\pi\left(\frac{r_o + r_i}{2}\right) \qquad (4.4\text{-}105)$$

where $_c$ is the wavelength in the medium of interest,
r_0 is the inside radius of the outer conductors and
r_1 is the outside radius of the inner conductor.

All in the same units.

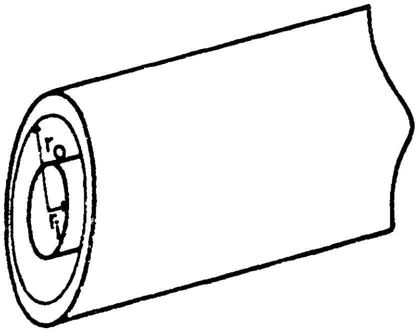


Figure 4.4-55. Coaxial cable.

If the line is operated somewhat below the frequency corresponding to this wavelength, the waveguide modes will be below cut-off frequent y and will not be propagated. Operation at or′ above this frequency can lead to serious problems with wave guide- type propagation in the lines

4.4.65 Waveguide

4.4.65.1 Waveguide transmission lines are commercially available in sizes suitable for frequencies from 300 MHz to 100 GHz. They are superior to coaxial cables in attenuation characteristics at all frequencies and will handle higher power levels. They are mechanically easier to fabricate and sturdier since no center conductor need be continuously supper ted. However, the requirement for precision fabrication may increase the cost over that of coaxia cable for the same service.

4.4.65.2 Several differently shaped cross sections are are availble in waveguide, with rectangular cross sections being the most common; other shapes are elliptical, circular, and square. Generally, square waveguide is used only on antenna feed horns where dual polarized operation is desired. Circular waveguide is not used for transhorizon systems.

4.4.63.3 The propagation of energy in a waveguide is different from a transverse electromagnetic wave which will propagate in free space or in a coaxial line. All waveguide modes exhibit a field component in the direction of propagation. If this component, in the direction of propagation is magnetic, the mode is called a TE (transverse electric) mode; if the component in the direction of propagation is electric the mode is called a TM (transverse magnetic) mode. The individual modes are identified by dual subscripts as, for example, a $TE_{2,1}$ mode.

4.4.65.4 In contrast to a coaxial line, which can be used for any frequency from dc to that where waveguide modes become possible, a waveguide has a low-frequency cutoff below which propagation will not occur in any mode. In a rectangular guide, the wavelength λ_c of the cut-off frequency is given by

$$\lambda_c = 2w \qquad (4.4\text{-}106)$$

where w is the inside width of the broad wall of the wave guide.

4.4.65.5 For waveguide of elliptical cross-sections the cut-off wavelength depends on the ratio of major-to-minor axes and can be obtained from manufacturers' data. For a typical ellipticity of 0.75, it can be said generally that it exceeds the cut-off wavelength of a rectangular waveguide circumscribing the ellipse.

4.4.65.6 At frequencies much above the fundamental cut-off frequency other waveguide modes will propagate. It is desirable to have only the fundamental mode present so there is a limited range of frequencies (usually specified by the manufacturer) over which a particular size of waveguide is used.

4.4.65.7 The return loss and VSWR of waveguide lines are strongly influenced by the regularity of the waveguide cross section. For this reason, great care must be taken to prevent deformation of the waveguide during installation or inspection. This is particularly important where long lengths of semi-flexible elliptical waveguides are used since just one kink or crush will ruin a long expensive piece of waveguide. For continuous-length waveguides, field fitted connectors should be avoided. It is very difficult to find field personnel who can consistently produce a mechanically and electrically adequate connector installation. If field-fitted connectors are used, great care must be taken and frequent inspections made by a qualified craftsman to insure an adequate job.

4.4. 65.8 In addition to long lengths of semi-flexible elliptical waveguide or 20 -foot lengths of rigid rectangular guide, other waveguide pieces are necessary. These include 45° and 90° bends in both polarization planes, 45° and 90° twists, short lengths of flexible twistable guide, and waveguide-to-coaxia!. adapters. other components made from rigid rectangular guide are available or can be made **up.** These components are necessary to complete a waveguide installation at the antenna and equipment connections.

4.4. 65.9 If an antenna is to be used for both horizontal and vertical polarization, two waveguide runs are necessary between antenna and equipment ‘f rectangular or elliptical waveguide is used. The signals are combined in a square waveguide polarization filter which is part of the antenna feed horn. The isolation between signals of orthogonal polarization in such a system should be 50 to 60 dB.

4.4.65.10 Figures 4.4-56, 4.4-57, and 4.4-58 now typical power capacity, attenuation, and range of single mode use of various coaxial and waveguide transmission lines.

4.4.66 Separating and Combing Elements

4.4.66.1 Since the four receivers and twc transmitters on a typical transhorizon radio link must use the four available antenna ports, some means are required to permit duplexing two receivers or duplexing a transmitter and a receiver on at least two antenna ports. The two most commonly used schemes for connecting the antennas to the equipment were shown earlier in figure 4.4-42 and 4.4-43. In figure 4.4-42, a duplexing filter is used to separate the two incoming signals which occupy the same waveguide. Since the filters handle only the low-level received signal energy, they need not be capable of passing large amounts of power. The diplexer often acts as the receiver preselector filter so it must be able to pass the desired frequency band and reject the receiver image signals at both carrier frequencies F_3 and F_4. Of particular concern is the filter rejection at the local transmit frequency.

4.4.66.2 Figure 4.4-43 shows an alternate configuration which uses a duplexer to separate a local transmitter signal from the incoming receiver signal. The duplexer is typically a three-port circulator where signals entering one port leave from the next one. This is shown schematically in figure 4.4-59. Such a configuration gives very good isolatic between transmitter and receiver but any transmitter signal reflected by discontinuities in the line or antenna feed will appear at port 3. Thus, the preselector filter must have very good rejection at the local transmitter frequency. Further, since the circulator must pass the high (1 to 10 kW) transmitter power, the forward loss must be very low (less than 0.1 dB) so the device will not overheat.

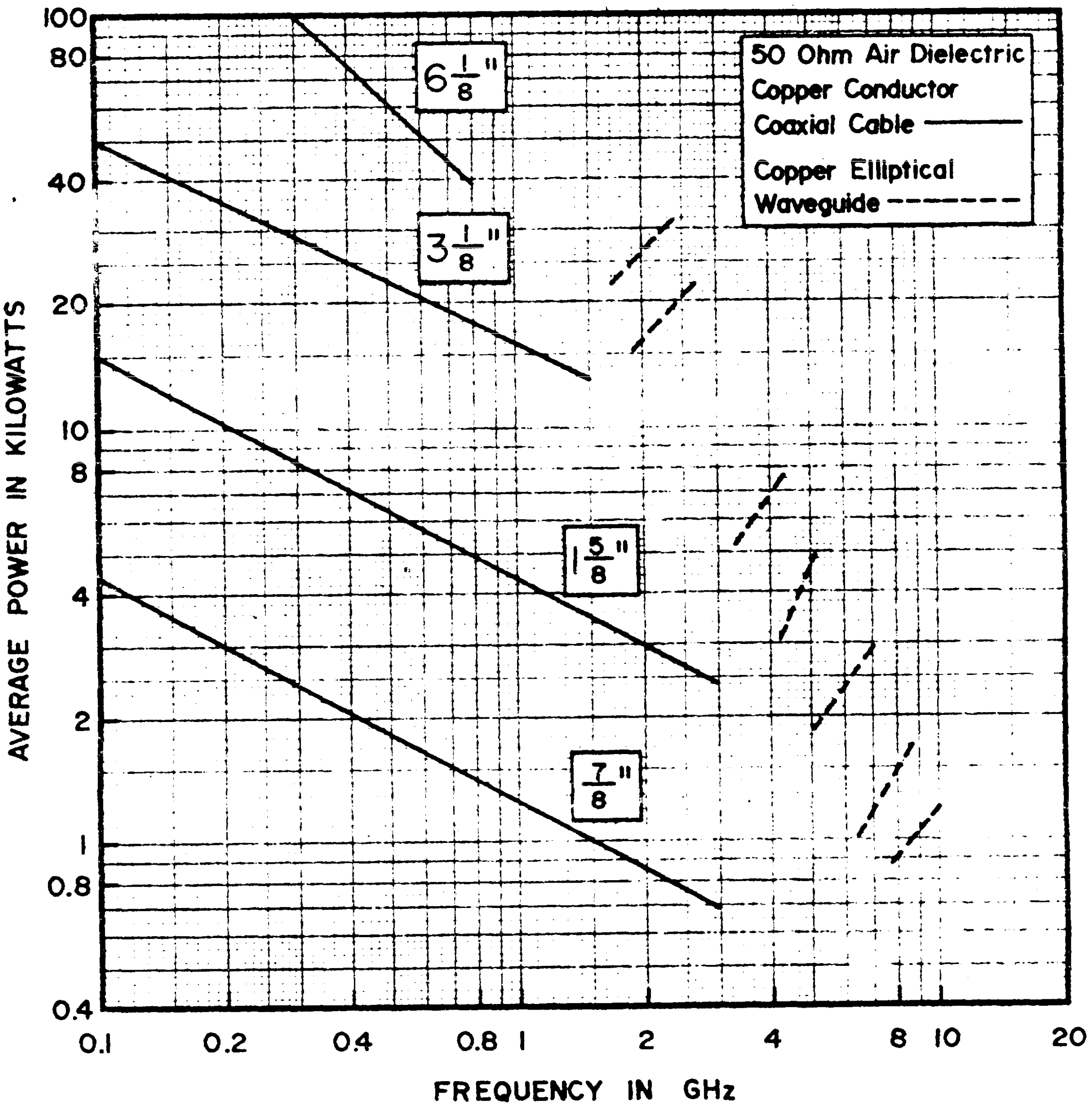


Figure 4.4-56 Transmission Line Average Power Capability

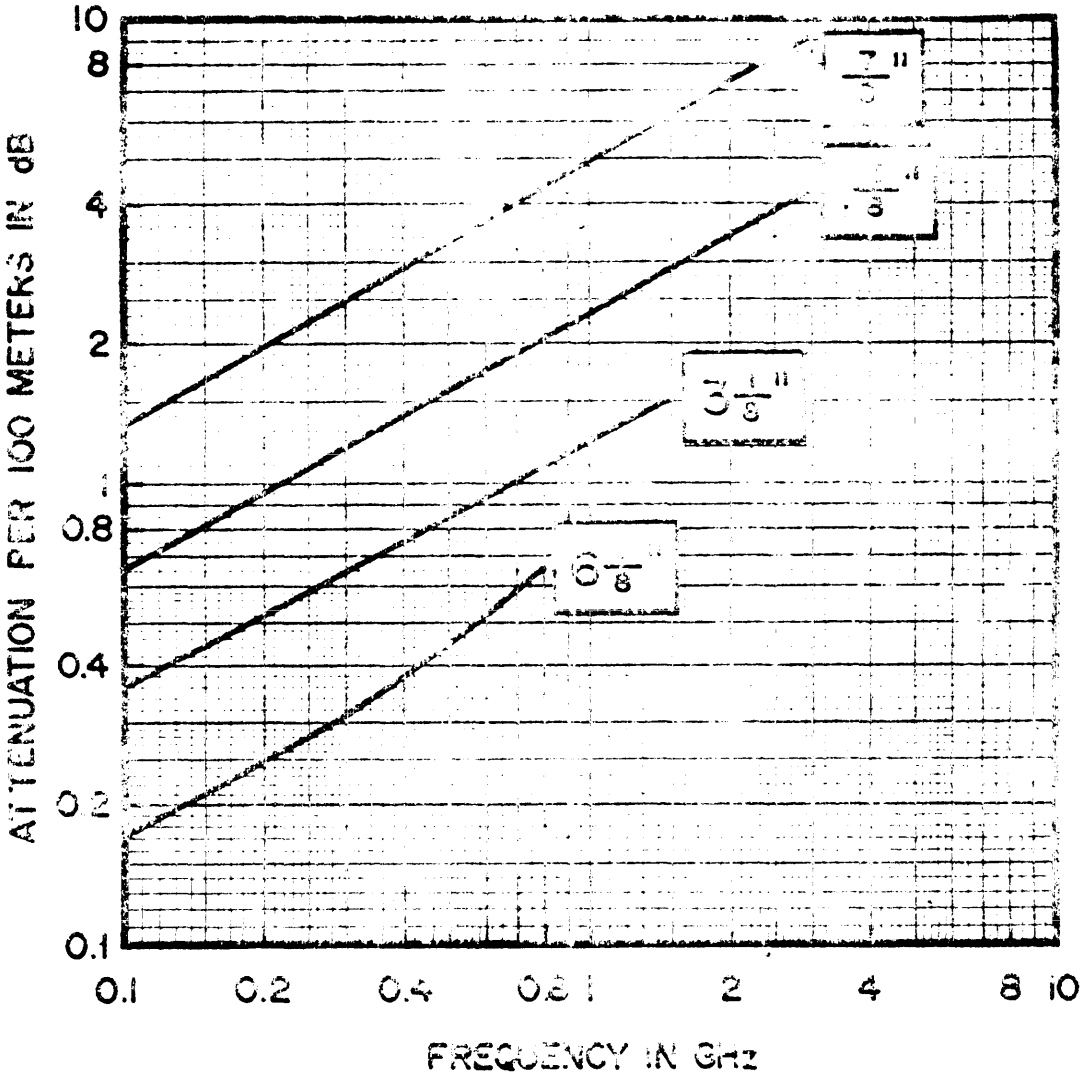


Figure 4.4-57 Attenuation in 50 Ohm, Air Dielectric, Rigid Copper Coaxial Transmission Line

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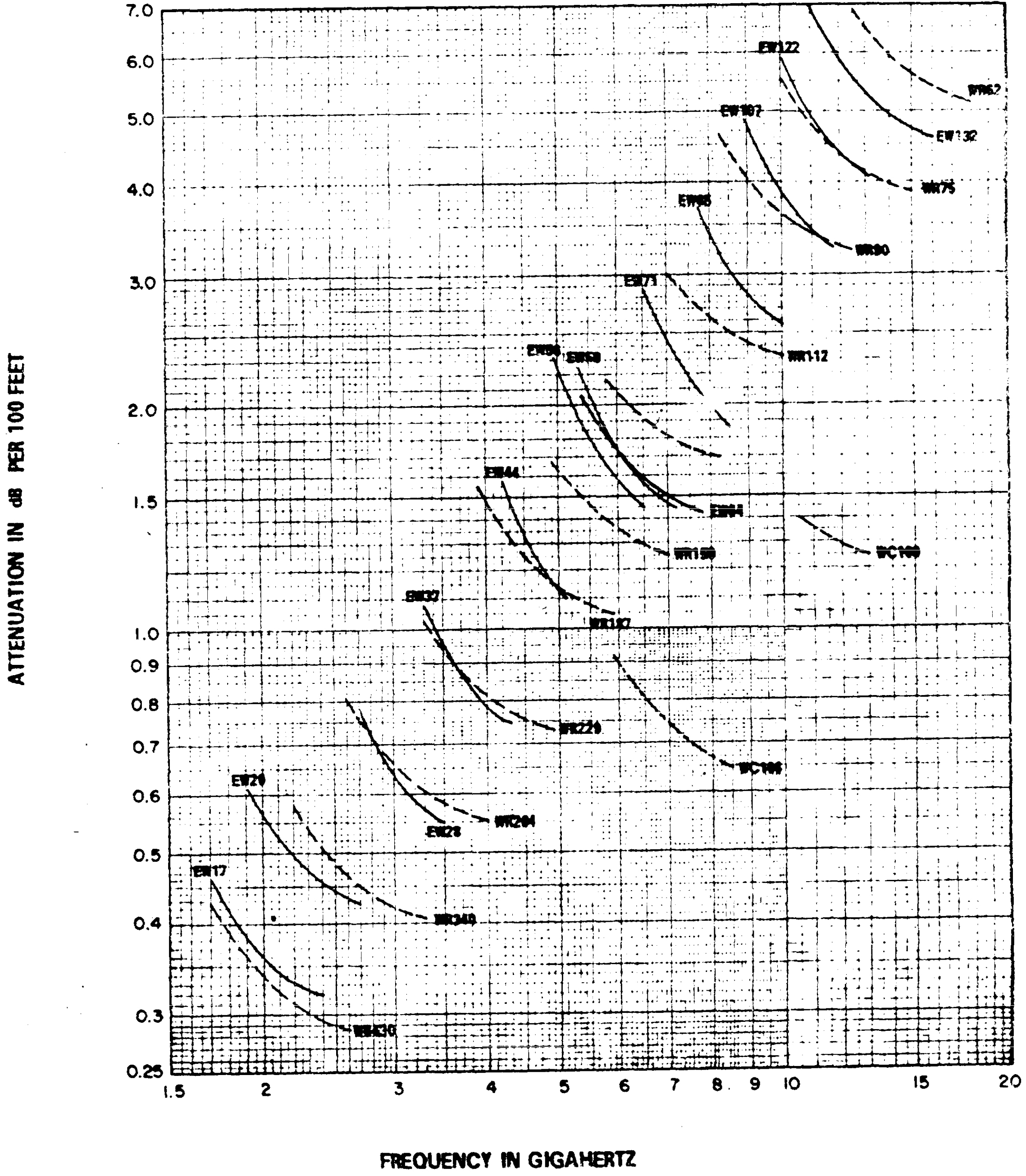
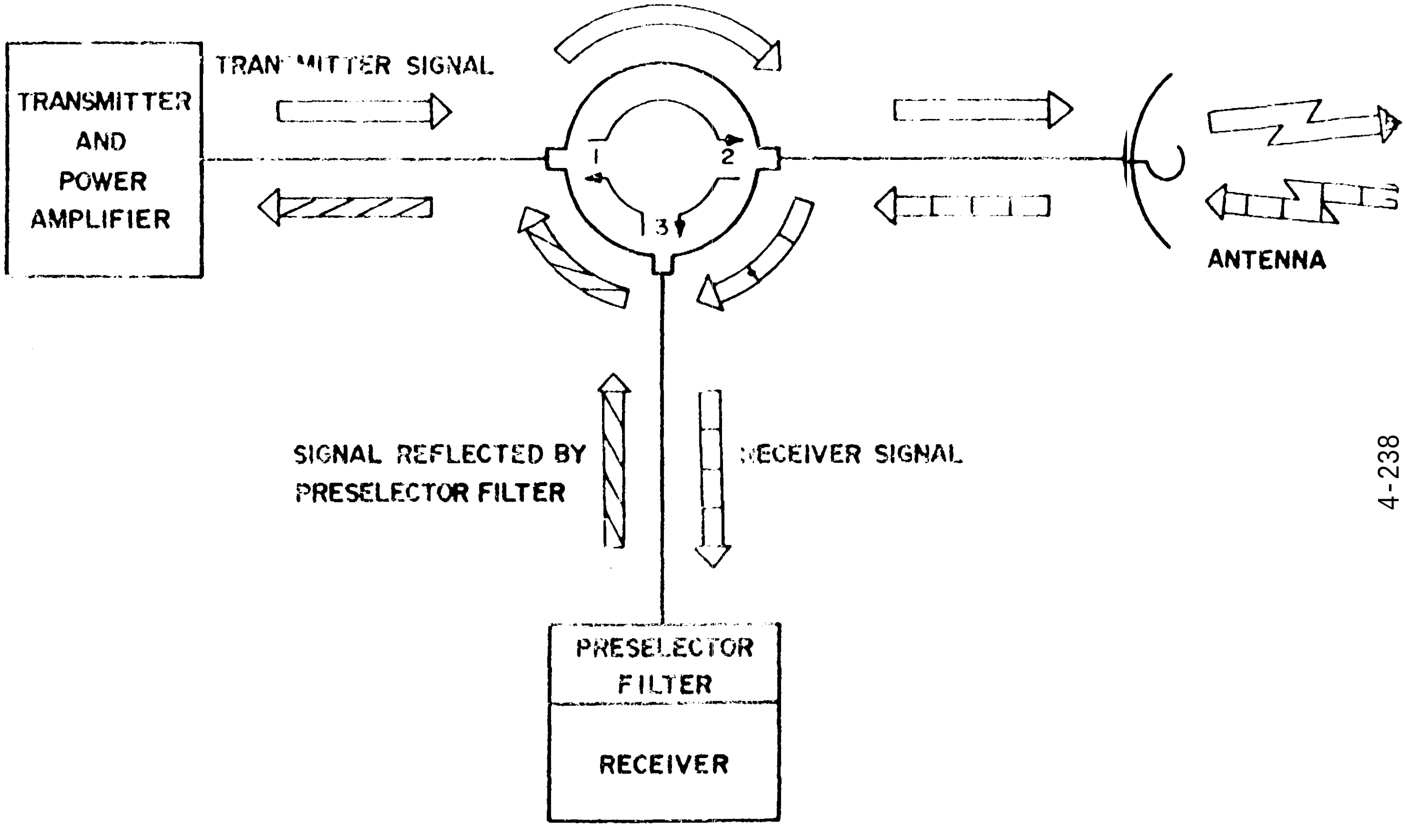


Attenuation curves based on:
VSWR 1.0
Ambient Temperature 24° C (75° F)

Conversion Data:
1 dB/100 feet = 3.28 dB/100 meters

Figure 4.4-58 Microwave Waveguide Attenuation



SIGNALS ENTERING PORT 1 ARE SENT OUT OF PORT 2;
SIGNALS ENTERING PORT 2 ARE SENT OUT OF PORT 3;

4.4.67 Transmitters

4.4.67. Figure 4.4-60 is a block diagram of a typical transmitter. The transmitter of a frequency modulation system normally comprises a baseband group, modulator oscillator, transmit mixer, and radio-frequency amplifier. In direct-modulation system the oscilltor which operates the radio-frequency is directly modulated in frequency, and the transmit mixer is omitted. The baseband group includes a pilot-oscillator and pilot tone detector for - alarm functions, preemphasis networks, and an insertion amplifier.

4.4.68 Modulation

4.4.68.1 The design and efficiency of radio -relay equipment is determined chiefly by the type of modulation. Essentially, two types are used; namely frequency modulation (FM) and pulsee code~ modulation (PCM). Of these, frequency modulation is most widely used; in broad-band systems it is the only type used at present. The following considerations therefore apply to frequency modulation systems.

4.4.68.2 The production of microwave frequencies with high accuracy and stability is possible with crystal oscillators and subsequent multiplication or with free-running oscillators (e. g. , klystrons, and solid-state arrangements). However, free -running oscillators must have auxiliary frequency stabilization to compensate for varia - tions in the ambient temperature and in the supply voltages. As reference for this automatic frequency control either a well designed temperature compensated resonator is used or a harmonic of a crystal-controlled lower frequency oscillator.

4.4. 68.3 When the microwave frequency is produced by multiplying a crystal-controlled oscillation, harmonic mode crystals (mostly around 100 MHz) are used in most cases in order to reduce the number of the multiplier stages. Multiplication formerly was achieved

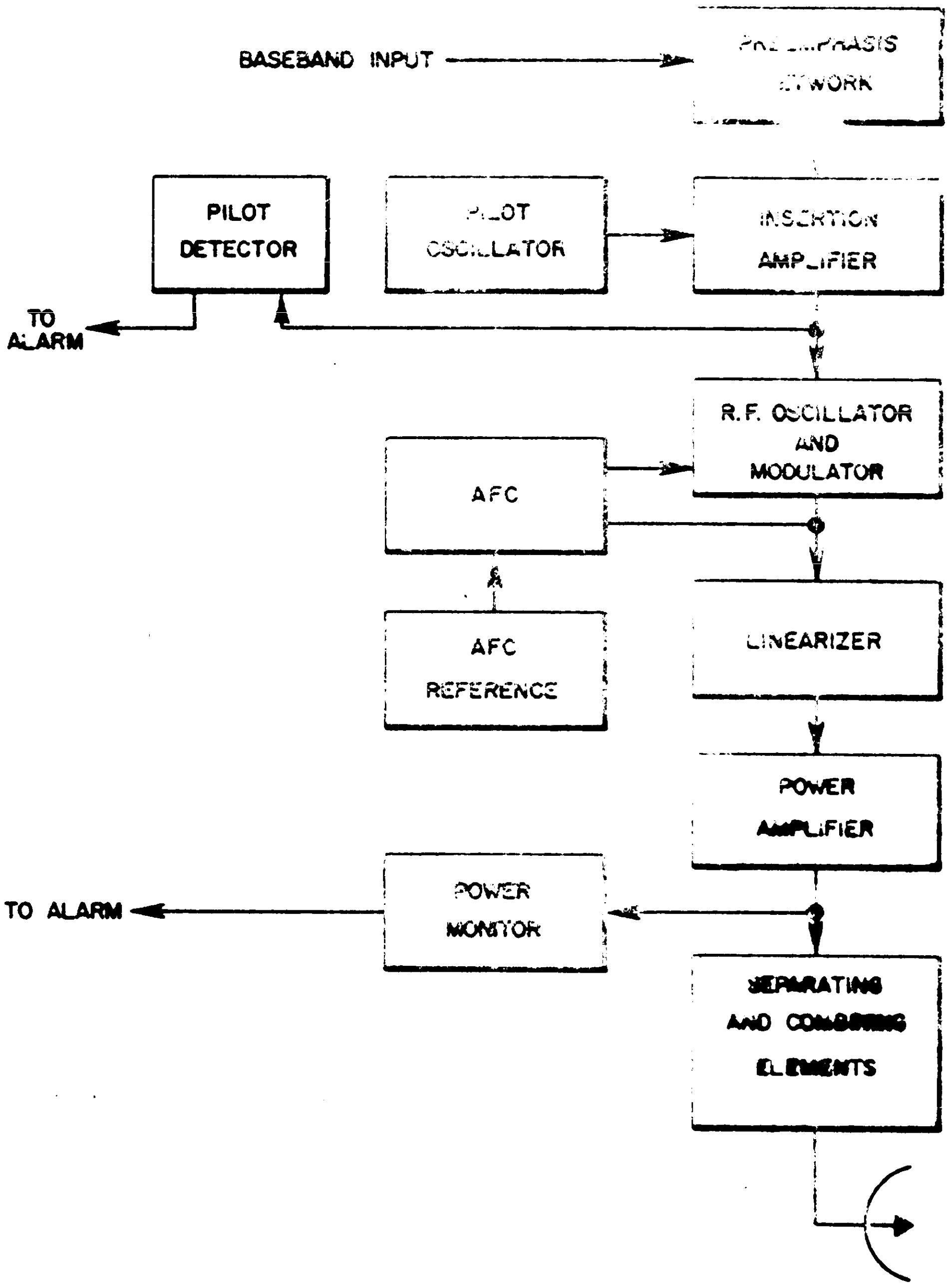


Figure 4.4-60 Block Diagram of Typical Micrewave Transmitter

exclusively by means of vacuum tubes, but today semi-conductors (variable capacitance diodes, or step-recovery diodes) are utilized. Not only the desired frequency, but also other harmonics of the fundamental frequent y appear (at the multiplier output), and these must be supprcssed by filters. Moreover, the noise problem needs particular consideration in this case since noise close to the carrier as generated will he expanded in bandwidth as the carrier is multiplied.

4.4. 68.4 The transmit power required for transhorizon systems ranges from 10 W to 100 kW, depending on the frequency and on path requirements. The power may be produced by dlystrons, or up to 100 W, by traveling-wave tubes. The power stage must be followed by an output filter to suppress harmonics and spurious radiations (by approximately 60 dB).

4.4. 68.5 The power amplifier can be changed without changing the basic design of the transmitter. Commercially available solid-state power amplifiers can produce only a few watts output. Large power amplifiers are one of the weakest links in the reliability chain because the y require hot-filament devices. Interlocking safety systems are required to protect both equipment and personnel from exposure to high voltages.

4.4. 68.6 A large variety of arrangements of components and types of components exist and others are being developed. The transmitter will probably be selected under one equipment specification stipulating such overall quality considerations as carrier frequency stability, levels, group delay, linearity, modulator linear deviation range, output carrier-to-noise ratio, and minimum noise power ratio. But for large transmitters, safety and reliability should be given special consideration.

4.4.69 Receivers

4.4.69. 1 As in the case of transmitters a large variety of component arrangements and type may be used in a commeriucal receiver and many others are being developed .4 block diagram of a typical microwave receiver is shown. in figare 4.4-61. Through not shown in the block diagram of the receiver, sensing and alarm fmctions are integral to all point -to- point commuticatioos systms.

4.4.69.2 A frequency modulation receiver which, in general, Operates on the superheterodyr. e princilpe consists essentially of a radio-frequency input filter, mixer, oscilator intermediate-frequency amplifier, limiter, discrminator and ‘baseband group

4. 4.69.3 The radio-frequency input filter serves to suppress unwanted frequencies outside the band to received particularly image frequencies), and at the same time prevents! unwanted apuriousi emissions of the oscillator frequency and of mixing products.

4.4. 69.4 In the mixer which is mostly made up of semi- conductor diodes, the arriving radio -frequenc’y signal must be translatred into the intermediate-frequency band with as little noise as possible being produced. For currently used diodes, receiver noise figures of 3 to 9 dB at 1 GHz and 10 dB at 7 GHz can be obtained. Lower noise figures (higher sensitivity) are achievable 'witkA tunneldiode ampifiers or parametric amplified,

4.469. 5 The principles applicable to the transmitting oscillators apply equally to the generation of the receiver local oscillator frequency.

4. 69.6 The intermediate-frequency amplifier must have a gain

7

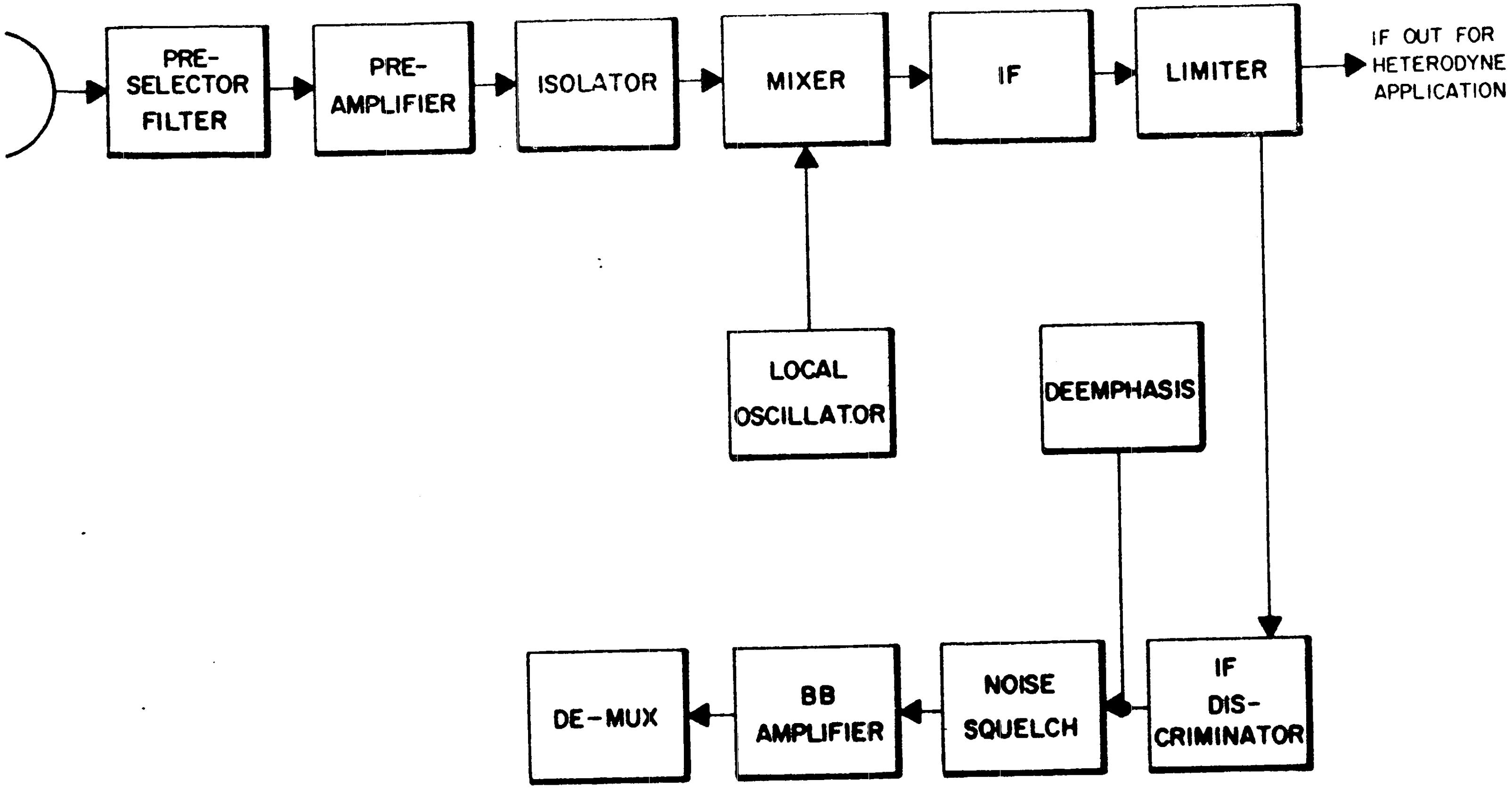


Figure 4.4-61 Block Diagram of Typical Microwave Receiver

systems, appropriate measures must be taken to provide amplitude and delay equalization.

4.4.69.7 In the subsequent limiter, the synchronous amplitude-modulation superposed on the frequency-modulation signal must be eliminated as far as possible.

4.4.69.8 The discriminator which demodulates the intermediate-frequency signal must meet high requirements with respect to freedom from distortion, especially in broadband transmission.

4.4.69.9 The receiver baseband group includes a pilot detector, noise limiting circuitry) a baseband amplifier, filters, and demultiplexing equipment.

4.4.69.10 In operation, a signal from the antenna passes through a waveguide preselector that provides a high IF image rejection ratio and eliminates interference from adjacent RF channels, and enters a waveguide filter tuned to its frequency. The filter bandpass is designed to reject unwanted signals. The signal passes through a ferrite isolator which reduces intermoduiation noise. The incoming signal is then mixed with the local oscillator output to produce the standard 70 MHz IF frequency [4]. The IF output is amplitude-limited. Output from the limiter is applied to a signal (IF) discriminator, a de-emphasis circuit and a noise-muting or squelch circuit that disconnects the baseband amplifier and demultiplexing equipment if system noise increases above a pre-set level. After the squelch circuit, the signal is passed to the baseband amplifier and then to the demultiplexing equipment where the original intelligence is retrieved.

4.4.69.11 Some of the overall equipment specification on a receiver which determine its quality are noise figure, local oscillator frequency stability, discriminator linear range, group delay linearity, amplitude linearity, and the minimum achievable noise power ratio. A preamplifier may be added or removed without changing the basic design of the receiver. If a suitable low-noise preamplifier can be placed at the antenna end of a required long transmission line or waveguide the line loss is eliminated in determining the carrier-to-noise ratio. In this manner additional receiver sensitivity can also be gained. Low-noise microwave preamplifiers most often use tuvvell diodes. These amplifiers become nonlinear at received carrier levels of -50 to -40 dBm. For this reason and their temperature characteristics, the following precautions should be taken when using tunnel diode amplifiers:

a) A preselector filter should be placed between the antenna terminal and the preamplifier input. The system must be designed to avoid abnormally high-wanted signal levels since this degrades amplifier performance.

b) Since the gain characteristics of tunnel diode preamplifiers are usually affected by temperature and they are often mounted external to the equipment shelter, a small compartment capable of protecting the amplifier from weather and having reliable thermostatic temperature control should be supplied. The input to the preamplifier is the location most susceptible to interference. Figure 4.4-62 shows noise figures for currently available preamplifiers as a function of carrier frequency.

4.4.70 Active Repeaters

4.4.70.1 An active repeater must be able to perform at least three essential functions; (1), it must provide gain (up to approximately 110 dB as required); (2), it can change the direction of the route; and (3), it must be able to change the carrier frequency slightly to minimize intrasystem interference. There are basically two types of active repeaters, the demodulating type and the non-demodulating type.

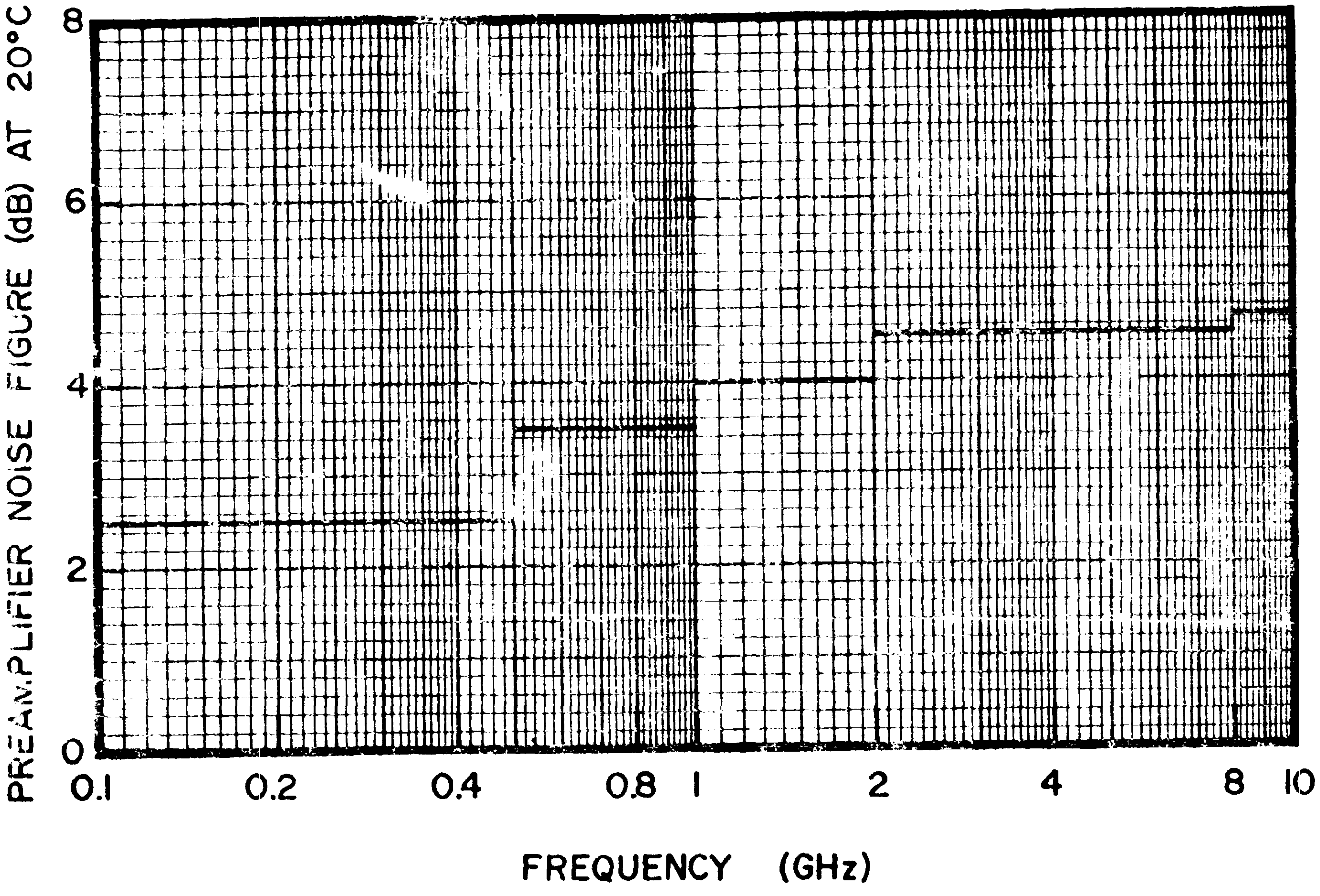


Figure 4.4-62 Nominal Noise Figures for Solid State Receiver Preamplifiers Commercially Available

4.4.70.2 For an FDM/FM system, a typical demodulating type is shown in figure 4.4-63. The advantages of the demodulating type are mainly flexibility and (at the time of this writing) price. The whole baseband is available allowing channels to be dropped or inserted in an efficient manner. The equipment price advantage occurs as a result of the manner in which gain is achieved; usually most of the repeater gain is obtained at the intermediate frequency and in the modulation - demodulation process. The disadvantages of the demodulating repeater are:

a) For FDM-FM systems it introduces more noise per hop than a non-demodulating repeater. However, this is not true when pulse code modulation (PCM) is used and the pulses are regenerated at each repeater site.

b) Baseband levels tend to be less stable because level variations occur primarily in the modulation and demodulation processes. These variations tend to be cumulative in the system.

c) The maintenance of modulator and demodulator linearity is critical for holding intermodulation noise to a minimum. Thus the costs of maintaining alignment are often larger for the demodulating repeater than for the non-demodulating type.

4.4.70.3 There are basically two types of non-demodulating repeaters - RF and IF types. The RF heterodyne obtain of its gain by using RF amplifiers. Obtaining gain in this manner is expensive and for this reason RF heterodyne repeaters are seldom used. The IF radio repeater is the most common heterodyne type. A block diagram of this type repeater appears in figure 4.4-64. It obtains its gain at the intermediate frequency which can be done cheaply and reliably with transistor amplifiers.

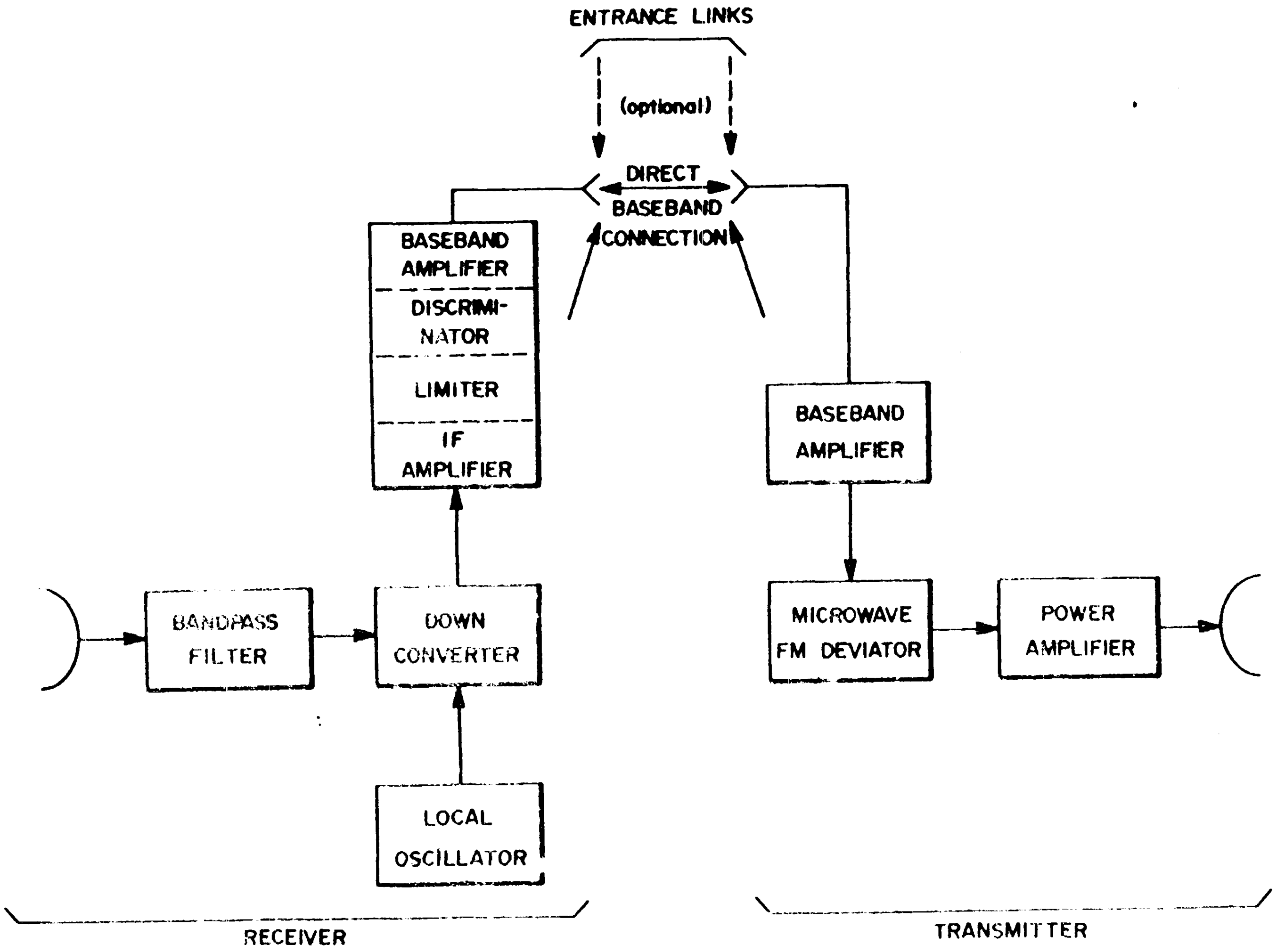


Figure 4.4-63 Block Diagram of Typical Demodulating Repeater for FDM/FM System

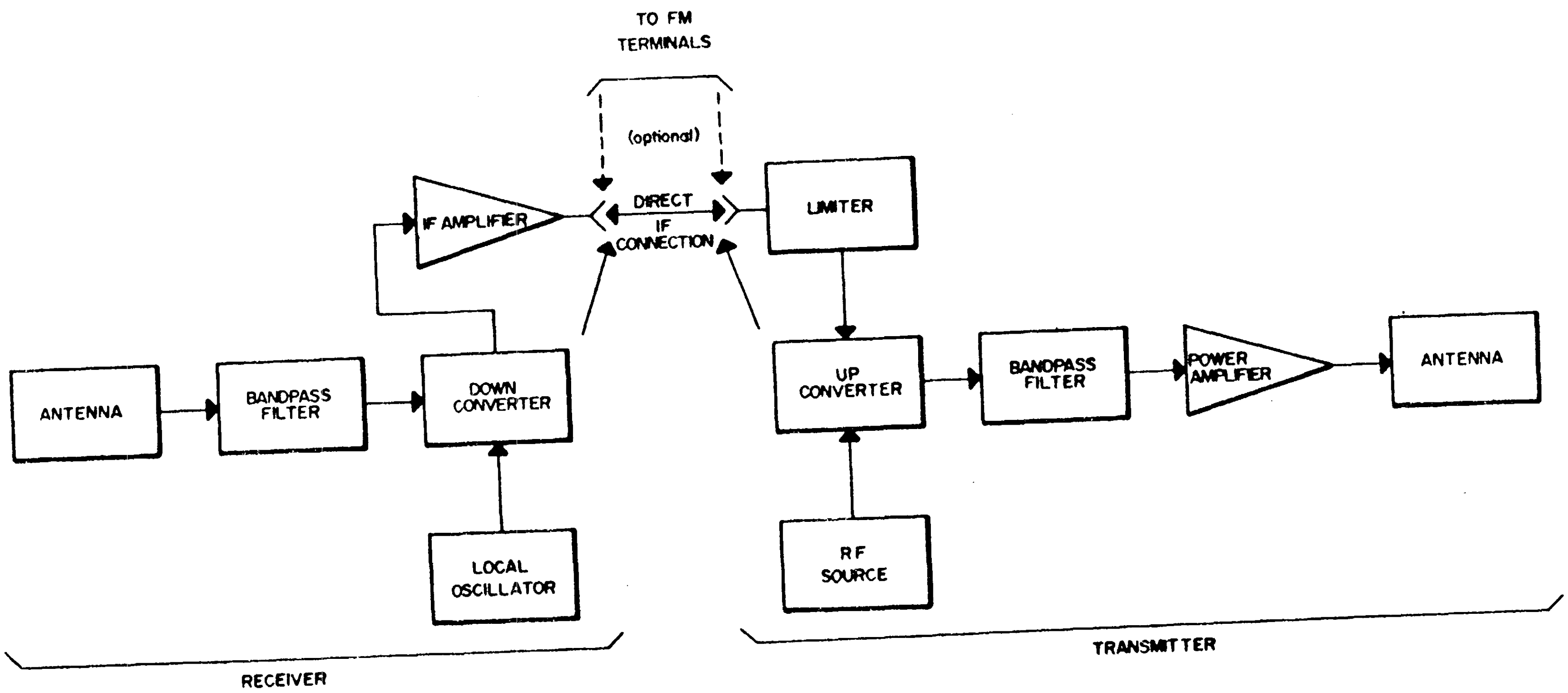


Figure 4.4-64 Intermediate-frequency Radio Repeater

4.4.70.4 The choice between through-connection at baseband frequencies or at intermediate-frequencies at repeators is determined by technical and economical considerations as well as by the traffic demands. Systems with direct radio-frequency modulation of the transmitter (and hence through-connection at repeater stations at baseband frequencies) are used primarily for transmitting smaller numbers of channels and for broadband links spanning minor distances. Direct modulation systems are particularly suited for networks with frequent drop-off and insertion of telephone channels.

4.4.70.5 In systems using modulation at intermediate-frequencies, the baseband signal is converted into a frequency modulation standardized intermediate-frequency signal in the modulator. In the radio-frequency equipment this modulated intermediate-frequency is converted into the final radio-frequency signal, and raised to the required level. At repeater stations, through-connection can be made in the intermediate-frequency band. Since, in this method, no modulators are used at repeater stations and the system is free from the noise these modulators would have contributed, it is used largely for broadband systems which must span thousands of kilometers.

STEP-BY-STEP PROCEDURES (A) FOR GREAT CIRCLE CALCULATIONS (Sec. 4.4.9)

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
1	Obtain coordinates of path terminals.	--	--	Round to nearest second of arc. Designate terminal with greater latitude as "B".	Latitude and longitude of A and B.
2	Plot terminals on index map of topographic quadrangles.	--	4.4-6		
3	Draw straight line between terminals.	--	4.4-6		
4	List latitudes or longitudes of intersecting map edges or other reference lines.	--	4.4-6	See text for explanation.	$\phi_{B'}$; longitudes will be used to determine values of C'.
5	Determine difference in longitude of terminals.	--	--		C.
6	Calculate initial bearings.	4.4-14a, 4.4-14b, 4.4-15	--	Function of latitudes ϕ_A, ϕ_B, and longitude difference C.	X, Y in degrees.
7	Calculate path distance in terms of angle Z.	4.4-16	--		Z in degrees.
8	Determine path distance d.	4.4-19a	--	Subsequent procedures require d in kilometers.	d in kilometers.

STEP	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
9 or	Calculate intermediate latitude values $\phi_{B'}$ for given latitude differences, C'.	4.4-17a, 4.4-17b	--	See step 4; use if path is essentially east-west.	$\phi_{B'}$ in degrees.
9a	Calculate intermediate longitude differences, C', for given latitude values.	4.4-18a, 4.4-18b	--	See step 4; use if path is essentially north-south.	C' in degrees.
10	Plot intermediate points on topographic quadrangles and connect with straight lines.	--	--	Ready for reading terrain elevations along path (see sec. 4.4.10.	

STEP-BY-STEP PROCEDURES (B) TO DETERMINE ATMOSPHERIC AND TERRAIN PARAMETERS (Sec. 4.4.3, 4.4.4, and 4.4.7)

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
1	Estimate $\overline{N}_o$ from map.	--	4.4-2	For long paths, separate values may apply to each terminal.	$\overline{N}_o$
2	Tabulate horizon elevations and antenna site elevations as defined in section 4.4.17.1	--	--	From surveys and terrain profiles plotted on special graph paper (see section 4.4.11.1).	h_{L1}, h_{L2}, e_{s1}, e_{s2}
3	Is e_{s1} more than 0.15 km lower than h_{L1}?	--	--	If yes, use e_{s1} in step 5 instead of h_{L1}.	
4	Is e_{s2} more than 0.15 km lower than h_{L2}?	--	--	If yes, use e_{s2} in step 5 instead of h_{L2}.	
5	Determine $\overline{N}_{s1,2}$ using appropriate value of $e_{s1,2}$ or $h_{L1,2}$ for h_s.	4.4-3d	--	h_{L1}, h_{L2}, or e_{s1}, e_{s2} must be in km.	$\overline{N}_{s1}$, $\overline{N}_{s2}$
6	Take average of $\overline{N}_{s1}$ and $\overline{N}_{s2}$.	--	--	$\overline{N}_s = (\overline{N}_{s1} + \overline{N}_{s2})/2$	$\overline{N}_s$
7	Determine effective earth radius, a.	4.4-4	4.4-3	Use of graph usually adequate.	a is in km.

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
8	Determine median Atmospheric absorption, A_a.	--	4.4-4	Function of total path distance and frequency. Visual interpretation of graph usually adequate.	A_a in dB.
9	If path is over water or smooth ground, go to step 15.				
10	Determine horizon distances	--	--	From terrain profiles.	d_{L1}, d_{L2} in km.
11	Ascertain heights of antenna centers above ground level.	--	--	From preliminary design plan, section 4.2.4.5.	h_{g1}, h_{g2} in km.
12	Determine antenna heights above mean sea level.	4.4-25a, 4.4-25b	--	All elevations must be in km.	h_{s1}, h_{s2} in km.
13	Calculate horizon elevation angles.	4.4-6a 4.4-6b	--	All elevations and heights must be in km. If there are several possible horizons, select <u>largest</u> θ_{e1} and θ_{e2}.	θ_{e1}, θ_{e2} in radians.
14	Go to step . 1				

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
15	For smooth earth, determine reference surface.	--	--	Sea level elevation or elevation of smooth surface.	
16	Determine antenna heights (center of antenna above reference surface).	--	--	From profile information use h_{s1}, h_{s2} if reference is at sea level, or h_{g1}, h_{g2}.	h_{s1}, h_{s2} or h_{g1}, h_{g2} in km.
17	Calculate horizon elevation angles.	4.4-8	--		θ_{e1}, θ_{e2} in radians.
18	Calculate horizon distances.	4.4-7	--		d_{L1}, d_{L2} in km.
19	Calculate distance between radio horizons.	4.4-9a	--	d is the total path distance in km. 4.4-9a also holds for irregular terrain.	D_s in km.
20	Approximate angular distance, θ.	4.4-9b	--	Use 4.4-9b only for smooth earth.	θ in radians.
21	Calculate angles α_o and β_o.	4.4-10a 4.4-10b	--	Use $\theta_{e1,2}$, from step 13 or step 17; for smooth terrain (steps 15-20), $h_{s1,2} \equiv h_{g1,2}$.	α_o, β_o in radians.

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
22	Determine θ	4.4-11	--	$\theta = \alpha_o + \beta_o$ (this constitutes a check for smooth earth step 20).	θ in radians
[illegible]	Determine s.	4.4-13	--	$s = \alpha_o/\beta_o$ if $\alpha_o \leq \beta_o$; otherwise $s = \beta_o/\alpha_o$ (dimensionless ratio).	
24	Determine h_o.	4.4-12	--	Only necessary for scatter loss.	h_o in km

STEP-BY-STEP PROCEDURES (C) FOR TRANSMISSION LOSS CALCULATIONS
(Sec. 4.4.13 to 4.4.25)

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
1	Assemble terrain and atmospheric parameters, path profiles, and other requirements.	--	--	From 4.4.3, 4.4.4, and 4.4.7, using also previous procedure sheets.	Parameters including d and A_a.
2	Determine nominal carrier frequency for path loss calculations.	--	--	Mid-band is normally adequate for this purpose (may have to be redetermined as a result of frequency optimization studies - see section 4.4.30).	f in MHz.
3	Determine free-space loss, L_{bf}	4.4-26	4.2-2		L_{bf} in dB.
4	Estimate effective antenna heights.	--	--	See discussion in 4.4.17.1 (m)	h_{e1}, h_{e2}.
5	Calculate the product, θd	--	--	θ in radians, d in kilometers.	θd
6	Inspect terrain profile to determine path type.	--	--	If single horizon, continue. If two horizons, apply criteria in Table 4.4-1 regarding necessity for considering two-horizon diffraction loss. If two-horizon diffraction can be neglected, go to step 66, if not, to step 41.	

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
	SINGLE OBSTACLE DIFFRACTION				
7	Calculate diffraction parameter, v.	4.4-28	--	All distances in km, frequency in MHz, θ in radians.	v
8	Can rounding of the obstacle be estimated and does the obstacle appear to be isolated?	--	--	From path profile or other available terrain information.	Case (a) No Case (b) Yes
9	If Case (a), determine $A(v,\rho)$.	--	4.4-11	Use empirical curve.	$A(v, \rho)$ in dB; go to step 22.
10	If Case (b), determine $A(v,0)$.	4.4-29	4.4-11	Use (4.4-29) for $v \geq 3$.	$A(v,0)$ in dB.
11	Estimate D_s in km.	--	--	From path profile and more detailed terrain information. Note that for diffraction calculations, D_s is the width of the diffracting obstacle (see section 4.4.17.1 (j)).	D_s in km.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
12	If $D_s \leq 0.01$ km, assume that knife-edge is ideal and isolated; determine A(v,0) from step 10 and go to step 22.	--	--	In this case, $A(v,\rho) = A(v,0)$	
13	If $D_s \geq 0.01$, determine r.	4.4-30	--	D_s is in km and θ is in radians.	r
14	Calculate $k = 2\pi/\lambda$.	4.4-27a (for λ)	--	λ must be in km.	
15	Determine if obstacle is isolated by criterion (4.4-31)	4.4-31	--		
16	If $kh[2/(kr)]^{1/3} >> 1$, go to step 18.	4.4-31	--	See discussion in section 4.4.20.5	
17	If not, estimate $A(v,\rho)$ from figure 4.4-11 for use in step 38. Alternatively, two-horizon diffraction methods may be used (section 4.4.22; steps 41 or 53).	--	4.4-11	Use empirical curve.	$A(v,\rho)$ in dB; go to step 22
18	Calculate $v\rho$.	4.4-32	--	f is in MHz, r is in km, θ is in radians.	$v\rho$

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
19	Divide $v\rho$ by v.	--	--	See discussion in section 4.4.20.	ρ
20	Read $A(0,\rho)$ and $U(v\rho)$	--	4.4-13	Alternately: read $A(v,\rho)$ directly from figure 4.4-12	$A(0,\rho)$, $U(v\rho)$ in dB.
21	Determine $A(v,\rho)$ for use in step 38.	4.4-33	--	For ideal knife-edge, $A(v,\rho) = A(v,0)$.	$A(v,\rho)$ in dB.
22	Test for necessity to use $G(\bar{h}_{1,2})$:	--	--	See discussion in section 4.4.20.2	
23	Determine $\sqrt{\lambda d_{L1,2}}$	--	--	λ, $d_{L1,2}$, $h_{L1,2}$, $h_{s1,2}$ in km.	
24	Determine $\lvert h_{L1,2} - h_{s1,2} \rvert$				
25	If $\sqrt{\lambda d_{L1,2}} \leq \lvert h_{L1,2} - h_{s1,2} \rvert$, then $G(\bar{h}_{1,2}) = 0$.	--	--	Skip calculations of $G(\bar{h}_{1,2})$ and go to step 38	$G(\bar{h}_{1,2}) = 0$.
26	If not, continue and calculate first $a_{1,2}$.	4.4-34	--	$d_{L1,2}$ and $h_{e1,2}$ in km.	a_1 and a_2 in km.
27	For vertical polarization over sea water, go to step 31.	--	--		

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
28	In all other cases, calculate $\bar{h}_{1,2}$ from (4.4-35)	4.4-35	--	$a_{1,2}$ and $h_{e1,2}$ in km, f in MHz.	h_1, h_2.
29	Read $G(\bar{h}_{1,2})$.	--	4.4-14	Use curve for $k \leq 0.001$.	$G(h_1)$, $G(h_2)$ dB.
30	Go to step 38	--	--		
31	Read K_o (for a=8500 km).	--	4.4-15	Function of frequency, polarization, & ground constant.	K_o
32	Read b.	--	4.4-16	Function of frequency, polarization, & ground constant.	b in degrees
33	Determine $C_{o1,2}$.	4.4-36	--	$a_{1,2}$ in km.	C_{o1}, C_{o2}.
34	Determine $K_{1,2}$.	4.4-37	--	K_o from figure 4.4-15	K_1, K_2.
35	Read B(k, b).	--	4.4-17	Use $K_{1,2}$ from step 34.	B(K, b) for a_1 and a_2
36	Determine $\bar{h}_{1,2}$.	4.4-38	--	a_1, a_2, h_{e1}, h_{e2} in km.	$\bar{h}_1$, $\bar{h}_2$.
37	Read $G(\bar{h}_{1,2})$.	--	4.4-14	Use curve for applicable K and b; interpolate visually as required.	$G(\bar{h}_1)$, $G(\bar{h}_2)$ in dB.

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
38	Determine total diffraction loss, A_k.	4.4-27	--	For ideal knife edge, use $A(v, 0)$ from step 10 instead of $A(v, \rho)$.	A_k in dB.
39	Calculate product θd	--	--		
40	Go to step 66 for determination of scatter loss	--	--	See section 4.4.24 on criteria for combining diffraction and scatter losses.	
TWO-HORIZON DIFFRACTION					
41	For smooth earth, continue; for irregular terrain, go to step 53.	--	--	See discussion in section 4.4.21	d_{L1}, d_{L2}.
42	Determine smooth-earth radio horizons.	4.4-7	--	See also discussion in section 4.4.21.2. a is a function of $\bar{N}_s$ (see figure 4.4-3).	
43	Read K_o.	--	4.4-15	Function of frequency, polarization, and ground constants.	K_o.
44	Read b.	--	4.4-16	Function of frequency, polarization, and ground constants.	b in degrees.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
45	Determine $C_o = \left(\frac{8500}{a}\right)^{1/3}$	4.4-36	--	Use a as a function of N_s (Figure 4.4-3).	C_o
46	Determine $K = C_o K_o$.	4.4-42	--		K(a)
47	Determine B_o.	4.4-41	--	f in MHz.	B_o
48	Calculate x_0, x_1, and x_2.	4.4-40	--	d, d_{L1}, and d_{L2} in km.	x_0, x_1, x_2
49	Determine $G(x_0)$, $F(x_1)$, $F(x_2)$.	4.4-43	4.4-19	Functions of K and b; interpolate between curves where required.	$G(x_0)$, $F(x_1)$, $F(x_2)$ in dB.
50	Determine $C_1(K,b)$.	--	4.4-18	Function of K and b.	$C_1(K, b)$ in dB
51	Determine A_{rd}.	4.4-39	--		A_{rd} in dB.
52	Go to step 66 for determination of scatter loss.				
53	Determine distances d_3 and d_4.	4.4-45a 4.4-45b	4.4-20	d, d_3, d_4 in km ; α_o, β_o, θ in radians. If $d_3 \cong d_4$, procedure can be simplified as indicated in paragraph 4.4.22.5.	d_3, d_4 in km.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
54	Check D_s	4.4-45c	--	Should agree with D_s from (4.4-9a)	D_s in km.
55	Calculate effective earth radii a_1, a_2, a_3, a_4.	4.4-46 4.4-47	--	All distances and heights in km; all angles in radians	a_1, a_2, a_3, a_4 in km.
56	Determine C_{o1}, C_{o2}, C_{o3}, C_{o4}.	4.4-36	--	$C_{o1,2,3,4} = (8500/a_{1,2,3,4})^{1/3}$	C_{o1}, C_{o2}, C_{o3}, C_{o4}.
57	Read K_o.	--	4.4-15	Function of frequency, polarization, and ground constants (see 4.4.20.10).	K_o.
58	Read b.	--	4.4-16	Function of frequency, polarization, and ground constants. (see 4.4.20.10).	b in degrees
59	Determine $K_{1,2,3,4}$	4.4-42	--		K_1, K_2, K_3, K_4.
60	Read B_1, B_2, B_3, B_4.	--	4.4-17	Read as a function of corresponding K and b.	B_1, B_2, B_3, B_4.
61	Calculate x_1 and x_2.	4.4-49	--	d_{L1} and d_{L2} in km, f in MHz.	x_1, x_2.
62	Calculate x_0.	4.4-50	--	d_3 and d_4 in km, f in MHz.	x_0.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
63	Read $C_1(K_1, b)$ and $C_1(K_2, b)$.	--	4.4-18	Function of appropriate K and b.	$C_1(K_1, b)$, $C_1(K_2, b)$ in dB.
64	Calculate $\overline{C}(K_{1,2})$.	4.4-51	--	Weighted average of $C_1(K_1, b)$ and $C_1(K_2, b)$.	$C_1(K_{1,2})$ in dB.
65	Calculate diffraction attenuation, A_{id}.	4.4-48	--		A_{id} in dB.
TROPOSPHERIC SCATTER CALCULATIONS					
66	Determine $F(\theta d)$.	4.4-61	4.4-21	Function of θd (step 40) and $\overline{N}_s$. Use (4.4-61) for $\theta d < 1$	$F(\theta d)$ in dB.
67	Calculate $r_{1,2}$.	4.4-62	--	Effective antenna heights h_{e1}, h_{e2} and wave length λ in same units.	r_1 r_2.
68	If $r_{1,2} \geq 20$, set $H_o=0$, and go to step 72; if $r_{1,2} \leq 20$, continue.	--	--		
69	Read η_s from figure 4.4-22.	--	4.4-22	Function of h_o from (4.4-12) and $\overline{N}_s$.	η_s

STEP NO.	ACTION	SEE Equation No.	SEE Figure No.	COMMENTS	RESULTS
70	Determine H_o	4.4-63	4.4-23	Function of r_1, r_2, and η_s. See section 4.4.23.5 for averaging and interpolation rules.	H_o in dB.
71	Calculate scatter basic transmission loss L_{bsr}	4.4-60	--	Frequency in MHz, path distance, d, in km.	L_{bsr} in dB.
72	Calculate scatter loss, A_s.	4.4-59	--	Use L_{bf} from step 3.	A_s in dB.
73	Compare A_s with $A_{diffr} \equiv A_k$, A_{rd}, or A_{id}.	--	4.4-10	See discussion in section 4.4.24.	
74	If $\|A_s - A_{diffr}\| > 15$ dB, identify smaller of the two as A_{cr}, and go to step 79.	--	--	See discussion in section 4.4.24.	
75	If $\|A_s - A_{diffr}\| \leq 15$ dB, calculate $A_{diffr} - A_s$.	--	--	See discussion in section 4.4.24	
76	Read R(0.5).	--	4.4-24		R(0.5) in dB.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
77	Calculate A_{ds}	4.4-64	--		
78	Determine A_{cr}	--	--	See 4.4.24.4.	A_{cr} in dB.
79	Calculate L_{bcr} (reference value)	4.4-24b	--	$L_{bcr} = L_{bf} + A_{cr} + A_a$	L_{bcr} in dB.
	TIME VARIABILITY ESTIMATES				
80	Calculate d_{s1}	4.4-68	--	f in MHz	d_{s1} in km.
81	Calculate d_{Lo}.	4.4-69	--	h_{e1} and h_{e2} are the effective antenna heights in km. (step 4).	d_{Lo}.
82	Calculate d_e.	4.4-70	--.	Use criteria in section 4.4.25.6.	d_e in km.
83	Read V(0.5).	--	4.4-25	Function of climate type; see Table 4.4-2 and discussions in 4 4.25.8 and 4.4.25.9.	V(0.5) in dB.
84	Read $Y_o(q)$.	--	4.4-26 to 4.4-32	Desired range of q is normally $0.0001 \leq q \leq 0.9999$.	$Y_o(q)$ in dB.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
85	Determine correction factor g(q,f), where applicable.	--	4.4-33	See discussion in section 4.4.25.10	g(q,f)
86	Determine Y(0.1,f) and Y(0.9,f).	4.4-71	--	Only required when $g(q,f) \neq 1$.	Y(0.1) and Y(0.9) in dB.
87	Determine Y(q) for desired range of q (usually $0.0001 \leq q \leq 0.9999$).	--	4.4-26 to 4.4-34	Read directly from figures, or use c-factors in Figure 4.4-35 (see discussion and table in section 4.4.25.11).	Y(q) in dB.
88	Obtain $L_b(q)$ for same range of q.	4.4-65a	--	Plot distribution on suitable graph paper.	$L_b(q)$ in dB.

STEP-BY-STEP PROCEDURES (D) FOR DETERMINATION OF PATH ANTENNA GAIN AND FOR FREQUENCY OPTIMIZATION

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
1	Select potentially usable antenna sizes; see discussion in sections 4.4.45 to 4.4.55 for maximum usable sizes.	--	--	Nominal dimensions usually in feet (diameter of parabolic reflector.	D in feet or meters.
2	Calculate free-space gains G_1 and G_2 as a function of frequency.	4.4-75a 4.4-75b	--	For antenna diameter in feet use 4.4-75b; for antenna diameter in meters use 4.4-75a.	G_1, G_2 in dB.
3	If $(G_1 + G_2) < 40$ dB, or if path is knife-edge or smooth earth diffraction, $G_p = G_1 + G_2$; go to step 5.				
4	If $(G_1 + G_2) \geq 40$ dB, calculate L_{gp}, or read from figure 4.2-3.	4.4-77b	4.2-3		L_{pg} in dB.
5	Calculate G_p.	4.4-76	--		G_p in dB.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
6	Repeat steps 2 to 5 for various potentially available frequency bands as required	--	--	Useful nominal frequencies for considerations are something like 500, 700, 1000, 2000, 5000 MHz if available for use.	
	Make table of G_p versus f	--	--		G_p in dB versus f in MHz.
8	Determine receiver noise figure for the available frequency bands.	--	--	From manufacturers' specifications.	F in dB.
9	Make table of F versus f.	--	--		
10	Determine total line and circulator losses for the available frequency bands.	--	--	From manufacturers' specifications and estimates of required waveguide lengths.	L_ℓ in dB.
11	Make table of L_ℓ versus f.	--	--		
12	Select required predetection noise bandwidth, b, in Hz.	--	--	From 4.2.16 (initial estimates), or from discussion in 4.4.28.4.	b in Hz.

STEP NO.	ACTION	SEE		COMMENTS	RESULTS
		Equation No.	Figure No.		
13	Determine B in dB (B = 10 log b).	--	--		B in dB.
14	Determine and tabulate M_o as a function of frequency.	4.4-79	--	L_{bcr} is from step 79 of Procedure C.	M_o in dB.
15	Select carrier-to-noise ratio, R_r, in dB.	--	--	From 4.2.19 (initial estimates), or discussion in 4.5.20.10 (as a function of receiver characteristics, diversity, or voice channel noise optimization).	R_r in dB.
16	Calculate P_{tcr} as a function of frequency.	4.4-78	--		P_{tcr} in dB.
17	Plot P_{tcr} versus frequency.	--	--	Use semi-log paper.	
18	Determine optimum frequency range.	--	--	Range for which P_{tcr} is minimum.	
19	If $P_{tcr} > 40$ dBW, repeat procedure for larger antennas or reduced bandwidth.				

No.	PATH TERMINAL	CARRIER FREQUENCY (MHz)	PATH DISTANCE (km)	SEA LEVEL REFRACTIVITY	HORIZON ELEVATION (km)	DISTANCE TO HORIZON (km)	ANTENNA SITE ELEVATION (km)	SURFACE REFRACTIVITY	AVERAGE SURFACE REFRACTIVITY	EFFECTIVE EARTH RADIUS (km)	ANTENNA HEIGHT ABOVE GROUND (km)	ANTENNA HEIGHT (km above msl)	HORIZON TAKEOFF ANGLE (rad)	DISTANCE BETWEEN HORIZONS (km)	ANGULAR DISTANCE (rad)			PATH ASYMMETRY FACTOR
		f	d	N_0	h_{L1} h_{L2}	d_{L1} d_{L2}	e_{s1} e_{s2}	N_{s1} N_{s2}	N_s	a	h_{g1} h_{g2}	h_{s1} h_{s2}	θ_{e1} θ_{e2}	D_s	θ	θd	a_0 β_0	S
	Martlesham Heath Hoek van Holland	4400	198	315	30×10^{-3} 0	14 18	30.9×10^{-3} 14.5×10^{-3}	314 315	315	8729	92.3×10^{-3} 12.3×10^{-3}	123.1×10^{-3} 26.6×10^{-3}	-1.156×10^{-3} -2.309×10^{-3}	166	0.0[illegible]	3.369	9.1915×10^{-3} 8.833×10^{-3}	1.079

Worksheet 4.4-1a Atmosphere and Path Parameters (example)

No	PATH TERMINAL	EFFECTIVE ANTENNA HEIGHT (km)		RADIUS OF CURVATURE (km)	DIFFRACTION PARAMETERS		INDEX OF CURVATURE		ATMOSPHERIC ABSORPTION	FREE SPACE TRANSMISSION LOSS	DIFFRACTION ATTENUATION, SINGLE OBSTACLE	DIFFRACTION ATTENUATION, SMOOTH TERRAIN	DIFFRACTION ATTENUATION, IRREGULAR TERRAIN	BASIC TRANSMISSION LOSS, FORWARD SCATTER	SCATTER ATTENUATION	ATTENUATION, MIXED MODES	REFERENCE ATTENUATION	REFERENCE BASIC TRANSMISSION LOSS
		h_o	h_{e1} h_{e2}	r	νp	ν	ρ		A_a	L_{bf}	A_k	A_{rd}	A_{id}	L_{bsr}	A_s	A_{ds}	A_{cr}	L_{bcr}
	Martlesham Heath Hoek van Holland	0.8404	$32.3 \cdot 10^{-3}$ $26.6 \cdot 10^{-3}$	N/A	N/A	N/A	N/A		1.5 dB	151.25 dB	N/A	N/A	N/A	214.9 dB	63.62 dB	N/A	63.62 dB	216.4 dB

Worksheet 4.4-1b Transmission Loss Calculations (example)

		DIFFRACTION PARAMETERS			DIFFRACTION ATTENUATION	EFFECTIVE RADIUS (km)	DIFFRACTION PARAMETERS					NORMALIZED ANTENNA HEIGHT		FRACTION PARAMETERS		
No.	TERMINAL	$A(v,0)$	$A(0,\rho)$	$U(v\rho)$	$A(v,\rho)$	a_1 a_2	K	b	C_{01} C_{02}	$K(a_1)$ $K(a_2)$	$B(K,b^\circ)$	h_1 h_2	$G(h_1)$ $G(h_2)$	B_0	x_0	x_1 x_2

Worksheet 4.4-1c Diffraction Loss Calculation

			DIFFRACTION PARAMETERS										SCATTER ATTENUATION FUNCTION	SCATTER PARAMETERS			
No.	PATH	TERMINAL	$G(x_0)$	$F(x_1)$ $F(x_2)$	$C_1(K,b)$	d_3 d_4	a_3 a_4	C_{03} C_{04}	$K(a_3)$ $K(a_4)$	B_1 B_2	B_3 B_4	$C_1(K_1,b)$ $C_2(K_2,b)$	$F(\theta d)$	r_1 r_2	η_s	H_0	$R(0.5)$

Worksheet 4.4-1d Diffraction and Scatter Loss Calculations

4.5 Integrating Link Design into System Design

4.5.1 General

4.5.1.1 Tentative values for various link parameters were calculated or selected by using the information in section 4.4. Some of these were antenna heights and separation, antenna types and gain, transmission feeder line type and length, transmitter powers and receiver noise figure. These choices should be checked after considering the total performance of the system (see sec. 4.5.30, 4.5.31, and 4.5.37). The system layout must be brought up to date with current information which involves adding information to system drawings and equipment requirement lists. Radio equipment block diagrams should be made for each site. The frequency plan must be completed and an analysis of intrasystem interference must be made.

4.5.1.2 Last of all, system performance predictions must be made; on the basis of these predictions, unreliable parts of the system will be changed to insure adequate noise performance. The total system design must also be checked from the standpoint of reliability. A prediction of system reliability cannot be accurately made but the system design can be examined for weak points.

4.5.1.3 After a discussion of system layout (sec. 4.5.2), equipment requirements (sec. 4.5.3), and frequency assignment and interference problems (sec. 4.5.4-4.5.12), methods will be presented in subsequent sections to evaluate the contributions of various-noise power sources to the performance of individual links and the entire system. This section includes appropriate worksheets and forms to aid in completing system design and optimizing the expected performance so that conformance with DCS standards can be achieved.

4.5.2 System Layout

4.5.2.1 A system layout with updated system parameter summaries should be prepared. These are essential steps for preparation of an accurate system analysis or even realistic cost estimates. The system layout may simply be a line drawing on an outline map as shown in figure 4.5-1, as an example; it points up potential self-interference problems and the general geometric relationship between the sites. Figure 4.5-1 represents an actual operating system, but no attempt is made to analyze it completely in this book. To supplement the layout drawing, three types of summary worksheets are required. First, a list of antenna locations shoud be prepared. (worksheet 4.5-la). Second, a list of parameters basic to the antennas and their orientation is needed to provide basic interface information for understanding the relationship between the terrain configuration and the equipment requirements (worksheet 4.5-lb) . Third, a summary of parameters for each path, using the transmission loss and path antenna gain calculations from section 4.4, must be provided to aid in preparation of system performance predictions (worksheets 4.5-lc and 4.5-ld).

4.5.3 Site Radio Equipment Requirements

4.5.3.1 Radio equipment block diagrams should be prepared for each site. The blocks used in these diagrams should identify the largest subsystems defining the radio equipment functions at each site. These subsystems may in some cases be broken down into more detailed modules. Each block should be given a number. This type of organization can be made to provide a detailed breakdown of equipment requirements. Descriptions of the various types of equipment appearing in the block diagram were presented in sections 4.4.44 through 4.4.69. Figure 4.5-2 is a typical radio equipment block diagram for a site being used not only as a repeater but also for branching and as a radio terminal.

4.5.3.2 Two primary reasons for preparing the block diagrams are: (a) they help insure that each equipment component will be considered individually and that no equipment will be overlooked, and (b) from

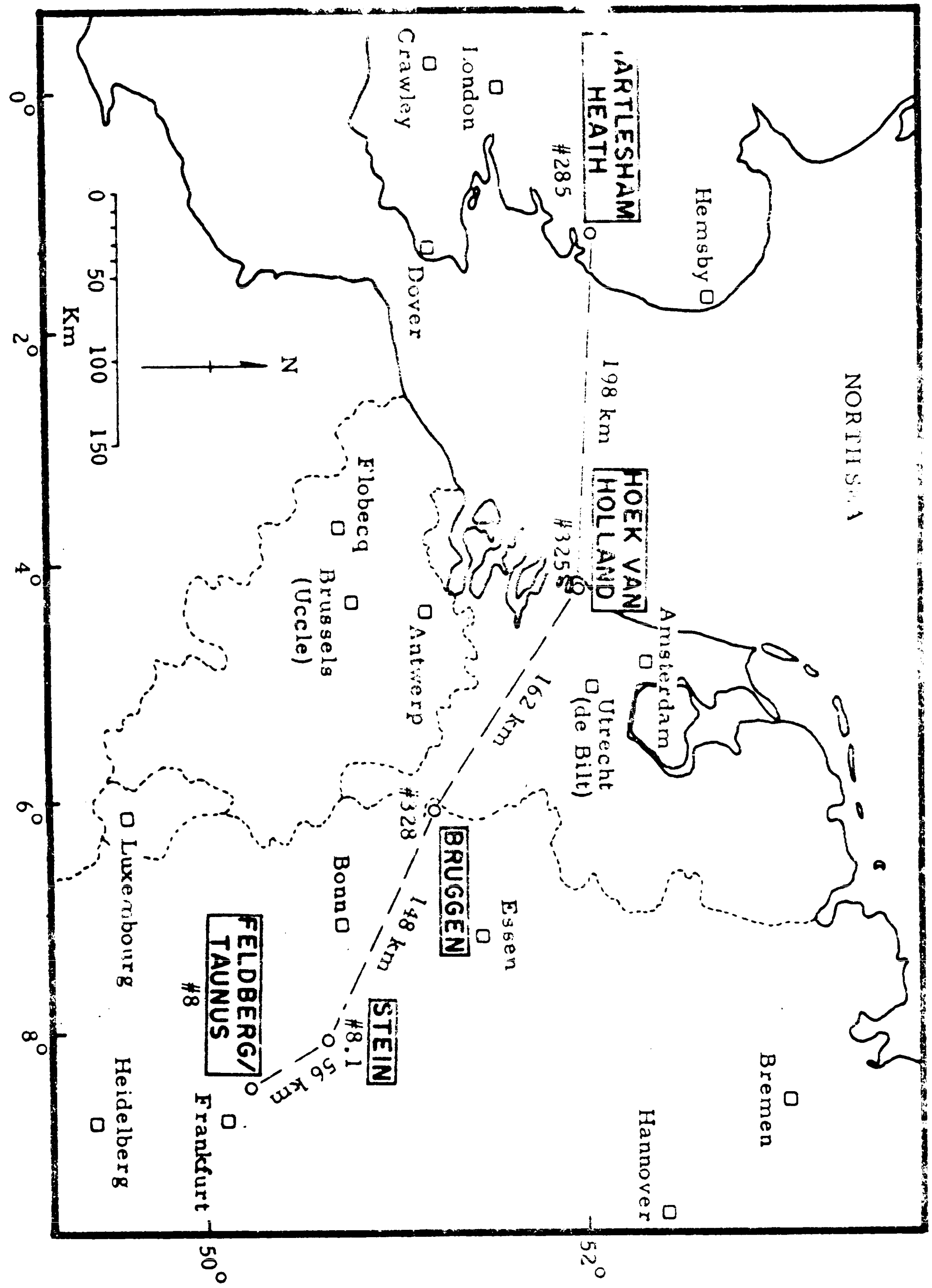


Figure 4.5-1 Typical System Layout Drawing

SITE NAME AND ANTENNA DESIGNATION	SITE AND ANTENNA ABBREVIATION	LATITUDE	LONGITUDE	TOWER BASE ELEVATION ABOVE M.S.L. (M)
Martlesham Heath *	285 (N & S)	52° 03' 08" N	01° 14' 30" E	30.8
Hoek van Holland *	325 (N & S)	51° 59' 07" N	04° 07' 01" E	14.3
* Antennas are horizontally spaced with common tower base coordinates.				

Worksheet 4.5-1a List of Antenna Locations.

ANTENNA IDENTIFICATION NUMBER	SITE	PATH	POINTING AZIMUTH FROM TRUE NORTH	HEIGHT ABOVE GROUND (M)	FREQUENCY (GHZ)	POLARIZATION (V OR H)	TYPE	DIAMETER (FT)	ANTENNA GAIN (dB)	BEAMWIDTH (DEGREES)	FUNCTION (RX OR TX)
North	285	to 325	91.1°	32.3	4.4	H & V	Parabolic	30	49.9	0.52	Rx & Tx
South	285	to 325	91.1°	32.3	4.4	H & V	Parabolic	30	49.9	0.52	Rx & Tx
North	325	to 285	273.3°	12.3	4.7	H & V	Parabolic	30	49.9	0.52	Rx & Tx
South	325	to 285	273.3°	12.3	4.7	H & V	Parabolic	30	49.9	0.52	Rx & Tx

Worksheet 4.5-1b Antenna Information Summary (example)

NO.	PATH	TERMINAL	PROFILE NUMBER	TOWER BASE ELEVATION ABOVE msl (m)	TOWER HEIGHT (m)	DISTANCE (km)	FREQUENCY (GHz)	MEDIAN TRANSMISSION LOSS (dB)	FEEDER LENGTH (m)	FILTER AND FEEDER LOSS (dB)	TOTAL LOSS (dB)	ANTENNA SIZE (ft)	HIGHEST ANTENNA HEIGHT ABOVE GROUND (m)	ANTENNA GAIN ABOVE ISOTROPIC (dB)	NET PATH LOSS (dB)	TRANSMITTER POWER (dBm)	MEDIAN RECEIVED CARRIER LEVEL (dBm)	IF BANDWIDTH (MHz)	RECEIVER NOISE FIGURE (dB)	NOISE THRESHOLD 10 log(kTB$_{IF}$f) (dBm)	WORST HOUR RECEIVED CARRIER LEVEL (dBm)			
	Martlesham Heath			30.8	36.8	198	4.4	216.4	50	2.31	220.1	30	32.3	49.9	133.1	70	-63.1	7.66	6	-99.2	-97			
	Hoek van Holland			14.3	16.8				30	1.39		30	12.3	49.9	133.1									

Worksheet 4.5-1c Path Information Summary.

Site Identification

(1) Martlesham Heath (Name) 235 (Abbreviation)	(2) Hoek van Holland (Name) 325 (Abbreviation)

Site Location and Physical Parame

(3) Latitude 52 ° 03 ' 08 " N	(4) Latitude 51 ° 59 ' 07 " N
(5) Longitude 01 ° 14 ' 30 " E	(6) Longitude 04 ° 07 ' 01 " E
(7) Altitude 30.8 m above msl	(8) Altitude 14.3 m above msl
(9) UTM Coord. N/A	(10) UTM Coord. N/A
(11) Azimuth to (2). 91 ° 06 ' — " True	(12) Azimuth to (1). 273 ° 18 ' — " True
(13) Proposed antenna height above (7). 32.3 m	(14) Proposed antenna height above (8). 12.3 m
(15) Proposed antenna horizontal diversity separation 12 m	(16) Proposed antenna horizontal diversity separation 12 m
(17) Proposed antenna type. Parabolic	(18) Proposed antenna type. Parabolic
(19) Size. 30 ft. 9.1 m	(20) Size. 30 ft. 9.1 m
(21) Expected antenna gain 49.9 dB above isotropic	(22) Expected antenna gain 49.9 dB above isotropic
(23) Design center carrier frequency, 4.4 GHz	(24) Receiver noise threshold, kTBF, -99.2 dBm
(25) Required waveguide length. 50 m	(26) Required waveguide length. 30 m
(27) Proposed waveguide type EW 44	(28) Proposed waveguide type EW 44
(29) Waveguide loss per standard length 4.66 dB per 100 m	(30) Waveguide loss per standard length 4.66 dB per 100 m
(31) Waveguide loss, 2.33 dB (including connectors)	(32) Waveguide loss, 1.4 dB (including connectors)
Circulator and/or Diplexer Losses	Circulator and/or Diplexer Losses
(33) Transmit. 0 dB	(34) Receive. 0 dB

Worksheet 4.5-1d Path and Equipment Parameters (example)

(35) Net fixed losses, (31) + (32) + (33) + (34), 3.73 dB

(36) Loss in antenna gain, L_{gp} 12.7 dB

(37) Effective path antenna gain, (21) + (22) - (36), 87.1 dB

(38) Proposed transmitter power, 10,000 watts, 70 dBm

(39) Path length, d , 198

(40) Median reference basic transmission loss, 216,4 dB

(41) Worst hour basic transmission loss, 250 dB

(42) Net loss, (35) + (40), 220.1 dB

(43) Net gain, (37) + (38), 147.1 dBm

(44) Expected median receiver input power, (43) - (42), -56.0 dBm

(45) DCA allowable yearly median noise, $n_y(0.5)$. 594pWO

Worksheet 4.5-1d (example contd.)

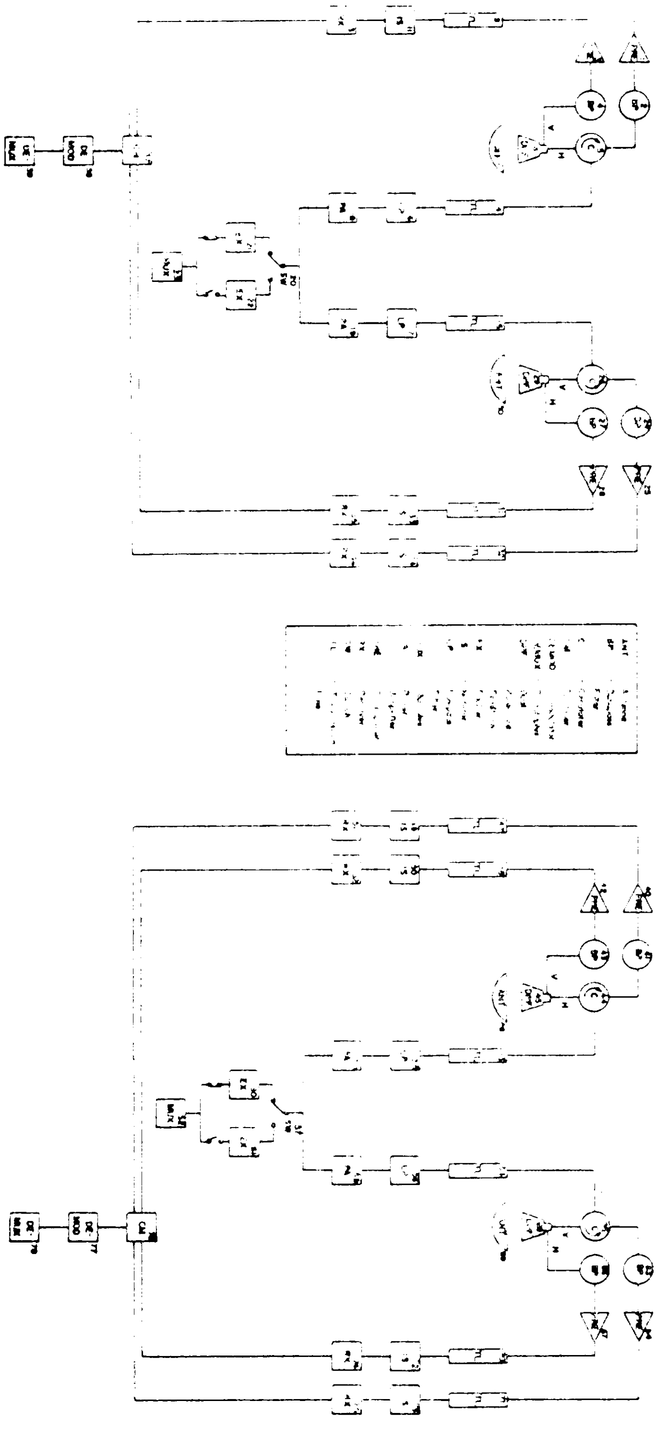


Figure 4.5-2 Site Radio Equipment Block Diagram

the equipment lists, a realistic cost estimate may be obtained. From figure 4.5-2, lists and tables commenting on each piece of equipment may be prepared, including possible military specifications (if applicable), manufacturers model n-umber, cost acquisition lead time, insertion gain or loss bandwidth VSWR, physical size, isolation, etc. The block diagrams may also be used to show some subsystem parameters such as RF transmit and receive frequencies, transmitter power, intrasite MUX channel routing, the path designation of the antennas etc. Also, appropriate parameters should be entered in worksheet 4.5-ld.

4.5.4 Frequency Compatibility

4.5.5 General Aspects of Frequency Allocation

4.5.5.1 Within the frequency bands that are allotted to microwave systems by international conventions, the CCIR has worked out radio-frequency channel arrangements for the various systems by indicating the number, frequencies, and spacing of the RF channels that can be used within the respective bands. Most of these arrangements, moreover, contain recommendations on the number and preferable polarization of the RF channels that may be carried over a common antenna.

4.5.5.2 The following items require careful consideration when making radio-frequency channel arrangements.

1. Through-connection of microwave systems across national borders;
2. Prevention of mutual interference between neighboring countries in the border areas;
3. Optimum utilization of the available RF spectrum;
4. Prevention of mutual interference within countries having great traffic densities.

4.5.6 Reference to the Appropriate Sections of the Radio Regulations

4.5.6.1 Article 3 of the Radio Regulations [43] provides general rules for the assignment and use of frequencies; Article 4 provides information on the conclusion of special agreements between two or more Members or Associate Members of the ITU regarding the suballocation of bands of frequencies. Guidelines for frequency management are also given in [32] . Revisions to the Radio Regulations were made at the Extraordinary Administrative Radio Conference in Geneva in 1963 [44], and the World Administrative Radio Conference for Space Telecommunications in 1971 [29] . Pertinent resolutins relate to satellite systems and fixed and mobile services in the frequericy band 1525 - 1540 MHz. Recommendation.s relating to the sharing of frequency bands between communication-satellte systems and terrestrial radio-relay systems were also drawn up. Changes in radio regulations are usually reflected in loose leaf additions or substitutions in [43].

4.5.7 Radio-frequency Channel Arrangements for Transnorizon Systems Using Frequecny Modulation

4.5.7.1 The following material is taken from CCLI information. in [4; Report 286] and is based on CCIR studies for establishing a radio-frequency channel arragement usabie over a wide geographical area. The results obtained [4; Report 285-2: have made it evident that it is neither possible nor even desirable to fix preferred radio frequency arrangements for *such* systems. On the contrary, the maxirmum amount of flexibility should be maintained in the design of such systems so that their characteristics can best be adapted to current needs.

4.5.7.2 To simplify the design of equipment and to facilitate its operation it is, however, desirable that studies of the necessary frequency arrangements in each case should be guided by certain basic rules. The following are some of the considerations on which a radio-frequency channel arrangement might be based:

1. The high radiated power of transhorizon systems and the long range of this propagation method may give rise to serious interference at distance extending beyond national frontiers, for example 1000 km
2. Interference both between and within transhorizon systems can be minimized by the coordination of radio-frequency channel arrangements over a large. geographical area;
3. The presence of high-power transmitters and very sensitive receivers in the same station makes protection against local interference very difficult, and as a result it is necessary to minimize such effects by a carefully planned arrangement of radio frequencies;
4. Radio-frequency channel arrangements should provide for various capacities of FDM telephony (e. g. from 12 to 120 telephone channels) and perhaps also for television as appropriate;
5. With the frequency deviations likely to be employed, the bandwidth of emission may range from a fraction of 1 MHz to several MHz (perhaps up to 8 MHz for television) ;
6. To avoid undue interference between stations, the minimum distance separating a receiving station from an interfering transmitting station operating on

the same frequency may have to be large, for example 1000 km or more, depending on the power used, the chracteritcs, orientations and polarizations of the antennas;

7. If it is desired to make interconnections, it is recommended that use be made of the intermediate frequencies 35 and 70 MHz, in conformity with Recommendation 403-l in [4]; see also Report 285-2 [4];
8. It is important that the arrangement used be resrponsive to all operational requirements;
9. The arrangement used should be amenable to the use of diversity reception. when, the..e system operates in dual-diversity, the avoidance of frequency diversity is recommended. Where frequency diversity must nevertheless be used in each direction of transmission, the diversity frequencies can either. be very close together (for example those in adjacent channels), or separated by several tens of MHz. The radio-frequency channel arrangement must be compatible with such requirements;

The frequency bands usable by tropospheric-scatter multichannel radio-relay systems between 100 MHz and 10 GHz have bandwidths ranging from a few MHz to more than 1 GHz. These bands are often taken from those allocated to the fixed and mobile services according to regional and national regulations. The frequency plan must reflect this situation.

4.5.7.3 General indications to be followed are listed below:

1. An appreciable reduction of the distance envisaged between stations likely to cause mutual interference can generally be realized, on condition that they can be operated on slightly different frequencies, the minimum useful frequency separation being about 0.5 to 1 MHz for narrowband frequency -modulation systems [45, 46], as well as for amplitude-modulation single-sideband systems;
2. Interference resulting from frequencies produced at a single station (frequencies of transmitters, local oscillators, frequency-changers) is chiefly linked to the choice of intermediate frequency. It is therefore) not wise to set up a channel arrangement without prior consideration of the value of the intermediate frequencies used. The most troublesome interference can usually be avoided by choosing a separation between channel, such that the intermediate frequency can never be a multiple of this separation. This rule must be respected, partictirly when the effective separations between channels are chosen as appropriate multiples of the unit step between 0. 5 and 1 MHz, as proposed in (1) above;
3. To apply a single-channel arrangement to several channels of various telephone capacities, a separation between channels in a station can be used which is a multiple of a frequency module. Typically, the radio-frequency channel separation required for 60 to 120-voice channel systems could be respectively

3 to 5 times that required for 12 to . channel systems, the RMS deviation. used being chosen in conformity with Recommendation 404-2 [4] ;

4. The first channel should be at a minimum distance from the end of the frequency band considerd equal to approximately half the channel width;

5. At each station, all transmitting frequencies should be in the same half of the band, and all receiving frequencies in the other half, The role of the two half-bands will be reversed in adjacent stations;

6. To minimize &e problem of duplexing, the minirnu.n frequency separation between transmitted and received signals on the same antenna . should be of the order
-- 40 MHz for systems operating at frequencies below 1000 MHz;
-- 80 MHz for systems operation at frequencies above 1000 MHz. The minimum frequency separation between transmitted and received signals at the same station, but not same antenna, should be of the order of:
-- 35 MHz for systems operating at frequencies below 1000 MHz;
-- 35 MHz for system operationg at frequencies above 1000 MHz.
Finally, the minimum separation between two tram - mitting frequencies, or two receiving frequencies at the same station, could be seven times the basic unit referred to in (3) above;

7. Taking account of the great number of usable channels, the variety of situations encountered in actual practice, and to keep the maximum flexibility in the use of frequencies, precise assignment of frequencies for interconnection should be the subject of an agreement between the Administrations concerned.

4.5.8 Types of Interference

4.5.8.1 The following definitions of various types of interference and much of the discussions in subsequent sections have been taken from an ITU publication [54; sec. B IV.2, p. 12 - 17]:

a) Cochannel interference

This term refers to interference from a source, modulated or otherwise, having a carrier frequency identical or close to that of the wanted carrier. When the interference is caused by the beat between two relatively high level carrier components having a frequency separation which falls within the baseband of the wanted signal, the predominant interference will be single-tone in character. When the carrier frequency separation falls outside the baseband range of the wanted signal, and when the interference is from a dispersed signal, the character of the interference will resemble that of random noise.

b) Adjacent channel interference

This term refers to interference due to the presence of one or more radio-frequency carrierss modulated or otherwise, in a frequency channel adjacent to that of the wanted modulated carrier. The term adjacent

IS NORMALLY TAKEN AS INDICATING THE TWO ADJACENT CHANNELS IN THE FREQUENCY CHANNELLING PLAN WHICH HAS BEEN ADOPTED.

c) Direct adjacent channel interference

As in b) above, this term refers to interference due to the presence of carriers in an adjacent channel which may be present when interference ue to b) above has become neglible and amplitude -modulted signals are produced by limiting. The mechanism of this type of interference, between requires modulated interfering carrier.

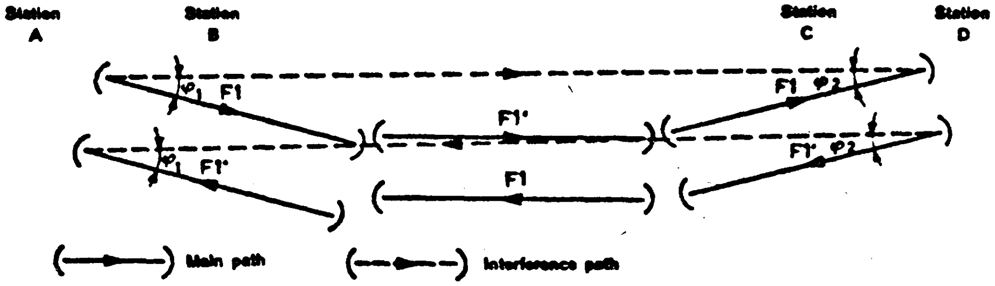
d) Other forms of interfence

This term refers to interference which can arise from external source, or from unwanted couplings within the radio equipment such as for example the image response of the receiver.

4.5.9. Cochannel interference

4.5.9.1 Cochannel intefererence arises when there is excessive interference between signal sources operating on he same, or similar frequencies. It is current practice to transmit a common carrier A-frequency (Fl) from every alternate repeater station of a radio -relay system. The remaining stations of the system tern transmit a second carrier frequency (F1^{1}) which differs from the first by an amount which depends on the particular frequency plan employed. As shown in figure 4.5-3, this arrangegement can result in overreach interference were station A, transmitting on frequency Fig illuminates the antenna of station D, and vice versa. Protection against such interference is normally provided by careful site selections and by insuring that sufficient antenna side-lobe suppression given by the angles ϕ_1 and ϕ_2

is provided to minimize the interference. It may also be possible to provide further discrimination by arranging that the polarization of the wanted and unwanted signals are orthogonal, but this is not always practicable. For example, a spur route may branch off from one of the stations; thus it is desirable to provide cross-polarization discrimination between the main route and the spur route. An alternate method of reducing interference is to employ an interleaved frequency plan over the section that is subject to interference. In this context, an interleaved frequency plan is one in which all carrier frequencies are changed in the same sense by an amount equal to half the adjacent channel frequency spacing. This value is approximately 14.5 MHz in the 2-, 4-, and 6-GHz bands when using standanrd CCIR recommended frequency plans [4; Recommendations 382-2 and 383 1]

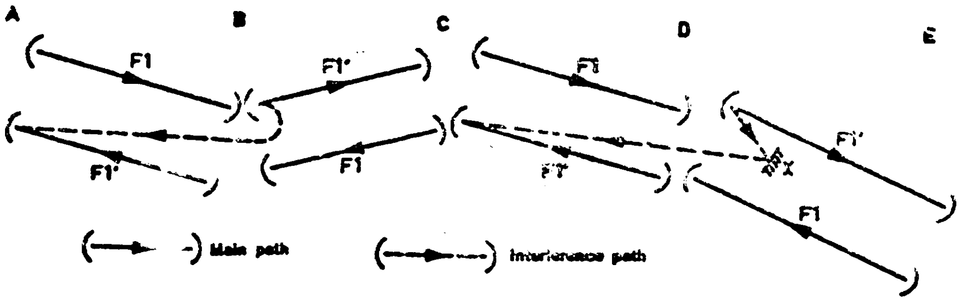


The ratio (wanted signal/ interfering signal depends on the gain of the antennas at angles ϕ_1 and ϕ_2 relative to the gain in beam and the difference of transmission losses between main and overreach paths.

Figure 4.5-3. Example of Overreach Interference.

4.5.9.2 The advantage to be gained by this angerment depends on the baseband width of the channels concerned relative to their carrier spacing and also their relative carrier levels. It is generally desirable to use a carrier freqecy spacing of not less than three times the highest baseband and frequency in order the first-order sidebands of one channel do not overlap the second-order sidebands of the other channel. Closer spacings in terms of muitiples of the highest baseband frequency may be used with care, depending on the relative levels of the wanted and unwanted carriers and the degree of interference that is acceptable.

4.5.9.3 A further interference mechanism can be seen in figure 4.5-4 where radiation at frequency F1'from the back of the antenna at station B is received at station A. Even when the front and back discrimination of the antenna is sufficient to reduce this interference to an acceptable level, reflections from nearby objects can cause coupling, as shown at station D (fig.4 5-4). The reduction of

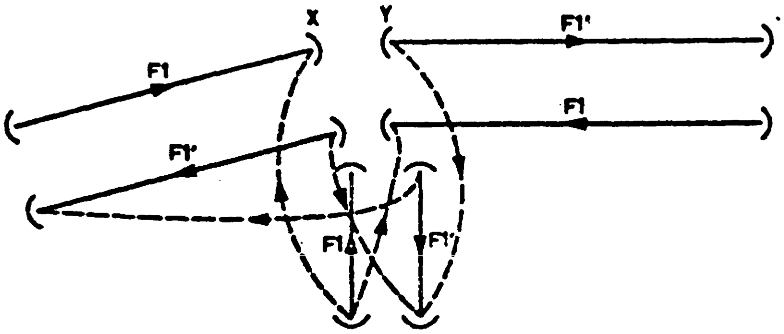


B Results from insufficient front- to-back discrimination.
D. Results from a reflection from nearby tzees, hills, buildings, etc. at point X.

Figure 4.5-4. Example of Adjacent Station Interference

interference from such a coupling must rely either on antennas of improved directivity or on the use of a more suitable sites or possibly on the use of an interleaved frequency plan. A front-to-back antenna discrimination of 65 dB, or better, at each station is necessary in order to limit cochannel interference to an acceptable level.

4.5.9.4 Figure 4.5-5 shows an example of interference from a spuur or crossing which is similar to one of the interference mechanisms shown in figure 4.5-4, except that in the case of figure 4.5-5, the angles involved are less, and it is the front-to-side lobe polarization discrimination of the antennas which controls the level of interference. If, on the main route, signals of the same frequency arriving from opposite directions are copolarized, the spur route can be cross-polarized with respect to both directions. If, however, the main route signals are cross-polarized (and there is not necessarily any advantage to this), the spur route should be cross polarized with respect to the direction having the least angular separation.



The ratio (wanted signal/ interfering signal) will depend on the front-to-side discrimination of the antennas X and Y.

Figure 4.5-5. Example of Spur Route Interference

4.5.9.5 In some cases it may be possible to reduce the effects of cochannel interference by applying dispersal to the unwanted signal. The effect of dispersal, which involves phase deviating the carrier by several radians at a slow rate, is to spread over many voice channels, at a reduced level, the interference which would otherwise have fallen into a few channels. The reduction in interference is most pronouced in the lower frequency channels which h are subject to the greatest interference; namely, that due to the beat tone between the wanted and unwanted residual carriers.

4.5.10 Adjacent Channel Interfence

4.5. 10.1 Adjacent channel interference can arise when (for a given baseband capacity and adjacent separation~ suppression of *the* adjacent carrier and overlapplng unwanted sideband inadequate. The reduction to an acceptable level of interference from this source is dependent upon several factors. First adequate separation of the adjacent channel spectra must be provided, and this is taken into account in the radio-frequency channel arrangement recommended by the CCIR [4; Recommendations 382-2 and 383-1 Second sufficient RF and lF selectivity must be provided to reduce the level of unwanted adjacent spectra. In providing such filtering, the equipment designer must take into account the possibility of introducing distortion into the wanted signal path and of overloading the receiver mixer. Third, cross-polarizatior discrimination between adjacent channels is provided to supplernect the selectivity given by the filtering. A cross-polarization discrimination of some 25 to 30 db both practicale and necessary.

4.5.11 Direct Adjacent Channel Interference

4.5.11.1 Direct adjacent channel interference appears to arise when the wanted and unwanted signals are tohether subjected to amplitude limiting. It is believed that partial conversion to amplitude modulation tothe unwanted frequency modulated signal takes place on the selectivity skirts of the wanted channel. The amplitude modulation thus produced is amplified but not limited in the limiter of the wanted channel and amplitude modulates the wanted signal. At the discriminator, the unwanted amplitude modulation appears at the output along with the wanted signal. The effect is characterized by the fact that intelligible crosstalk is produced and that the level of the interference varies by 2 dB for each 1 dB variation in the wanted-to-unwanted carrier ratio. The problem of reducing to an acceptable level interference from this source is again one for the equipment designer who must insure that, together with the cross -polarization discrimination between adjacent channels, adequate selectivity is provided prior to limiting.

4.5.12 Other Sources of Interference

4.5.12.1 Interference can occur within a system as a result of deficiencies in the equipment itself. For example, a superheterodyne receiver has several sensitive regions at which interference can be received; namely:

Sensitive Region	Frequency with respect to Received Signal Frequency
Channel carrier frequency	$F_0 \pm 1/2$ IF
Local oscillator frequency	± 1 IF
Image frequency	± 2 IF
+3 IF region	± 3 IF
-IF region	∓ 1 IF

4.5.12.2 Adequate selectivity prior to the low-level mixer is necessary to desensitize the receiver in all regions but that of the channel carrier frequency- The designer must also insure that the outputs of alI local oscillators are of high spectral purity i. e. as free as possible from spurious signals, random noise and both long-term and short-term frequency changes. spurious in local oscillators can arise from imperfection of the crystal itself, inadequate filtering of undesired crystal harmonics or semioscillation and general instability in varactor multiplier chains.

4.5.12.3 A further interference mechanism exists on systems which employ common antennas and feeders to transmit and receive more than one frequency band. All waveguide feeders exhibit amplitude nonlinearity to some. extent mainly resulting from imperfections at joints. Such nonlinear elements result in intermodulation between the outputs of two or more transmitters, and the resulting unwanted products may fall close to receiver frequencies, either in the same frequency band or in a different frequency band from that of the originating transmit channles. A careful seiection of associated frequencies and of joints of the waveguides is required to avoid the worst effects.

4.5.15 Transhorizon Performance Estimates for Hops and Systems

4.5.14 Procedures and Flow Chart

4.5.14.1 This section includes methods to calculate hop and system noise for transhorizon links, and to evaluate system performance in terms of noise allowances given by DCS and CCIR standards. A flow chart to aid in the calculations leadiug to the total voice channel noise power for a single hop is shown in figure 4.5-6. Required input parameters for such calculations have already been assembled following the work outlined in preceding subsections, and are more fully

ters and the expected long-term distributions of basic transmission loss for each hop; also a discussion of noise objectives and allowances, a review of FDM-FM transmission characteristics and techniques, a more detailed discussion on equipment parameter selection, methods

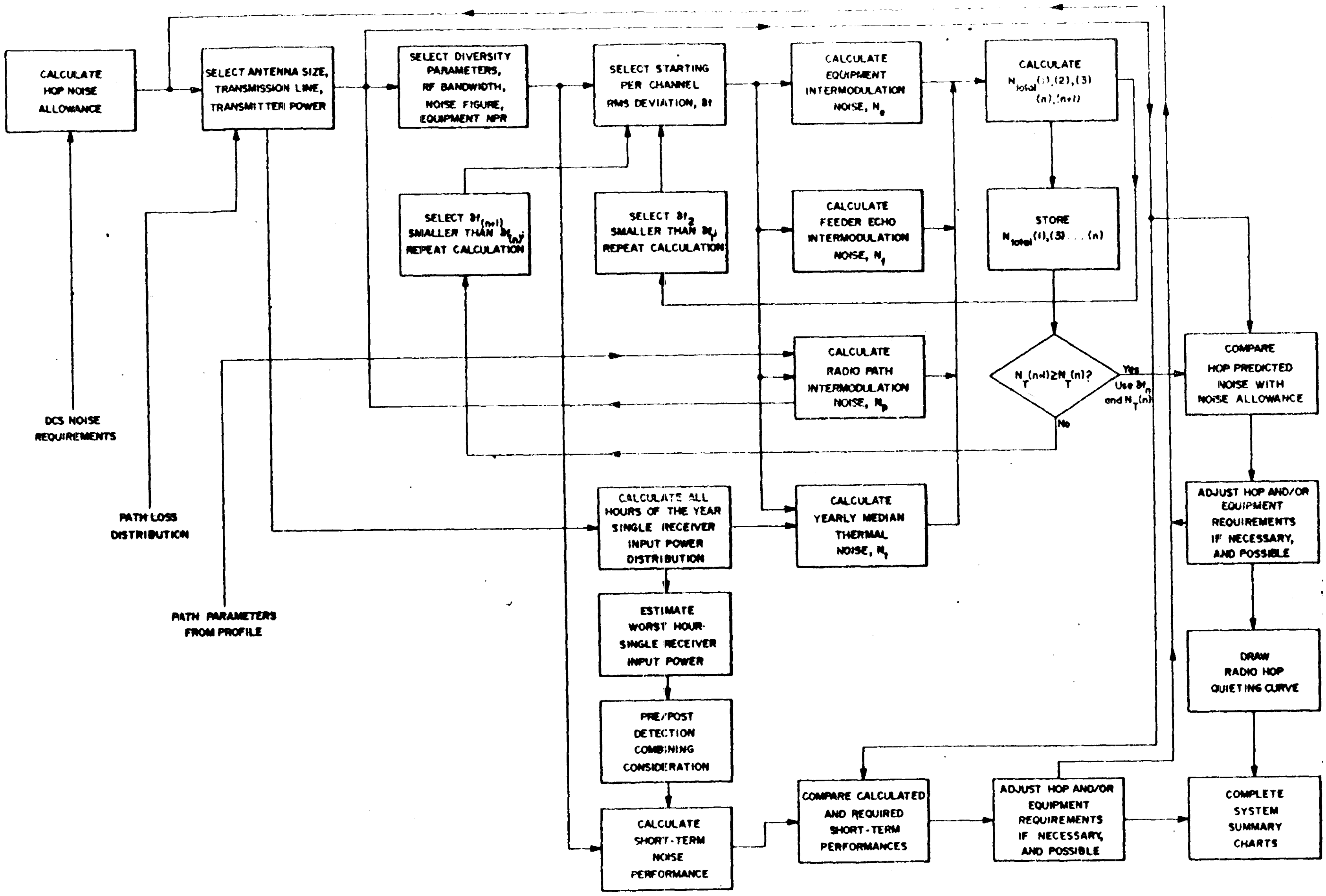


Figure 4.5-6 Hop Noise Calculation Flow Chart

for calculating the various components of noise, effects of diversity operation, and finally, the combination of all noise contributions from the individual hops to calculated the expected system performance. The presentation includes worksheets, forms, and graphs to facilitate the assembly of information the sequence of the required calculations. Examples are given where appropriate. Additional applicable worksheets will be found at the end of section 4.5.

4.5.15 DCS Noise Requiernents

4.5.15.1 One of the primary goals in establishing communication system performance is the selection of maximum permissible long-term median voice channel noise power. Allowable noise power is given by applicable military standards (MIL-STD- 188-313; see paragraph 4.2.2.1.1.1) as 3.333. . . pWpO per nauical mile. This is a psophometricaily weighted noise power unit However, for reason of simplicity, noise calculations in this handbook are based on flat weighting within the individual voice channels. A useful design objective for transhorizoa systems is based on an allowance of 3 pWO (flat weighted) long-term median noise power per kilometer of path length and is somewhat more conservative than the military standard specification. However, as noted in section 1.1.1, it will always be necessary to refer to the appropriate current military standards for operating criteria when designing Defense Commune - cation Systems.

4. 5. 15.2 restrict adherence to this allocatior. of noise power may in cases be physically or economic difficult or may result in needless demands on the radio spectrum. Thus, higher noise levels must often be tolerated in real systems. Requirements for short-term noise allocation will be discussed in section 4.5.19.

4.5.16 Units for Noise Calculations

4.5.16.1 For ease in handling, all calculations in section4.5 WILL BE in terms of flat (unweighed) noise power over the 3.1 kHz voice channel bandwidth. This is measured in picowatts (pW), and the symbol pWO signifies that the power level is referenced to the zero transmission level point, i.e., the point where the reference signal is determined. Further definitions and relationa to units which utilize various weighting factors are included in (MIL-STD-120). If the designer desires to use various weighting factors, these may be Included at the conclusion of the design To convert from flat weighted noise power, multiply flat weighted noise by 0.678 for "C Msg", by 0.452 for FIA, and by 0.562 for Psophometric.

4.5.17 Long-term and Short-term Noise Allowance

4.5.17.1 For design purposes, the noise allocation is separated into yearly median and short-term noise, where the latter usually refers to an allocation for a "worst hour" or "worst few hours". These two parts in the noise calculations will be discussed more completely in the following subsection8.

4.5.18 Yearly Median Noise Allocation

4.5.18.1 The noise objective for each radio hop will be prorated on the basis of the hop great-circle length. An example of a transhorizon system consisting of three radio hops in tandem was shown in figure 4.5-1, and this will be used in the following discussions. Consider the hop from Martlesham Heath to Hock van Holland. As shown in figure 4.5-1, it is 198 km long; thus, the all- year median noise allocation (at 3 pWO per km) will be 594 pWO per equivalent voice channe1 Similarly for the Hoek van Holland to Bruggen link the allocation would be 486 pWO; and for the Bruggen to Stein path 444 pwo.

4.5.19 Short-term Noise Allocation

4.5. 19. 1 The sense of CCIR Recommendation 397-2 [4] in regard to short-term noise allocation can be interpreted in two parts, as follows.

First, the allowable noise power In a voice channel suing various fractions of a month Will be interpreted in terms of worst several hours of the year, as indicated by the all-year distribution of hourly median transmission loss, since the range of transmission loss is described in this way. The recommendation suggests that the one-minute mean power not exceed 100,000 pWO (approximtely equivalent to 63,000 pWp) more t-ban 0.5% of any month. The time period involved (0.5% of a month) is about four hours, so the interpretation used here is that this allocation will apply cluing four hours of the worst month, which are then the worst four hours of the year! .

4.5.19.2 Also involved in the short- term noise allocation is the requirement that the noise not exceed 1,000, 000 pWO for 0.05% of any month or for about 22 minutes during the “worst several hours of the year" in the same sense as interpreted in the preceding paragraph. In view of the foregoing requirements, the restriction set forth must be met simultaneously, and for actual radio hops one or the other of the short-term requirements may be most difficult to meet. In any event, the . requirements can be stated as follows:

1. The hourly median voice channel noise during the worst four hours of the year will not exceed 100,000 pwo (-40 dBmo) .
2. The voice channel nioise measured with a five millisecond averaging time will not exceed 1,000,000 pWO (-30 dbmO) for more than accumulative 22 minutes of the year.

Methods for evaluating short-term voice channel noise will be given in section 4.5.34.

The yearly median noise allocation from subsection 4.5.18.i should be entered on worksheet 4.5-ld.

4.5.20 FM Transmission Theory

4.5.20.1 At this point the system designer must consider the nature of the FDM-FM transmission technique and select those parameters which will determine system performance and cost.

4.5.20.2 The basis of an FM communication system is the linear transformation of the instantaneous values of voltage of an information signal to instantaneous values of radio frequency, the transmission of the radio frequency as a radiated electromagnetic wave to a distant receiver, and the linear transformation of the instananeous frequency of the RF signal back to instantaneous values of voltage of the informs-tion signal at the receiver. Thus an ideal FM communication link is transparent to the information signal, but to be transparent% the RF channel must be of infinite bandwidth and of infinite signal-to-noise ratio. Since such RF channels are unrealizable, it is the task of the system designer-engineer to assess the various sources of degradation of the information signal as it passes through a nonideal channel and to reach a design compromise which will deliver the information signal to the customer in such a way that the information is not totally masked by noise and distortion and the communication system costs remain within reasonable bounds.

4.5.20.3 Figure 4.5-7 shows diagrammatically the FM modulation and demodulation process and indicates the sources of noise and distor - tion (which will be covered in detail in lter sections) In general the noise sources are thermal noise (due to loss of RF energy in traversing the path and receiver front end noise), echo noise (which arises because the echo-delayed signals resemble modulated~ interfering carriers of the same frequency due to transmission line impedance mismatches), and nonlinear noise (due to modulator and demodulator nonlinearities and radio path frequency-selective fading and multipath effects).

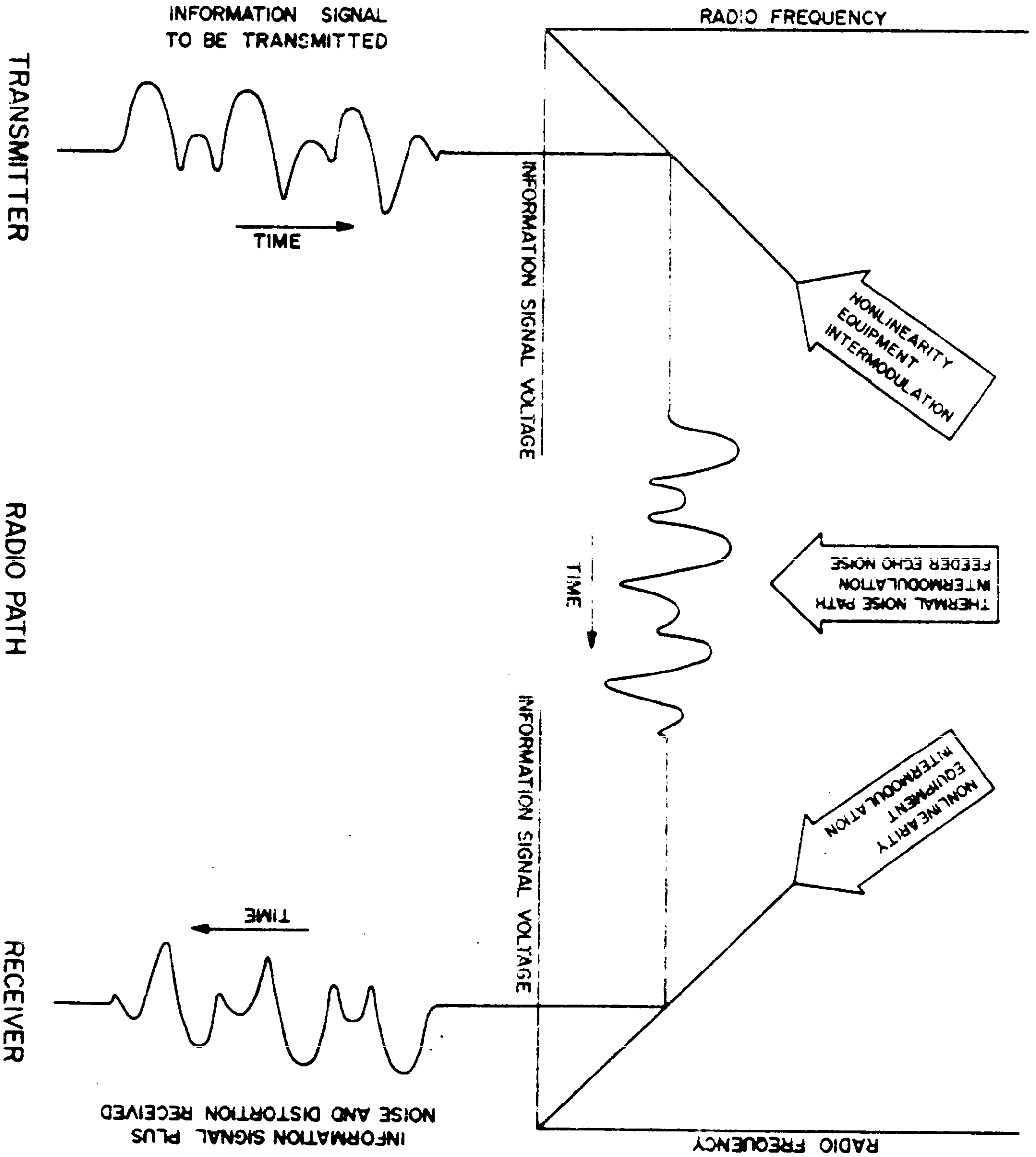


Figure 4.5-7 Illustration of a Typical FM Radio System

4.5.20.4 With these concepts in mind, we may proceed to discuss the process of modulation in more detail first considering the equation of a sinusoidal alternating current voltage in its general form [55]:

$$e = A \sin o(t) \qquad (4.5\text{-}1)$$

where

e = instaneous amplitude,

A = peak amplitude (in the same units as e)

and

$\phi(t)$ = total angular displacement at time t.

The instantaneous angular velocity w_i is then by definition the instantaneous rate of change $\frac{d\phi(t)}{dt}$ of angular displacement $\phi(t)$, or instantaneous angular velocity $2\pi f_i = \frac{d\phi(t)}{dt}$. (4.5-2)

Considering now a single sinusoid as the modulating signal, the instantaneous angular velocity may be expressed by:

$$\omega_i = \omega_c + 2\pi\Delta F \cos \omega_m t \qquad (4.5\text{-}3)$$

where

w_C = angular velocity of the carrier wave
= average angular velocity,

W_m = 2π times the modulating frequency f_m

ΔF = maximum deviation of instantaneous frequency from average.

A fundamental characteristic of a frequency modulated wave is that the frequency deviation AF is proportional to the peak amplitude of the modulating signal and is independent of the modulating frequency. Since $\omega_i = \frac{d\phi(t)}{dt}$ and $\phi(t)$ is required for insertion in (4.5-1) we may integrate ω_i to give

$$\int_0^t \omega_i dt = \phi(t) = \omega_c t + \frac{2\pi\Delta F}{\omega_m} \sin(\omega_m t) + \theta. \qquad (4.5\text{-}4)$$

For convenience, set the constant of integration o equal to zero to is the angular position at time 0). Thus (4.5-1) become

$$e = A \sin\left(\omega_c t + \frac{2\pi\Delta F}{\omega_m} \sin \omega_m t\right) \qquad (4.5\text{-}5)$$

or (4. 5-5) can be rewritten as

$$e = A \sin(\omega_c t + m_f \sin \omega_m t) \qquad (4.5\text{-}6)$$

where m_f is termed the modulation index of the frequency modulated wave and has the definition

$$m_f = \frac{\text{peak frequency deviation}}{\text{modulating frequency}} = \frac{\Delta F}{f_m} \cdot \qquad (4.5\text{-}7)$$

The frequency components actualliy contained in this wave can be determined by using the trigonometric formula for the sum of two angles and expanding the resulting expression in terms of Bessel functions [60, 66]:

$$\begin{aligned} e = A \{&J_0(m_f) \sin \omega_c t \\ &+ J_1(m_f) [\sin(\omega_c + \omega_m) t - \sin(\omega_c - \omega_m)t] \\ &+ J_2(m_f) [\sin(\omega_c + 2\omega_m) t + \sin(\omega_c - 2\omega_m)t] \\ &+ J_3(m_f) [\sin(\omega_c + 3\omega_m) t - \sin(\omega_c - 3\omega_m)t] \\ &+ \ldots \} \end{aligned} \qquad (4.5\text{-}8)$$

where $J_n(m_f)$ is the Bessel function of the first kind and nth order, with argument m_f.

4.5.20 This analysis shows that a carrier wave with sinusoidal frequency modulation results in a spectrum made up of a carrier and of sideband components spaced at integral multiples of the modulating frequency. The amplitudes of the carrier and sideband components are proportional to the values of the Bessel functions as given in (4.5-8)

4.5.20.6 A similar analysis is possible for a phase modulated wave which is one in which the value of the reference phase, θ, is varied so that its magnitude is proportional to the instantaneous amplitude of the modulating signal. Thus for sinusoidal phase modulation at a frequency, $f_m = \frac{\omega_m}{2\pi}$, we have

$$\theta = \theta_0 + m_p \sin \omega_m t \qquad (4.5\text{-}9)$$

where θ_0 is the phase in the absence of modulation and m_p is the maximum value of the phase change introduced by modulation, and is called the modulation index for phase modulation. If we define $\phi(t)$ from (4.5-1) as

$$\phi(t) = \omega_c t + \theta \qquad (4.5\text{-}10)$$

where $\omega_c = 2\pi$ times the carrier frequent y and substitute (4.5 -9), we get

$$\phi(t) = \omega_c t + m_p \sin \omega_m t. \qquad (4.5\text{-}11)$$

Substitution of (4.5-11) in (4. 5-1) results in:

$$e = A \sin (\omega_c t + m_p \sin \omega_m t). \qquad (4.5\text{-}12)$$

Fourier transforms of (4.5-12) and (4.5-6) indicate that for equal frequency and phase modulation indices, the power spectra of both signals will be identical. However, the process of defining the modulaion index is different for the two systems. The instantaneous frequency of the phase modulated wave is obtained by differentiation of the instantaneous angular displacement as given in (4.5-11). Then,

$$\omega_i(\text{phase modulated wave}) = \omega_c + \omega_m m_p \cos \omega_m t. \qquad (4.5\text{-}13)$$

Comparing this with (4.5-3) indicates that the maximum frequency deviation $(\Delta f)_p$ of a phase modulated wave is $\omega_m m_p / 2\pi$ or

$$(\Delta f)_p = f_m m_p. \qquad (4.5\text{-}14)$$

Thus the frequency deviation ($\Delta f)_p$ due to a constant phase modulation index m_p is also a function of the modulating frequency, f_m Note: A fundamental characteristic of phase modulation is that the frequency deviation, $(\Delta f)_p$, is proportional to both the peak amplitude and the frequency of the modulating signal. Although the linearity of the modulation and demodulation processes is very important, it should be pointed out that neither frequency nor phase modulation are linear processes in themselves, that is, the principle of superposition does not hold. This implies that if more than one sinusoidal tone is modulating the carrier, the resultant spectrum does not simply contain the sidebands caused by each tone separately, but rather includes all intermodulation products of the modulating tones and their harmonics. This aspect is discussed in detail in [56] [57] and [60]. Thus the spectrum of a carrier frequency modulated by a complex wave is even more complicated than the single modulating tone analysis indicates.

4.5.26.7 Returning now to frequent y modulation (FM) systems, note that from the definition of the FM modulation index, m_f in (4.5-7), if the modulating frequency is increased for signals of constant "amplitude, the value of the modulation index is decreased. It will be shown in the following sections that the noise rejection of an FM system is proportional to the modulation index squared. For this reason, there is higher thermal noise power in the upper voice channels of a radio-relay system. To compensate for this effect in most of the radio-relay systems, pre -emphasis is applied. This means that before frequency modulation is effected in the transmitting station, the level of the upper frequencies of the baseband is increased while the level of the lower frequencies is decreased. This is done in such a way that the mean power of the baseband signal is the same with or without pre-emphasis. On these assumptions, the CCIR has standardized the frequency characteristic of the pre-emphasis which is a common characteristic for all types of broadband systems [4; Recommendation 275-2]. Between the lowest and the highest voice channel, the pre - emphasis (i.e., the difference in level) is 8 dB.

4.5.20.8 The previous discussion provides the background for consideration of wideband multichannel communication links. Since all of the noise allocations and time availability considerations are in terms of single voice channel performance parameters, the following sections will center on evaluating these per voice channel parameters. The reason for this is that a single voice channel can be accessed and tested; furthermore, the voice channel itself is the basic building block of the system. In general, the most significant parameter which is largely influenced by radio hop performance is the voice channel signal-to-noise ratio, S/N. It is defined as ten times the common logarithm of the ratio of a RMS single-tone signal power (usually 1000 Hz and at such a level that the sine-wave voltage peaks are roughly equal to the voltage peaks in a signal developed by a telephone talker) to average (over a period of several milliseconds) noise power in a 300 to 3400 Hz bandwidth.

4.5.20.9 In a wideband communication system in which many voice channels are frequency-division multiplexed into a baseband signal which extends over a large spectrums it is necessary to be able to analyze the performance of any voice channel in the band. However, only the channel occupying the highest frequency position in the baseband is usually analyzed since its quality is expected to be the poorest of the channels because of its lower modulation index, even with pre - emphasis.

4.5.20.10 The first step in this noise anlaysis is to consider the relationship between the desired RF energy and the thermal noise which occurs in the RF spectrum occupied by the signal. This function is alled the carrier-to-thermal noise ratio, C/N and is expressed in decibels following generally accepted practice. The notation c/n be used to denote a power ratio (a numeric) so that C/N = 10 LOg (c/n) A similar convention will be followed in the definition and discussion of other signal to -noise ratios in the following subsections. The voice channel signal- to-thermal-noise ratio s/n is directly proportional to c/n above FM threshold if both are expressed as power ratios (see sub-section 4.5.20.12.

4.5.20.11 The actual carrier-to-noise ratio may be described by the equation

$$C/N = 10 \log \left[p_r / kTB_{IF} f \right] \text{ dB} \qquad (4.5\text{-}15a)$$

where p_r is the single receiver input carrier power in milliwatts

kTB_{IF} is the antenna thermal noise in milliwattts within the IF bandwidth, B_{IF}

f is the receiver noise factor expressed as a number so that F = 10 log f dB,

k is Boltzman's constant, 1. 3804 x 10^{-20} millijoules/K°,

and T is the antenna noise temperpera:ue (taken to be 290°K) .

4.5.20.12 The relationship between carrier-to-noise (C/N) and equivalent voice channel signal-to-noise ratio (S/N) for the linear region above FM threshold (both in decibels) can be expressed by [5]:

$$S/N = C/N - PF - NLR + 20 \log \frac{\Delta F}{f_m} + 10 \log \frac{B_{IF}}{b_c} \text{ dB} \qquad (4.5\text{-}15b)$$

where PF is the base-band peak-to-RMS voltage ratio in dB (12F is generally assumed to be 13.5 d33),

NLR is the RMS noise loading ratio in dB (i.e., NLR = -10 + 10 log n where n is here the number of voice channels for all new equipment. Other loading factors may have to be considered when using NLR to evaluate circuits with older equipment).

Δ F is the peak carrier deviation in Hz due to the composite baseband signal,

f_m is the highest baseband modulating frequency in Hz,

B_{IF} is the IF bandwidth in Hz,

and b_c is the usable voice channel bandwidth (taken to be 3100 Hz).

The relationship used to convert per-channel RMS deviation to peak composite carrier deviation is [5):

$$\Delta F = (\delta f)\,(nlr)\,(pf) = (\delta F)\,(pf) \qquad (4.5\text{-}15C)$$

where pf is the numerical ratio of peak to RMS baseband voltage, or $pf = \text{antilog}\ \frac{PF}{20}$,

nlr is the numerical ratio of RMS baseband voltage to RMS channel test tone voltage or $nlr = \text{antilog}\ (\frac{NLR}{20})^2$

bf is the per-channel test tone RMS carrier deviation.

4.5.20.13 The factor $\Delta F/f_m$ is sometimes referred to as the deviation ratio or modulation index of the system, although strictly speaking, the modulation index is defined only for a single tone modulating a carrier. The system constants PF and NLR relate this composite modulation index to the modulation index of the top channel considered individually. The term $10 \log B_{IF}/b_c$ corrects for the fact that C/N has a noise bandwidth of B_{LF} while a single voice channel (to which S/N applies) has a much narrower noise bandwidth b_c. Thus for any system capacity (number of equivalent 4-kHz voice channels), the S/N can theoretically be increased to any desired extent by increasing the composite deviation ratio $\Delta F/f_m$. Note that as wider deviations are employed, the receiver to dwidth, B_{IF}, must be increased in accordance with [56; p. 171]

$$B_{IF} = 2(\Delta F + f_m) \text{ Hz.} \qquad (4.5\text{-}16)$$

4.5.20.14 While the predetection carrier-to-noise ratio, c/n, is useful parameter in system design, it is usually much easier to deal with (and measure) the receiver input signal power, p_r. In fact p_r is the carrier power, c, in the ratio, c/n, but it is normally expressed in decibels relative to 1 W or 1 mW and denoted P_r (= 10 log p_r). To convert one to the other, it is necessary to evaluate the components of the noise power, n, in c/n. One comporient is the thermal noise, kT, which is received by the antenna as discussed first in section 4.2.17. Here, k is Boltzmann's constant and T is the antenna noise temperature in ^{o}K, kt represents noise power per hertz of bandwidth. AIThough this noise is very broadband, the communication receiver is a device which is sensitive to signais over a limited bandwidth so that only rhe noise contained in the spectrum of interest to the receiver must be considered. Thus the power per hertz of bandwidth is multiplied by the bandwidth to arrive at a total noise power n, which is the product, kTBif expressed in watts or milliwatts.

4.5.20.15 Another noise component is introduced by the receiving system itself It arises as a consequence of the fact that no receiver or amplifier In reproduce the input signal at the output without adding nouse to the signal. This means that the output signal-to-noise ratio, s_{out}/n_{out} is ess than the input signal-to-noise ratio, s_{in}/n_{in} This may be expressed by using a factor, f, so that

$$s_{out} / _{out} = s_{in}/fn_{in} \qquad (4.5\text{-}17)$$

or rearranging,

$$f(s_{out}/n_{out} = s_{in}/n_{in}. \qquad (4.5\text{-}18)$$

f is a positive number greater than one and is assumed to be independent of input and output signal levels (within the dynamic range of the device), and is therefore a fixed system constant. It is called the <u>noise factor</u> if expressed as a number and the <u>noise figure</u> if expressed in logarithmic (dB) units (F = 10 log f). Since it is a multiplier of the input noise, then the <u>equivalent noise</u> at the input of an ideal amplifier or receiver (that is one which adds no noise) would be the product:

$$n_{in}(\text{equivalent}) = kTB_{IF}f \text{ W or mW.} \qquad (4.5\text{-}19)$$

n_{in} is the noise power, n, in the ratio c/n discussed in subsection 4.5.20.10.

4.5.20.16 Figure 4.5-8 shows the effects of a preselector filter on the equivalent noise in the IF. Although no transhorizon receiver is operated without an RF preselector filter, it is sometimes either necessary or convenient to measure the noise figure of a receiver without the preselector filter. The figure illustrates that the noise figure of the receiver without the preselector will appear to be 3 dB greater than the actual operating noise figure and this must be taken into account in system measurements and evaluation.

4.5.20.17 Based on the preceding discussion and using equation (4.5- 19), equation (4.5-5b) can be written in terms of P_r as:

$$S/N_t = P_r - PF - NLR + 20 \log\left(\frac{\Delta F}{f_m}\right) - 10 \log kTb_c f \text{ dB.} \qquad (4.5\text{-}20)$$

This equational, then, relates the output voice channel signal-to-noise ratio in dB S/N_t, to the receiver input powers, P_r, in dBw or dBm by a number of system constants which may be chosen to provide the

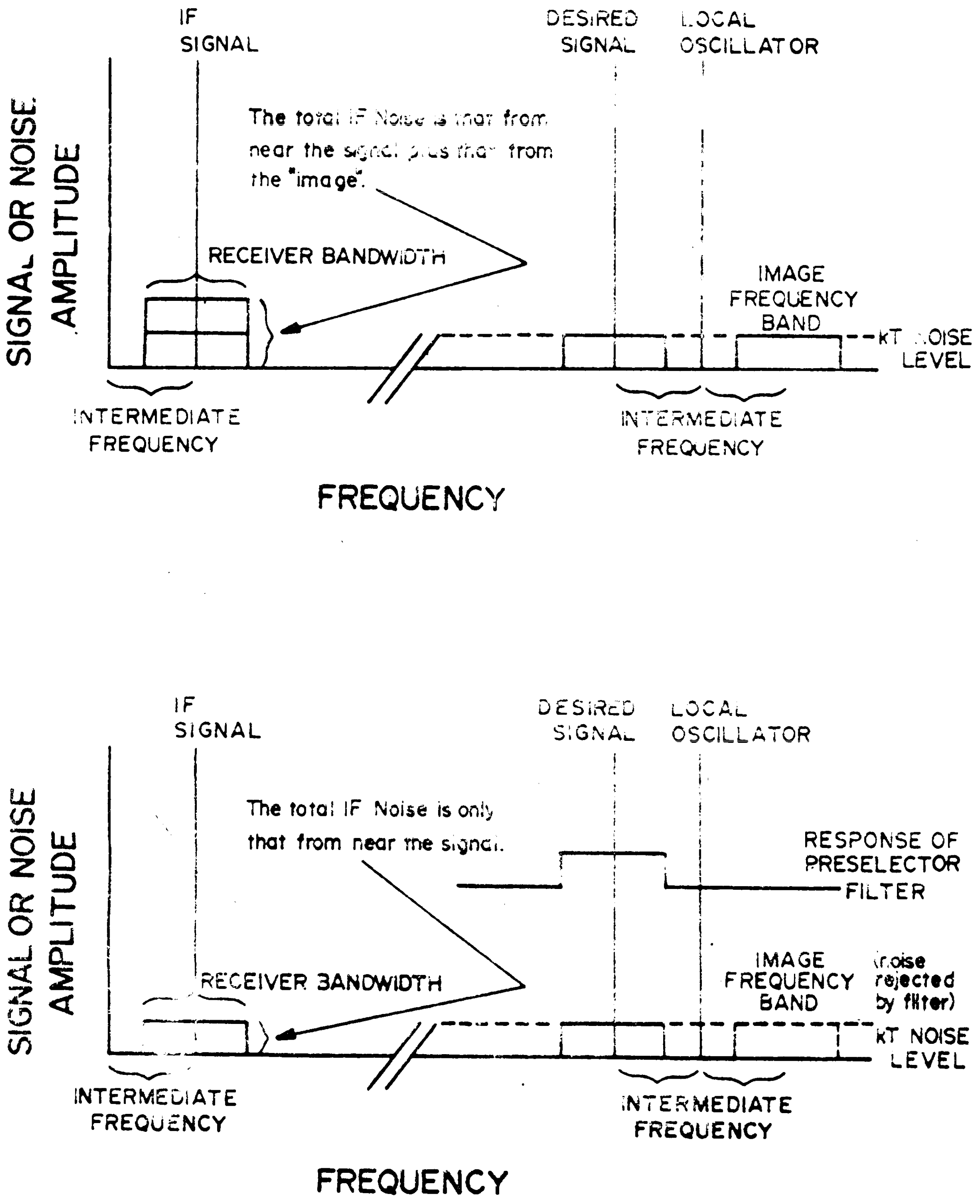
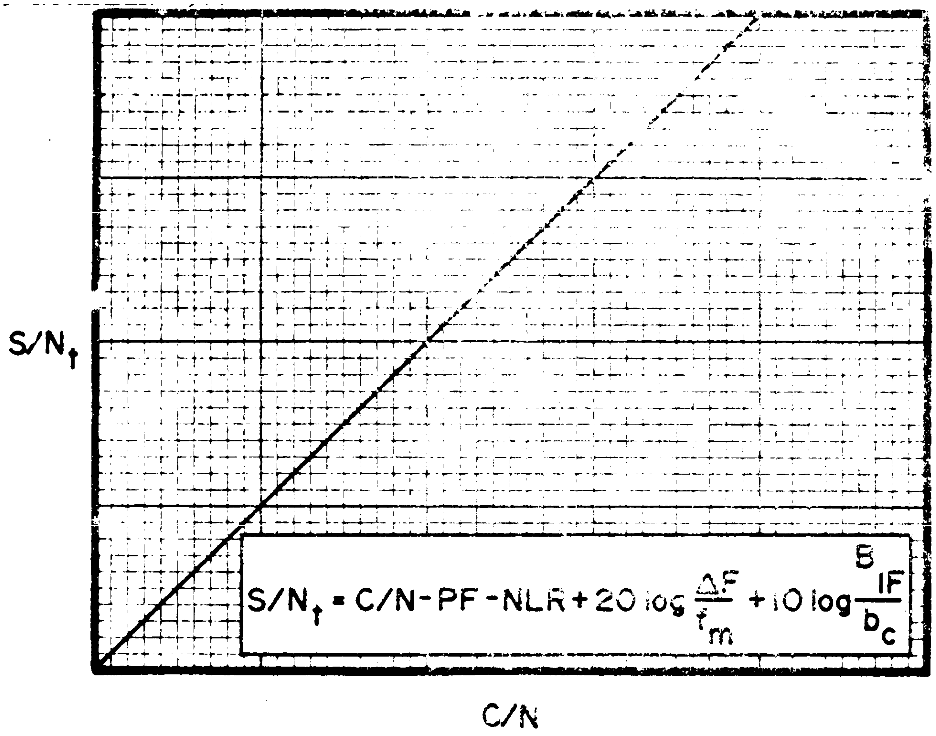


Figure 4.5-8 Illustration of the Effect of a Preselector Filler on IF Noise.

quality of service desired. The voice channel signal-to-noise ratios calculated from the above equations are interpreted as the decibel ratio of RMS test tone power (0 dBm0) to average t Thermal noise power in the top baseband voice channel. The equations do not include considera - tion of other noise contributions such as those arising from equipment inter modulation or from multiplex nor do t hey include factors for noise reduction expected from the use of pre - and de-emphasis.

4..5.20.18 If equations (4.5-15b) and (4.5-20) are plotted with S/N_t versus P_r or C/N, t he result is a straight line extending over all values of C/N or P_r as Shown in figure 4.5-9. However, this is not a true representation of the complete action of an FM discriminator. An FM discriminator must be provided with a signal from which all amplitude variations (due to additive noise or signal level variations) have been removed since the discrimiator will demodulate amplitude modulation as well as frequency modulation. In order to provide such a signal to the discriminator, the IF signal is passed through an amplitude limiter which clips its peak voltage excursions. This system works well provided that the. amplitude variations due to additive noise remain considerably lower than the sigal amplitude. However, when the RMS value of signal power decreases until it is only 10 dB greater than the RMS noise power, the noise peak levels begin to exceed the RMS signal level, the limiter output contains subs'antial noise power, and the output signal-to-noise ratio is degraded. Further decrease of signal level causes a rapid decrease in output S/N_t. While at high values of C/N or $P_=$ levels the linear relation in (4.5-15b) or (4.5-20) is applicable and the output S/N_t decreases one dB for a one dB reduction in C/N or P_r, at values of C/N equal to or less than 10 dB, a one dB reduction in C/N or P_r causes a much larger reduc- tion in S/N_t. This is illustrated in figure 4.5-10. The value C/N



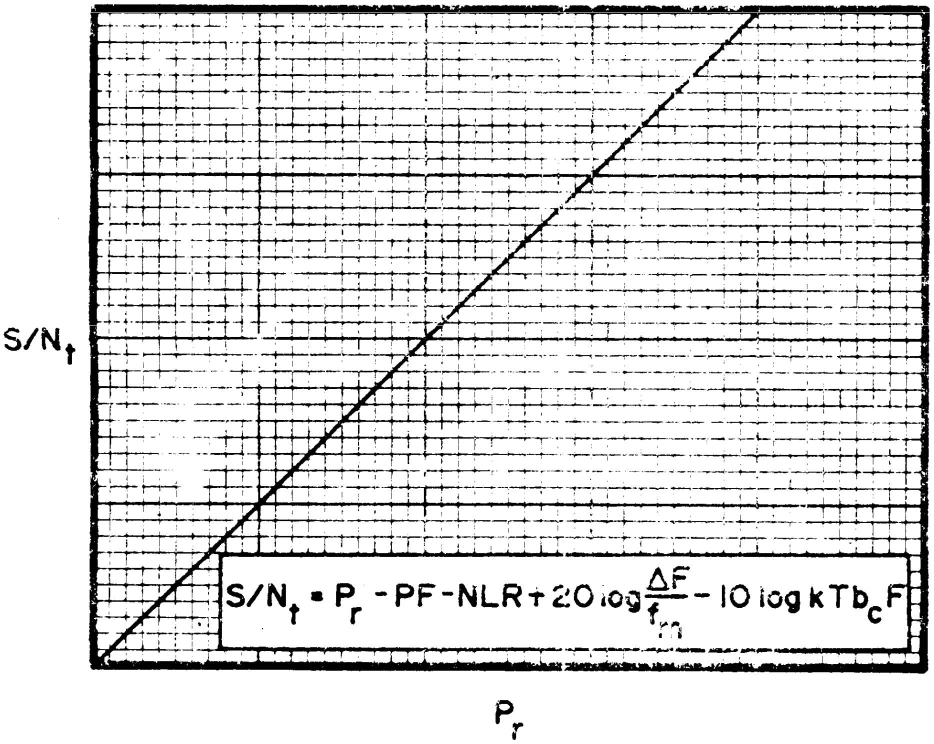
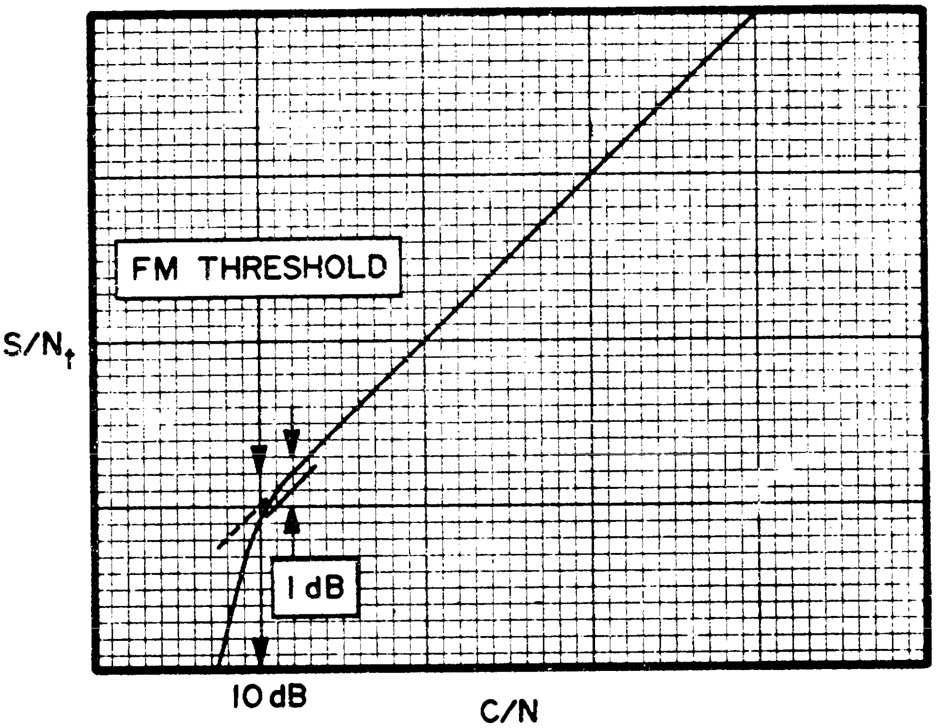


Figure 4.5-9 Equations 15 and 20 in Graphical Form



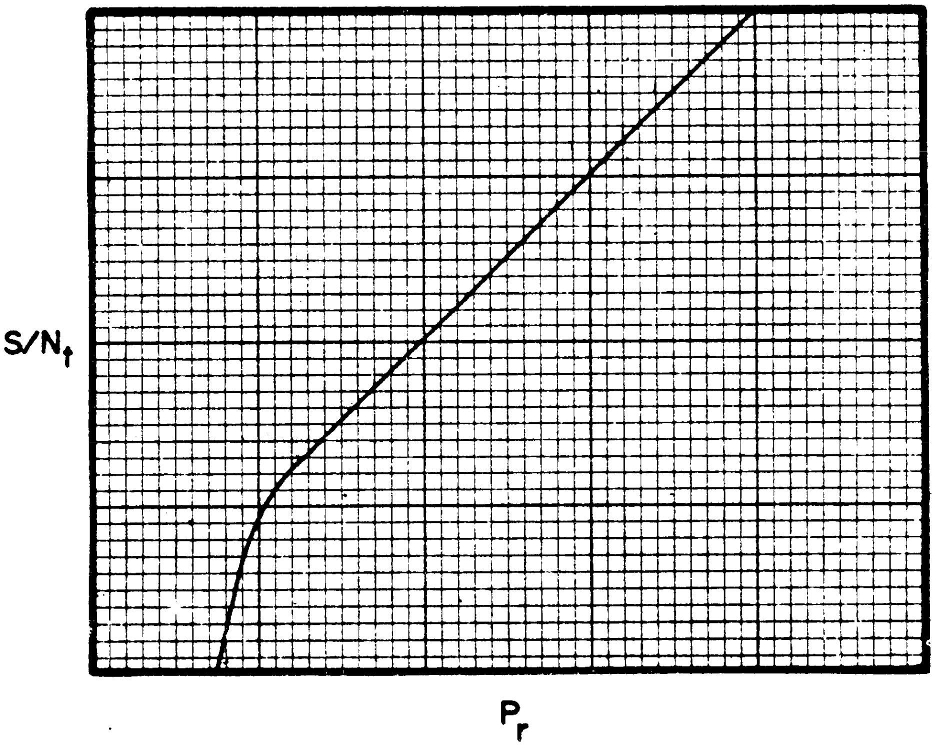


Figure 4.5-10 ILLustration of FM Threshold

= 10 dB and the corresponding value of P_r are kn as the FM threshold of the receiver and this :s generally the lower limit of usable performance. To calculate the receiver input power, Pr(th), at FM threshold we may write:

$$C/N = 10 \text{ dB} = 10 \log p_r(th) - 10 \log \left(kTB_{IF}\right) - F \text{ dBm} \qquad (4.5\text{-}21)$$

or

$$P_r(th) = 10 \log p_r(th) = 10 + 10 \log \left(kTB_{IF}\right) + F \text{ dBm} \qquad (4.5\text{-}22)$$

where, with p in milliwatts, the term 10 log (kTB IF) is

(-174 + 10 log B_{if}) dBm, B_{IF} in Hertz.

4.5.20.19 Since transhorizon radio signais are observed to fluctionate continually and occasionally decrease to very low values, various techniques are used to extend the range of acceptable performance of systems operating over such paths. The most commonly used technique is diversity reception which is simply a system configuracion which uses several receivers at each end of the radio hop. The signais to each of the receivers are obtained either antenna antennas spaced along a line normal to the radio path or from a single antenna with the individual signals at different carrier frequencies. Some of the commonly used diversity schemes were discussed in section 4.4. 35 and shown in figures 4.4-40,41,42,43, and 4.4-44. The effects of such diversity systems on a transhorizon radio hop can be explained by referring to figure 4.5-11 [6}. The lowest curve shows a cumulative distribute-. of instantaneous values of received signal levels within the hour for a Rayleigh-fading signal which generally may be assumed for transhorizon links. Note that the signal drops 22 dB below the median or 50% value for short periods (0.5% of the hour). The upper four curves show the effects of diversity operation on such a short-term distribution. As can be seen, the dual diversity level will drop only about 8 dB for 0.5%0 of the hour and the quadruple diversity level will

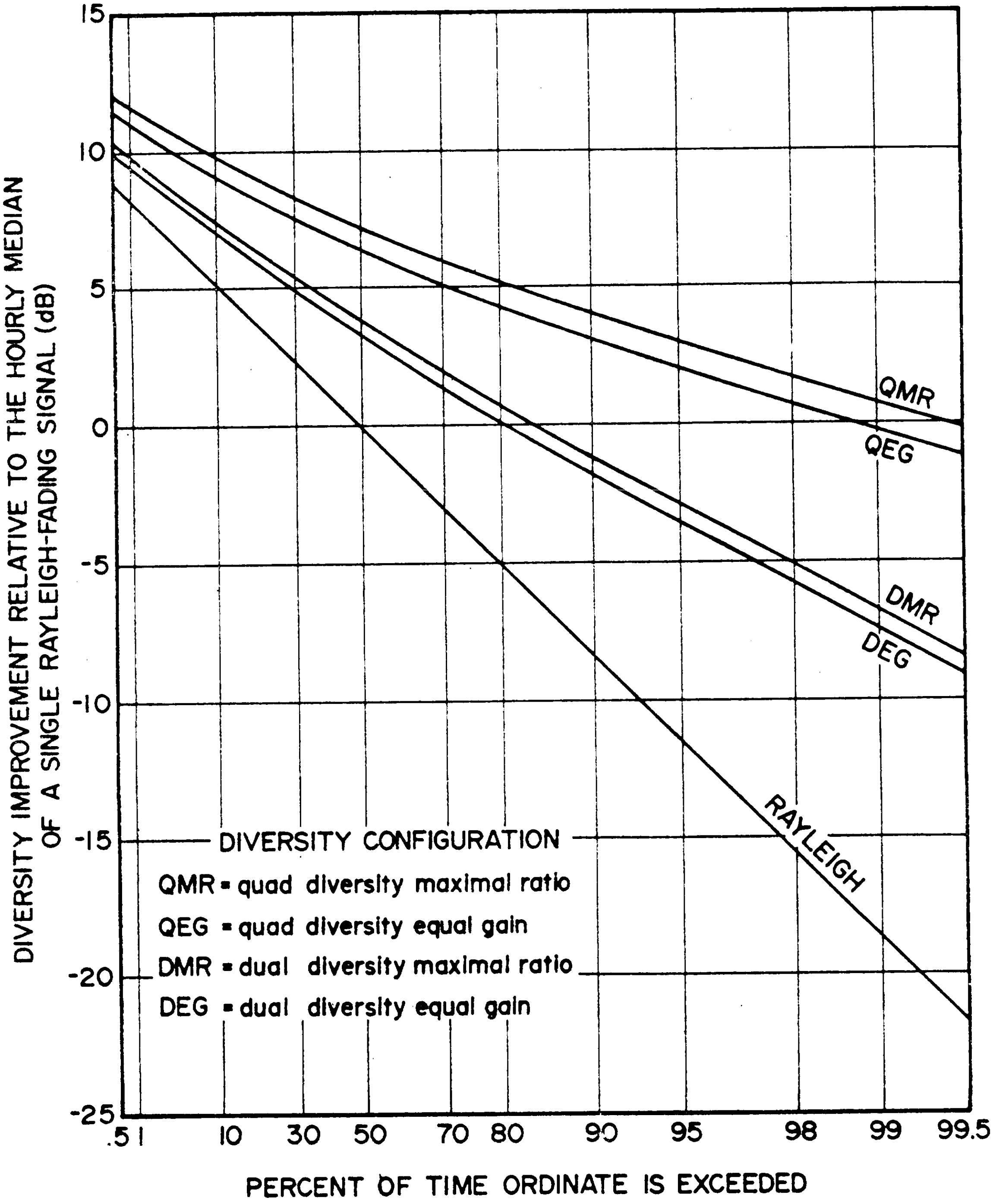


Figure 4.5-11 Diversity Improvement for Signals well above FM Threshold

almost equal the single receiver hourly median for same fraction of the hour. The curves are for various combining schemes as noted on the figure. Thus, a diversity system with a good method of combining the signals will significantly reduce the percentage of time during which low signal levels exist because of rapid, short-term fading.

4.5.20.20 Another technique which is used to increase the useful dynazmic range of an FM receiving system is called threshold extension. As the name implies, the action of a threshold extension system is to lower the received signal level at which threshold occurs. there are a number of methods to do this but basically the effective IF bandwidth is automatically reduced during low signal coalitions. This reduces the noise power level N in C/N so that the FM threshold break point is moved to a lower value of received signal level. Some of these schemes are discussed in [58]. The rationale behind all threshold extenders is that if the bandwith is narrowed, even though the intermodulation noise is greatly increased, the thermal noise in the threshold region is so large in comparison to the high intermoduation noise that the latter is of no concern since it will not noticeably degrade this already low signal-to-noise ratio. Typically, threshold extenders will reduce the receives signal level threshold point by about 7 [59].

4.5.20.21 Figure 4.5-12 illustrates, as a qualitative summary, the effect of varing the parameters or system constants under control of the system designer. Note that an increase in the modulation index ΔF - moves the FM threshold to higher values of C/N *or* P_r as does increasing the noise figure, F. * In addition, the figure shows the

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*Usually f_m has been fixed by traffic requirements.

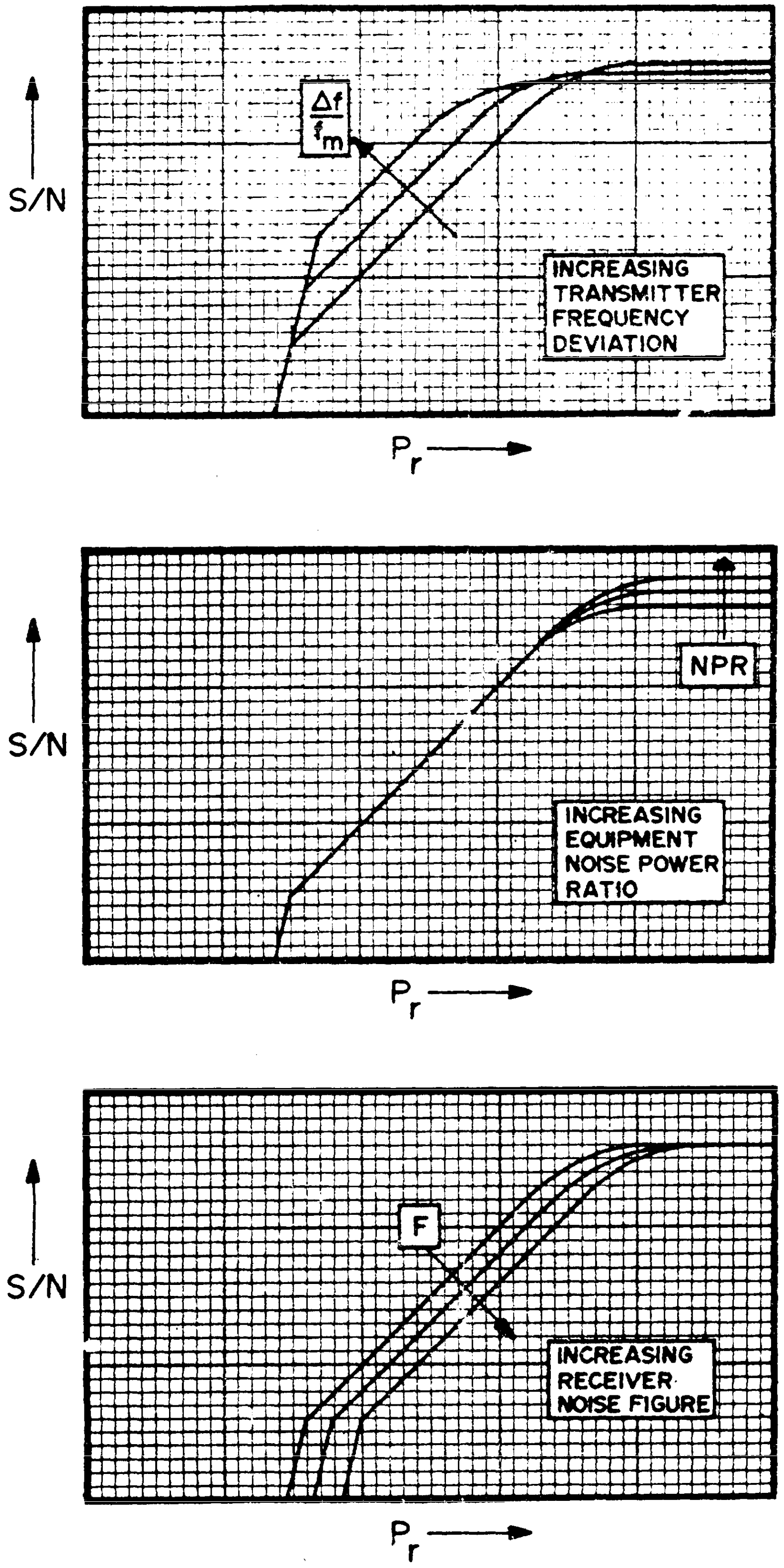

Figure 4.5-12 Effect of Parameter Varriation on Transfer Characteristics

effect of equipment intermodulation noise (expressed as the equipment noise power ratios NPR) on the S/N versus w. or P_r curves.

4.5.20.22 On a troposphereic scatter path, there is another noise component called path intermodulation noise. It results from the fact that a tropospheric scatter signal is composed of many random components which arrive over paths with different electrical lengths. Thus, the "slow" components resemble cochannel interference to the "fast" components and vice versa. Since the path intermodulation noise is a function of path physical parameters, modulation index, and antenna size, the selection of these parameters is interrelated. For increasing $\frac{\Delta F}{f_m}$ and decreasing antenna size (and increasing antenna beamwidth), path intermodulation increases. Its calculation will be described in section 4.5.26.

4.5.21 <u>System Parameter Selection</u> (Worksheets 4.5-1c, -1d, -2a, and -2b).

4.5.21.1 From the procedures in section 4.4, transmission loss cumulative distributions for all hours of the year and the corresponding distributions of single receiver input power are now available. The factors in the system equation (4.4-72) used to relate transmission loss to received signal level are antenna gain as a function of size transmission line losses (including diplexers duplexer and filters and transmitter power. They are also entered on worksheet 4.5-1d.

4.5.21.2 for the example system (see sec. 4.4.32) assume a center carrier frequency of 4.7 GHz and a channel capacity of 120 voice channels. The largest diameter of paraboiic antennas considered for this frequency band is nominally 10 m (.30 -ft)S and the maximum obtainable transmitter power is 10 kW. The cumulative distribution of basic transmission loss and related parameters for the Martlesham Heath to Hock van Holland radio hop was shown in figure 4.4-37.

4.5.21.3 The important values from this distribution are the all-year median (50%) value at the 0.5 confidence level (the center of the center line) and the 99.99% (0.9999) point at the 0.95 confidence level (the right-hand end of the bottom line). The first value, the yearly median, will determine the median system noise while the second value, approximately corresponding to the worst hour of the year, will affect the link time availability

4.5.21.4 As was discussed in section 4.4.28, the system equation is used to convert a value of (or a distribution of) basic transmission loss to a level of input signal power available to a single receiver. This has been expressed by (4.4-72) in section 4.4.28:

$$P_r = P_t + G_p - L_\ell - L_b \tag{4.5-23}$$

where

P_r is the single receiver signal level in dBm or dBW,

Pi is the nominal transmitter power in the same units as $P_{r\$}$

G_p is the effective path antenna gain in dB (see sec. 4.4.29),

L_L is the sum of all transmission line losses in dB between transmitter and antenna and antenna and receivers including the loss due to isolators, circulators, and filters,

Lb is the basic transmission loss in dB.

4.5.21.5 In selecting values for the gain components, the -strongest constraint will in most cases be the loss which is exceeded for only

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*In section 4.4 power levels were conveniently expressed in dBW (decibels relative to one watt) since for transhorizon systems transmitter powers are on the order of watts or even kilowatts. However, it has been customary for evaluation of receiver performance to use dBm (decibels relative to one milliwatt) as the basic unit.

small fractions of the year (that is the 0.9999 time availability at a 0.95 confidence level). This is because the difference between the yearly median and the worst hour is sometimes greater than 50 dB (it is approximately 40 dB for the example in figure 4.4-37). The worst hour noise will usually be thermal while the yearly median noise will be determined by intermodulation and noise resulting from equipment and path parameters which are fixed by cost and geography. For paths with small differences both short-term and long term performance goals must be considered in selecting equipment parameters.

4.5.21.6 We have previously discussed thee receiver FM threshold but the concept must be enlarged at this point to Include the equivalent combined receiver threshold. This concept is easier to describe for a predetection combiner ‘because only FM discriminator is used. Consider four individual signals feeding into a voltage adder. If the four signals are equal and are kept coherent in phase, the voltages will simply add, resulting in a signal voltage 12 dB greater than any lf. dividual signal. If we assume that the noise voltages add incoherent-iy and that four times the noise power is injected into the discriminator (6db more noise than for a single signal), the net improvement in carrier-to-noise ratio is 6 dB. Thus, the FM discriminator would reach threshold level 6 dB lower with four signals than with any one of the signals alone. The analysis for four signals whose level is varying (as is the case with tropospheric scatter or diffraction signals) is more complex but the results are similar [6]. Suffice it to say that for a predetection combining system .a median threshold improvement cf 6 db can be realized; with postdetection combining, an improvement of about 4 dB is available. This permits a minimum design value of the angle receiver C/N = 4 db at FM threshold to be used for a quadruple diversity predetection combining system and a C/N FM threshold to be used for a quadruple diversity postdetection combining system.

4.5.22 Calculate and Plot the Single-receiver Input Power Distribution for All Hours of the Year (worksheets 4.5-2a and -2b)

4.5.22.1 The problem of system design at this point reduces to one of matching as closely as possible the C/N (and correspoding received signal levels P_r) at FM threshold to the $L_b(0.9999, 0.95)$ point on the transmission loss distribution. Since this relation is linear in decibels, it amounts to adding proper ordinate scales of C/N or P_r to graphs, such as was done in figure 4.4-37.

4.5.22.2 To proceed, let us select typical parameters for the radio hop used as an example. As already noted, a 120-voice channel capacity is required and the 4.4 to 5.0 GHz band, is to be used (with a 4.7-GHz center frequency). Equipment with a predetection combining system is available as are preamplifiers with a 5-dB noise figure. The maximum antenna diameter considered will be 30 ft; free-space antenna gain at this frequency is about 50 dB from (4.4-75b) and maximum transmitter power is 10 kW. Line and other circuit element losses will be typically 4 dB total, including both ends of the path.

4.5.22.3 From figure 4.2-7, the IF bandwidth required for 120 channels may vary from 7.5 MHz for δf = 200MHz to 2.2 MHz for δf = 35 kHz(δf, also denoted by in section 4.2, is the RMS per channel deviation). Choice of a middle value of bandwidth such as 5.5 MHz for 6f = 140 kHz, will provide an allowance for changes that might be required.

4.5.22.4 From figure 4.4-37 for the example, $L_b(0.9999, 0.5)$ is 251 dB and $L_b(0.9999, 0.95)$is 275 dB. The single receiver threshold is assumed to correspond to C/N = 10 dB; thus, for the 5.5 MHz IF bandwidth and a 5-dB receiver noise figure, the threshold (from 4.5-22) corresponds to P_r(th) = 10 + 10 log (kTB_{IF}) + F = 1.6 db input power. Assuming quadruple university predetection combining, the combined FM threshold is reduced by 6 dB to -97.6 dBm. If we assume further a threshold extension of 7 db by appropriate techniques, the combined FM threshold becomes -104.6 dBmn. From the total free-space antenna gain, $G_1 + G_2$ = 100.2 dB, the loss in path antenna gain, G_p, can be determined from (4.4-77b) of section 4.4.29, or from figure 4.2-3, and is about 13.2 dB, leaving a net path antenna gain G_p = 87 dB. Then:

$$P_r(th) = -104.6 \text{ dBm}$$

$$P_t = +70 \text{ dBm (10 kW)}$$

$$G_p = 87 \text{ dB}$$

$$L_\ell = 4 \text{ dB}$$

$$L_b(0.9999,\ 0.95) = 275 \text{ dB.}$$

From (4.5-23),

$$Pr(0.99999,\ 0.95) = 70 + 87 - 4 - 275 \text{ dBm} = -122 \text{ dBm},$$

anti, for this example, a more general form of (4.5-23) is

$$P_r\ (q,\ Q) = 153 - L_b(q,\ Q) \text{ dBm.}$$

4.5.22.5 The transmission loss distribution values and their canverted values (to received signal leves) are entered on worksheet 4.5-2a together with appropriate parameters from section 4.4.28 and also plotted on worksheet 4.5-2b.

4.5.22.6 Also, note that P_r(0.9999, 0.95) is lower than P_r(th) which means that the radio hop as designed will not have a service probibility of 0.95 in the sense discussed in section 4.4.31. Since the terminals cannot be moved to shorten the path and the maximum antenna size and transmitter power and the most sensitive receiving system have been assumed, it will be necessary to calculate the relation between time availability and service probability for this hop, as was explained in section 4.4.32. Applying (4.4-90) for a time availability q = 0.9999, the corresponding standard normal deviate is obtained

$$z = \frac{P_r(0.9999,\ 0.5) - P_r(th)}{\sigma_c(0.9999)} = \frac{6.6}{15.5} = 0.426. \qquad (4.5\text{-}24)$$

From figure 4.4-36, the value Of service Probility, Q, corresponding to z = 0.426, is about 0.665. This is the service probability in the sense explained in sections 4.4.31 and 4.4.32 during the worst hour for the given path and equipment parameters. The values obtrained here differ somewhat from those read from figure 4.4-39 in section 4.4.32.6 since in the previous analysis no consideration was given to median diversity improvement and threshold extension techniques.

4.5.22.7 If the resulting value of service probability is not acceptable, a complete redesign of this link will be necessary including perhaps a decrease in channel capacity and changed frequency allocations.

4.5.22.8 The calculations made to this point have resulted in distributions of transmission loss and received signal level for the link under design. As was pointed out in the section on calculating transmission loss, the distributions are *estimates* based on empirical data from many radio links. These distributions should *not* be treated as absolutely accurate predictions for any given link. It must be borne in mind that the basis for any statistical prediction is not the prediction of the results of individual events, but the overall average of results from many events considered together. The confidence limits shown are intended to serve as an indication that the probability of obtaining adequate service is increased if additional system margin is provided.

4.5.22.9 From the discussions in the foregoing sections, the designer should have sufficient guideline to make a rcasonable and realizable choice of pertient eq ipment parameters for initiating the final design. These choices are used to correct the preceding worksheets, and are also entered on worksheet 4.5-4.

4.5.23 Selection of the Per Channel RMS Deviation

4.5.23.1 At the start of the calculations to estimate noise in each link and in the systems the designer must make an initial selection of RMS per channel deviation. A choice would best be made by using the maximum capability of t he specific equipment or 200 kHz, which ever is less. In repeating the calculations to determine minimum noise, each succeeding choice of per channel deviation, for convenience, should should be $\sqrt{2}$ times the previous choice. The initial per channel deviation value should be entered an worksheet 4.5-4.

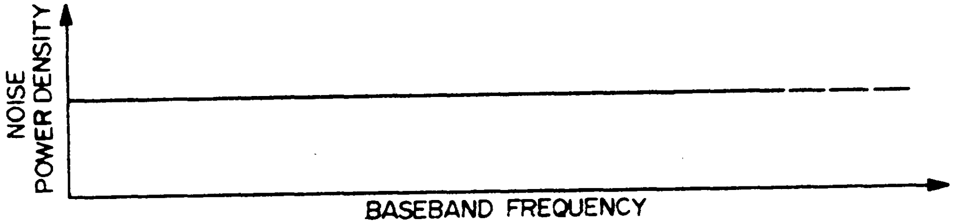
4.5.24 Equipment Intermodulation Noise Calculation (Worksheet 4.5-7)

4.5.24.1 While passing through a transhorizon radio relay system a message is present in either of two basic forms: as an amplitude-modulated signal, or as a frequency-modulated signal. The signal is normally transmitted from one station to another in frequency-modulated form, demodulated and processed in amplitude-modulated form and retransmitted in frequency-modulated form. The presence of modulation in either form causes instantaneous, nonsinusoidal changes in either voltage or frequency within the circuits. Because such circuits cannot be made completely linear and cannot respond istantanously to the instantaneous changes in voltage or frequency, modulated signals are produced by each channel of the system as a result of the modulation, and occur across a wide frequency spectrum. Although the spurious signals produced in each channel are very small, the additive effect produced by a large number of signals from a number of channels beating together forms inter modulation noise signals whose magnitude is often large enough to impair communication circuits. Some of these spurious signals will fall within the bandwidth of adjacent channels, causing intermodulation noise to appear in these channels. The magnitude of the intermodulation noise is a function of equipment characteristics, the number of channels in the system, and the modulation levels in the channels producing the noise. The higher the modulation level in the channels producing the spurious signals, the higher the intermodulation noise will be in those adjacent channels whose bandwidth include the frequencies of these noise products. The values of the intermodulation noise under specific channel loading conditions must be obtained from equipment performance specifications or the intermodulation noise must be measured under actual operating conditions.

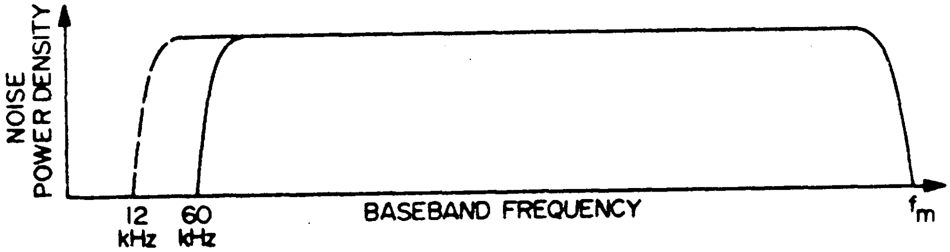
4.5.24.2 Intermodulation noise, for purposes of system noise calculation, is defined as noise from all sources that is produced as a result of the presence of a modulated signal in the system. Intermodulation noise is measured in a channel which has all modulation removed, and with all remaining channels loaded with actual traffic or with an equivalent amount of white (randomly-distributed) noise over a specific bandwidth. The intermodulation noise power in the channel is then equal to the measured total noise with modulation present less the measured thermal noise with no modulation present.

4.5.24.3 A common method of determining total noise under maximum traffic conditions consists of using a "white noise" generator to produce a noise spectrum that simulates the spectrum produced by a multichannel multiplex system. The output noise level from the generator is adjusted to a desired multiplex composite baseband level (composite noise power or NLR). The output noise illustrated in figure 4.5-13a is restricted by appropriate filters to the shape shown in figure 4.5-13b. The shape of the noise spectrum is futher modified by filters which remove the signals from narrow frequency intervals as shown in figure 4.5-13c. The depth of the notches is greater than 80 dB as shown to eliminate almost totally the signal in the notches. A noise receiver or analyzer with a response as shown in figure 4.5-13d is connected to the output of the system. Figure 4.5-13e shows the spectrum of figure 4.5-13c after it has passed through a system or device which caused a measurble amount of intermodulation distortion. In use, the spectrum shown in (b) is introduced to the system ba e-band input and the noise analyzer or receiver is normalized at each of the three slot frequency bands to a known response. The notch filters are then introduced into the signal path so that the input to the system is as shown in figure 4.5-l3c. The changes in input attenuators of the noise analyzer are equal to the difference in level in the various slots which the noise analyzer receives and is commonly called the noise power ratio or NPR as noted in figure 4.5.13e.

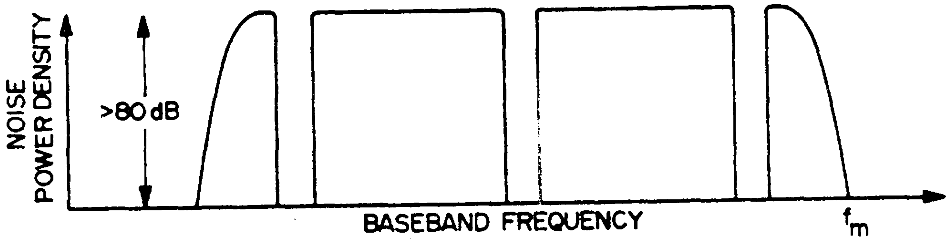
4.5.24.4 The presence of various types of non-linearities in the system will cause a poor NPR in the low, middle, or high slots and thus the technique can be used for trouble-shooting and system alignment. Commercially available equipment designed specifically for this purpose is generally used to perform the "NPR test" as it is called. When the NPR measurement is made at high RF signal levels, in an RF back-to-back configuration, the dominant component of noise is that due to equipment inter modulation. The resuiting value is used as an approximation of the equipment inter modulation noise contribution. It should be obtained from operations and maintenance records or from published manufacturer's specifications on the equipment to be used and for a stated equivalent noise loading. If reliable information



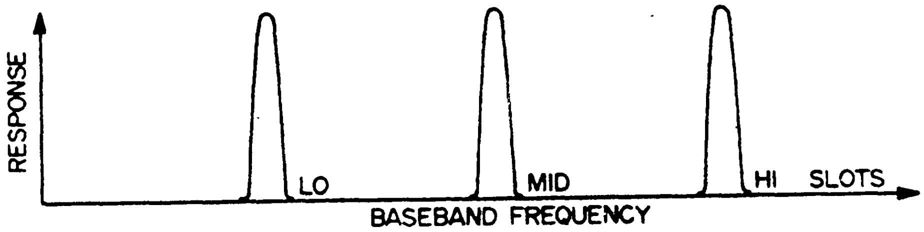
a) Unfiltered noise generator output.



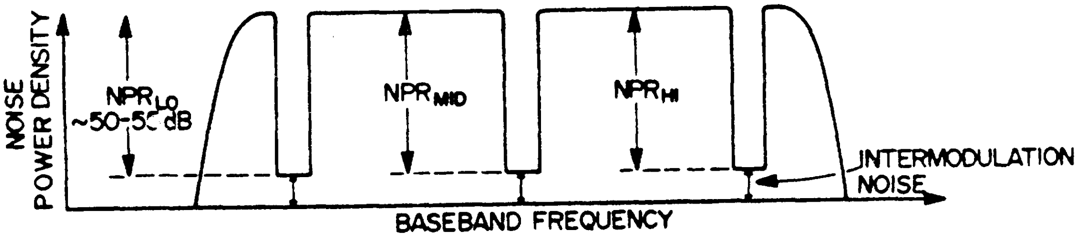
b) Noise generator output filtered to simulate multiplex signal.



c) Noise generator output filtered to simulate multiplex signal and with notch filters switched in.



d) Response of noise analyzer connected to system output.



e) System output. Note that noise level in notches has increased.

Figure 4.5-13 Noise Power Ratio Testing of Wideband Communication system is not available, an NPR of 55 dB can be assumed for new, quality equipment which is properly aligned.

4.5.24.5 The above discussions bald for remodulating. (baseband) radios. If the designer is concerned with heterodyne repeaters, a problem arises since the above measurements become very difficult to make. Again, the designer has to rely on manufacturer's specifications, or, as an alternate, to use as a "rule of thumb", a 4-dB improvement over the demodulating radio [63]. For example, if 55 dB were chosen for the remodulating radio, a 59-dB NPR would be used; or a similar heterodyne unit.

4.5.24.6 Next, the NPR can be converted to an equivalent voice. channel signal-to-equipment intermodulation noise ratio, S/N_e, and further to equipment intermodulation noise power, n_e.* In equation form this is expressed as :

$$S/N_e = \text{NPR} + 10 \log \frac{B_b}{b_c} - \text{NLR dB.}$$

$$n_e = \text{antilog} \frac{90 - S/N_e}{10} \text{ pW0},$$

where

B_b is the baseband width in Hz,

b_c is the nominal voice channel bandwidth, 3100 Hz,

"NLR is the RMS noise loading ratio in dB, and depends on the type and amount of loading used when measuring NPR (see section 4.5.20.12).".

4.5.24.7 Allocation of this calculated noise now becomes a question, particularly when there are mixed systems on a hop, i.e., a remodulating transmitter on one end of a hop and a receiver of a heterodyne repeater on the other end of the hop. Very little information exists on the noise contribution cf the individual components or even that of the transmitter and receiver separately. For an

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*As already noted, S/N_e and similar expressions in the following subsections are in decibels while lower case letters such as Designate power (usually picowatts).

engineering estimate the equipment intermodulation noise may be allocated in equal parts to the transmitter side and the receiver side of a radio hop.

4.5.24.8 The foregoing calculations are for the top voice channel of the system which is normally assumed to be the “worst” channel. The equipment intermodulation noise is considered to be independent of path loss variation or received signal level. Consequently, this will be considered as a component of the time-invariant, nonlinear noise.

4.5.25 Feeder Echo Intermodulation Noise Calaculation (Worksheets 4.5-5 and 4.5-6)

4.5.25.1 If a transmission line, many wavelengths long, is mismatched at both the generator and load ends, the frequency-phase response is linear with a small sinusoidal ripples and this leads to reflected waves in the transmission line that cause distortion of an FM signal. It is more convenient to consider this type of distortion as being caused by an echo signal that is generated in a mismatched line, and causes inter modulation distortion. The resulting intermodulation noise reaches levels that become significant when the waveguide lengths exceed approximately 20 meters per antenna, or 30 meters per hop.

4.5.25.2 The feeder intermodulation noise is also considered to be independent of path loss variations and is considered to be the second component of the time-invariant nonlinear noise. Its calculation is well treated in the literature [61, 62]. The feeder noise may be approximated, given the transmission line lengths, the velocity of propagation in the lines, the transmission system component VSWR's, and directional losses. The calculations are performed separately for each end of a hop, i.e., transmitter and receiver, and finally summed to determine the total hop contribution. The calculation proceeds as follows: determine echo delay time, wing the transmission line length, L, and the effective velocity of propagation, V, along the transmission line from figure 4. 5- 14. The delay time τ is given by:

$$\frac{2L}{V} \text{ sec}, \qquad (4.5\text{-}27)$$

where V = (3×10^8) (V/100)m/sec with v the appropriate ordinate value from figure 4.5-14. The echo delay time is then converted to radian delay ω_τ:

$$\omega_\tau = 2\pi f_m \tau \qquad (4.5\text{-}28)$$

$$= \frac{\delta F}{f_m}$$

where δF is the RMS carrier deviation given by $\delta F = \delta f($ (nlr). The parameters δf, nlr, and f_m were introduced in section 4.5.20.12; f_m and δF must be in the same units. By using the parameter A and the radian delay from (4.5-28), a value (S/D - r) for signal-to-distortion ratio S/D less the echo amplitude r (both in dB) may be determined from the curves in figure 4.5-15.

4. 5.25.3 It now remains to determine the echo attenuation, r. Consider the top illustration in figure 4.5- 15a. The echo energy at the transmitter side travels along the path shown, and is reduced by each reflection at an interface by the return loss associated with the voltage standing wave ratio (VSWR) at that interface. Such values of return loss (or VSWR) must be measured with the equipment in its operating configuration. Return loss values for the radio frequency interface, the antenna input, and the transmission line (measured at the point where it connects to the RF interface with tune antenna connected) may be assumed to be at least 26 dB corresponding to a VSWR value of 1:1.10. However, return loss values of 32 dB or better corresponding to VSWR values of 1:1.05 are not unrealistic, and are frequently specified*. The solutions between return loss, reflection coefficient, and standing wave ratio are given in the next paragraph.

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*Current military standards do not provide complete and consistent information in this respect.

4.5.25.4 The echo energy is reduced by the return loss at the antenna port the one-way attenuation through the transmission line antenna feeder, the return loss at the RF interface, and another one-way attenuation through the same line. The total echo attenuation in dB is thus the sum of these decibel losses. Similar considerations apply to the echo attenuation at the receiver side as shown in the lower portion of figure 4.5-15a. If parameters other than return loss are provided such as the VSWR or the voltge reflection coefficient, ρ, they can be converted to return loss, RL, using the following expressions which already have been given in section 4.4.49 and are repeated here for convenience:

$$P = \frac{VSWR - 1}{VSWR + 1} \qquad (4.5\text{-}30)$$

$$RL = 20 \log (1/P). \qquad (4.5\text{-}31)$$

Also, table 4.5-1 or figure 4.5-16 can be used for this conversion.

4.5.25.5 The approach described above is somewhat conservative, and may slightly overestimate voice channel feeder echo noise since it assumes that the reflections of the echo energy will result in maximum delay time and hence in nearly maximum noise. This occurs because the echo energy arriving at the RF interface in the case of the transmitter (or the antenna in the case of the receiver) in fact contains components that have been reflected at many intermediate points along the transmission line (such as waveguide joints or transitions). All of these have shorter delay times than the total echo path.

4.5.25.6 The calculation of echo attenuation (separately for transmitter and receiver) outlined above can now be converted to voice channel noise. To do this, the total echo attenuation, r, is added to the (S/D - r) value obtained from the procedures in paragraph 4.5.25.2. This results in the signal-to-distortion ratio, S/D which

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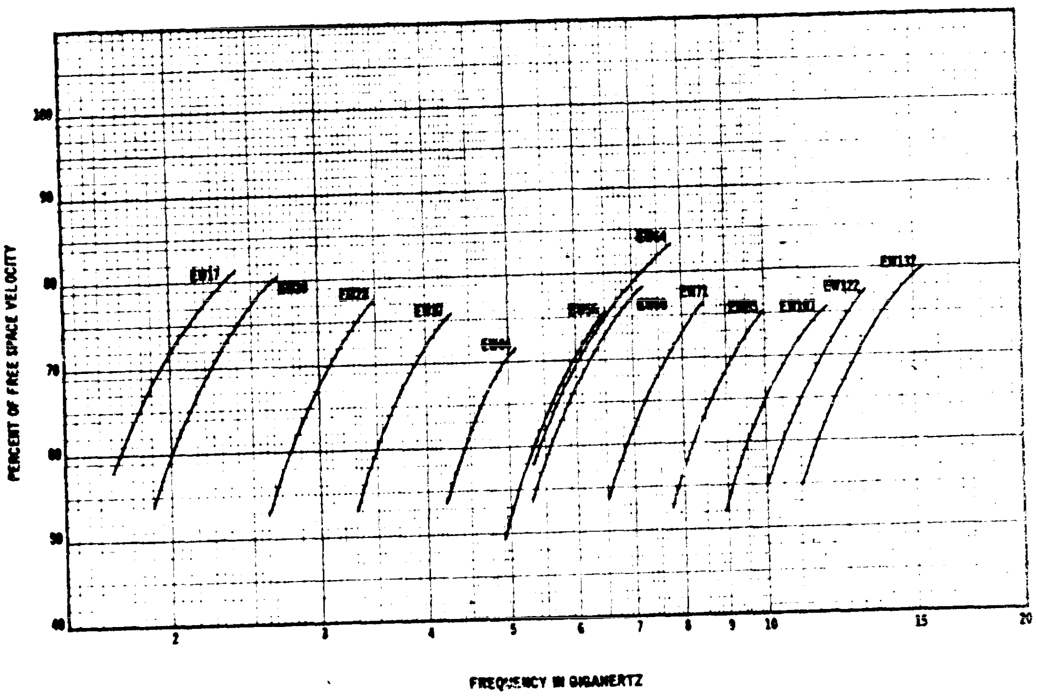
VELOCITY OF PROPAGATION FOR ELLIPTICAL WAVEGUIDE



VELOCITY OF PROPAGATION FOR RECTANGULAR WAVEGUIDE

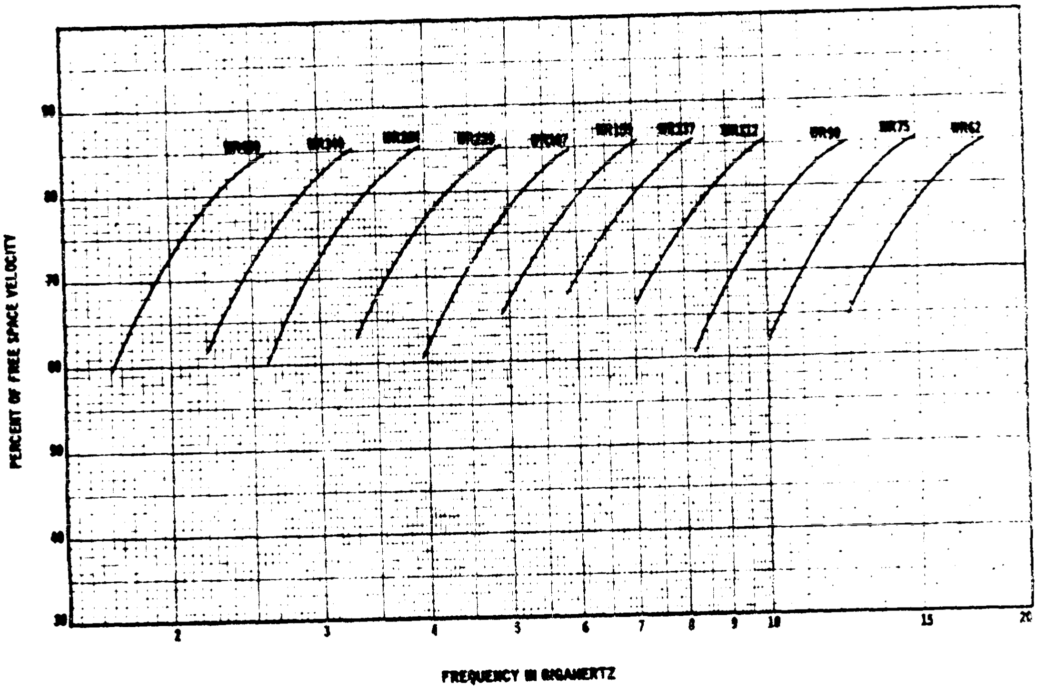


Figure 4.5-14 Waveguide Velocity of Propagation Curves

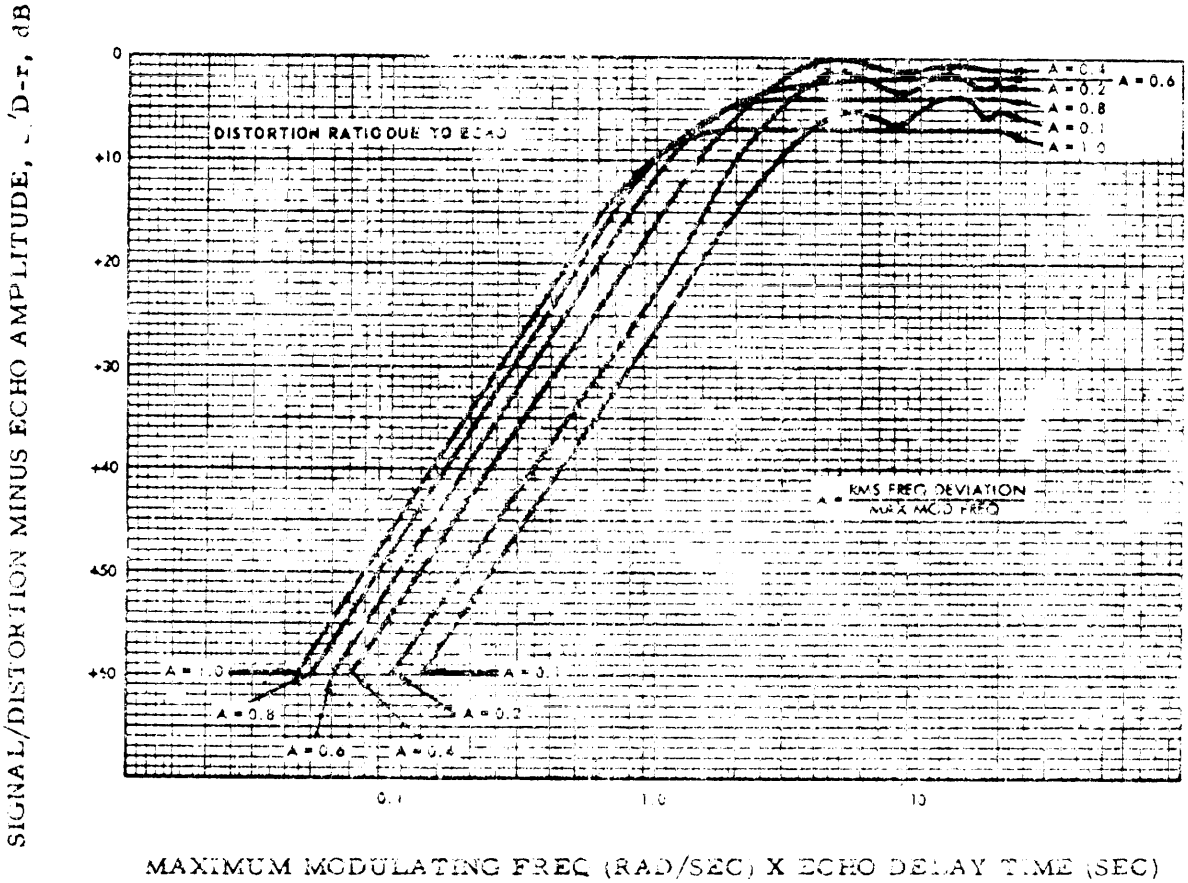


Figure 4.5-15 Maximum Distortion-to-signal Ratio due to Feeder Echo

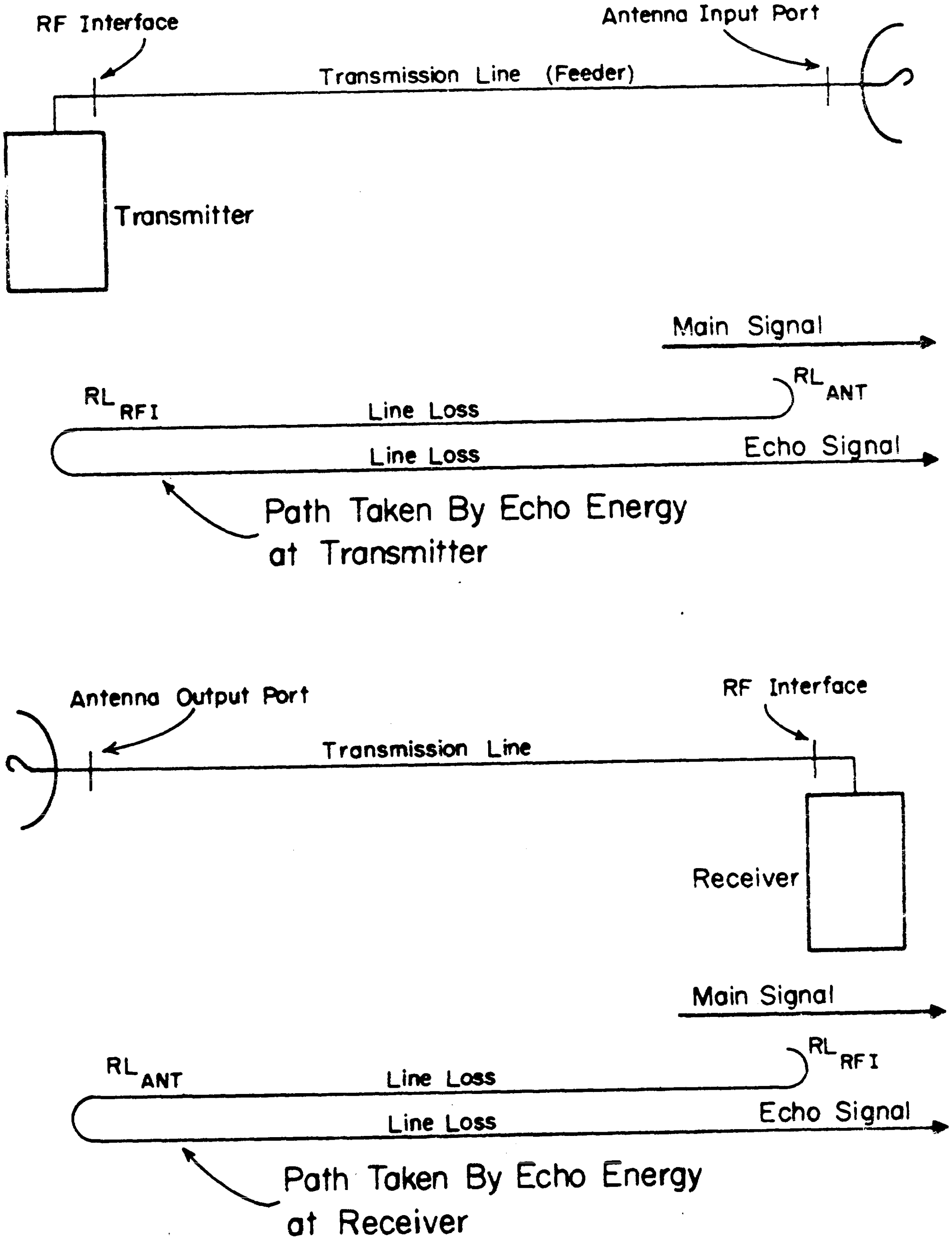


Figure 4.5-15a Illustration of Principal Signal Echo Paths

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VSWR	ρ	RL(dB)	VSWR	ρ	RL(dB)	VSWR	ρ	RL(dB)	VSWR	ρ	RL(dB)
1.001	0.0005	66.025	1.041	0.0201	33.941	1.081	0.0389	28.196	1.142	0.0663	23.571
1.002	0.0010	60.009	1.042	0.0206	33.736	1.082	0.0394	28.093	1.144	0.0672	23.457
1.003	0.0015	56.491	1.043	0.0210	33.536	1.083	0.0398	27.992	1.146	0.0680	23.346
1.004	0.0020	53.997	1.044	0.0215	33.341	1.084	0.0403	27.892	1.148	0.0689	23.235
1.005	0.0025	52.063	1.045	0.0220	33.150	1.085	0.0408	27.794	1.150	0.0698	23.127
1.006	0.0030	50.484	1.046	0.0225	32.963	1.086	0.0412	27.696	1.152	0.0706	23.020
1.007	0.0035	49.149	1.047	0.0230	32.780	1.087	0.0417	27.600	1.154	0.0715	22.914
1.008	0.0040	47.993	1.048	0.0234	32.602	1.088	0.0421	27.505	1.156	0.0724	22.810
1.009	0.0045	46.975	1.049	0.0239	32.427	1.089	0.0426	27.411	1.158	0.0732	22.708
1.010	0.0050	46.064	1.050	0.0244	32.256	1.090	0.0431	27.318	1.160	0.0741	22.607
1.011	0.0055	45.240	1.051	0.0249	32.088	1.091	0.0435	27.226	1.162	0.0749	22.507
1.012	0.0060	44.489	1.052	0.0253	31.923	1.092	0.0440	27.135	1.164	0.0758	22.408
1.013	0.0065	43.798	1.053	0.0258	31.762	1.093	0.0444	27.046	1.166	0.0766	22.311
1.014	0.0070	43.159	1.054	0.0263	31.604	1.094	0.0449	26.957	1.168	0.0775	22.215
1.015	0.0074	42.564	1.055	0.0268	31.449	1.095	0.0453	26.869	1.170	0.0783	22.120
1.016	0.0079	42.007	1.056	0.0272	31.297	1.096	0.0458	26.782	1.172	0.0792	22.027
1.017	0.0084	41.485	1.057	0.0277	31.147	1.097	0.0463	26.697	1.174	0.0800	21.934
1.018	0.0089	40.993	1.058	0.0282	31.000	1.098	0.0467	26.612	1.176	0.0809	21.843
1.019	0.0094	40.528	1.059	0.0287	30.856	1.099	0.0472	26.528	1.178	0.0817	21.753
1.020	0.0099	40.086	1.060	0.0291	30.714	1.100	0.0476	26.444	1.180	0.0826	21.664
1.021	0.0104	39.667	1.061	0.0296	30.575	1.102	0.0485	26.281	1.182	0.0834	21.576
1.022	0.0109	39.267	1.062	0.0301	30.438	1.104	0.0494	26.120	1.184	0.0842	21.489
1.023	0.0114	38.885	1.063	0.0305	30.303	1.106	0.0503	25.963	1.186	0.0851	21.403
1.024	0.0119	38.520	1.064	0.0310	30.171	1.108	0.0512	25.809	1.188	0.0859	21.318
1.025	0.0123	38.170	1.065	0.0315	30.040	1.110	0.0521	25.658	1.190	0.0868	21.234
1.026	0.0128	37.833	1.066	0.0319	29.912	1.112	0.0530	25.510	1.192	0.0876	21.151
1.027	0.0133	37.510	1.067	0.0324	29.785	1.114	0.0539	25.364	1.194	0.0884	21.069
1.028	0.0138	37.198	1.068	0.0329	29.661	1.116	0.0548	25.221	1.196	0.0893	20.988
1.029	0.0143	36.898	1.069	0.0333	29.538	1.118	0.0557	25.081	1.198	0.0901	20.907
1.030	0.0148	36.607	1.070	0.0338	29.417	1.120	0.0566	24.943	1.200	0.0909	20.828
1.031	0.0153	36.327	1.071	0.0343	29.298	1.122	0.0575	24.808	1.210	0.0950	20.443
1.032	0.0157	36.055	1.072	0.0347	29.181	1.124	0.0584	24.675	1.220	0.0991	20.079
1.033	0.0162	35.792	1.073	0.0352	29.066	1.126	0.0593	24.544	1.230	0.1031	19.732
1.034	0.0167	35.537	1.074	0.0357	28.952	1.128	0.0602	24.41[illegible]	1.240	0.1071	19.401
1.035	0.0172	35.290	1.075	0.0361	28.839	1.130	0.0610	24.289	1.250	0.1111	19.085
1.036	0.0177	35.049	1.076	0.0366	28.728	1.132	0.0619	24.164	1.260	0.1150	18.783
1.037	0.0182	34.816	1.077	0.0371	28.619	1.134	0.0628	24.042	1.270	0.1189	18.493
1.038	0.0186	34.588	1.078	0.0375	28.511	1.136	0.0637	23.921	1.280	0.1228	18.216
1.039	0.0191	34.367	1.079	0.0380	28.405	1.138	0.0645	23.803	1.290	0.1266	17.949
1.040	0.0196	34.151	1.080	0.0385	28.299	1.140	0.0654	23.686	1.300	0.1304	17.692

LEGEND: VSWR Voltage Standing Wave Ratio ρ Voltage Reflection Coefficient RL(dB) Return Loss in dB

Table 4.5-1 VSWR and Related Parameters

VSWR	ρ	RL(dB)
1.310	0.1342	17.445
1.320	0.1379	17.207
1.330	0.1416	16.977
1.340	0.1453	16.755
1.350	0.1489	16.540
1.360	0.1525	16.332
1.370	0.1561	16.131
1.380	0.1597	15.936
1.390	0.1632	15.747
1.400	0.1667	15.563
1.410	0.1701	15.385
1.420	0.1736	15.211
1.430	0.1770	15.043
1.440	0.1803	14.879
1.450	0.1837	14.719
1.460	0.1870	14.564
1.470	0.1903	14.412
1.480	0.1935	14.264
1.490	0.1968	14.120
1.500	0.2000	13.979
1.520	0.2063	13.708
1.540	0.2126	13.449
1.560	0.2188	13.201
1.580	0.2248	12.964
1.600	0.2308	12.736
1.620	0.2366	12.518
1.640	0.2424	12.308
1.660	0.2481	12.107
1.680	0.2537	11.913
1.700	0.2593	11.725
1.720	0.2647	11.545
1.740	0.2701	11.370
1.760	0.2754	11.202
1.780	0.2806	11.039
1.800	0.2857	10.881
1.820	0.2908	10.729
1.840	0.2958	10.581
1.860	0.3007	10.437
1.880	0.3056	10.298
1.900	0.3103	10.163

VSWR	ρ	RL(dB)
1.920	0.3151	10.032
1.940	0.3197	9.904
1.960	0.3243	9.780
1.980	0.3289	9.660
2.000	0.3333	9.542
2.100	0.3548	8.999
2.200	0.3750	8.519
2.300	0.3939	8.091
2.400	0.4118	7.707
2.500	0.4286	7.360
2.600	0.4444	7.044
2.700	0.4595	6.755
2.800	0.4737	6.490
2.900	0.4872	6.246
3.000	0.5000	6.021
3.100	0.5122	5.811
3.200	0.5238	5.617
3.300	0.5349	5.435
3.400	0.5455	5.265
3.500	0.5556	5.105
3.600	0.5652	4.956
3.700	0.5745	4.815
3.800	0.5833	4.682
3.900	0.5918	4.556
4.000	0.6000	4.437
4.100	0.6078	4.324
4.200	0.6154	4.217
4.300	0.6226	4.115
4.400	0.6296	4.018
4.500	0.6364	3.926
4.600	0.6429	3.838
4.700	0.6491	3.753
4.800	0.6552	3.673
4.900	0.6610	3.596
5.000	0.6667	3.522
5.200	0.6774	3.383
5.400	0.6875	3.255
5.600	0.6970	3.136
5.800	0.7059	3.025
6.000	0.7143	2.923

VSWR	ρ	RL(dB)
6.200	0.7222	2.827
6.400	0.7297	2.737
6.600	0.7368	2.653
6.800	0.7436	2.573
7.000	0.7500	2.499
7.200	0.7561	2.428
7.400	0.7619	2.362
7.600	0.7674	2.299
7.800	0.7727	2.239
8.000	0.7778	2.183
8.200	0.7826	2.129
8.400	0.7872	2.078
8.600	0.7917	2.029
8.800	0.7959	1.983
9.000	0.8000	1.938
9.200	0.8039	1.896
9.400	0.8077	1.855
9.600	0.8113	1.816
9.800	0.8148	1.779
10.000	0.8182	1.743
11.000	0.8333	1.584
12.000	0.8462	1.451
13.000	0.8571	1.339
14.000	0.8667	1.243
15.000	0.8750	1.160
16.000	0.8824	1.087
17.000	0.8889	1.023
18.000	0.8947	0.966
19.000	0.9000	0.915
20.000	0.9048	0.869
22.000	0.9130	0.790
24.000	0.9200	0.724
26.000	0.9259	0.668
28.000	0.9310	0.621
30.000	0.9355	0.579

VSWR	ρ	RL(dB)
32.000	0.9394	0.543
34.000	0.9429	0.511
36.000	0.9459	0.483
38.000	0.9487	0.457
40.000	0.9512	0.434
42.000	0.9535	0.414
44.000	0.9556	0.395
46.000	0.9574	0.378
48.000	0.9592	0.362
50.000	0.9608	0.347
55.000	0.9643	0.316
60.000	0.9672	0.290
65.000	0.9697	0.267
70.000	0.9718	0.248
75.000	0.9737	0.232
80.000	0.9753	0.217
85.000	0.9767	0.204
90.000	0.9780	0.193
95.000	0.9792	0.183
100.000	0.9802	0.174

Table 4.5-1 Continued

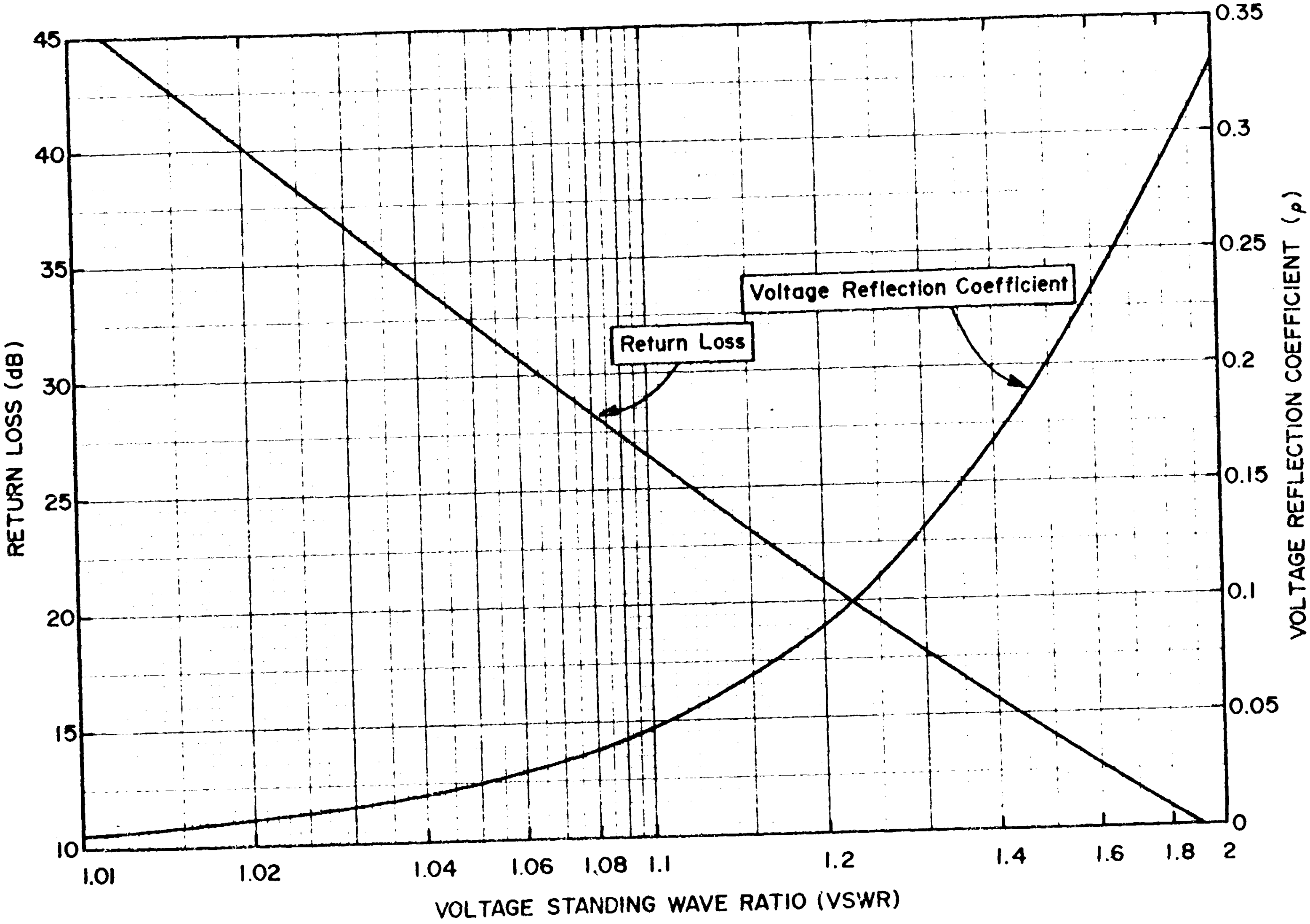

Figure 4.5-16 Return Loss and Voltage Reflection Coefficient versus VSWR

must be corrected for the ratio of baseband to voice channel bandwidth and for the RMS load factor. In equation from, the voice channel signal-to-feeder echo noise ratio becomes:

$$S/N_f = S/D + \log \frac{B_b}{b_c} - LF \quad dB \qquad (4.5\text{-}32)$$

The conversion to flat-weighted noise, n_f in pW0, is as follows:

$$n_f = \text{antilog} \frac{90 - s/h_f}{10} \quad pw0. \qquad (4.5\text{-}33)$$

The foregoing feeder echo noise calculations are performed separately for each end of a hop by arbitrarily designating one end the transmitter and the other end the receiver. At the conclusions these two noise results are summed together to give a total hop feeder echo noise contribution.

4.5.26 Path Intermodulation Distortion

4.5.26.1 The transmission of signals by way of the scatter mechanism has characteristics of random multipath or in a conceptually simpler view, a multitude of echoes. These echoes produce the same type of intermodulation noise as that due to mismatches in a transmission line. The transmission path may be approximated by a two-path model, consisting of the path described by the center lines of the antenna main beams and a second path described, by the ray emanating from and arriving at a angle coincident with the antenna half-beamwidths. The analysis of path delay and path intermodulation distortion predictions is well treated in Beach and Trecker [64]* and Sunde [65]; in this handbook we will follow basically sunde's approach.

4.5.26.2 Path delay (called "differential transmission delay" by Sunde) is the time difference between signals arriving via a path described by the center lines of the antenna main beams and a path originating and arriving at an angle from the center line which corresponds to one-half of the half-power antenna beamwidth. Using the approximate equation (22)in Sunde's derivation [65], we make the simplifying assumptions that (a) the antenna beam centers are aligned on the radio horizon, (b) the path is symmetrical with $\alpha_o = \beta_o = \theta/2$ (see sec.4.4.17.1), and (c) the antenna sizes at each end of the Path are equal. For unequal antenna sizes the average of the two beamwidths is used. The path delay, Δ in seconds, can then be simply expressed as a function of the path distance d in km and the antenna half-power beamwidth Ω in radians:

$$\Delta = \frac{d^2\Omega}{2.16 \times 10^{10}} + \frac{d\Omega^2}{4.8 \times 10^6} \text{ seconds.} \qquad (4.5\text{-}34)$$

"The half-power beam with Ω in radians can be obtained from θ_n, which is in degrees, by the relation $\Omega = 0.01745\ \theta_n$ degrees. θ_n is plotted in figure 4.4-48 as a function of the antenna gain.".

Equation (4.5-34) has been put in graphical form in figure 4.5-17 with Ω labeled in degrees for easier use. From (19) in [65], the ratio of the median intermodulation noise power, p_i, to the median signal power, p_s, can be written as:

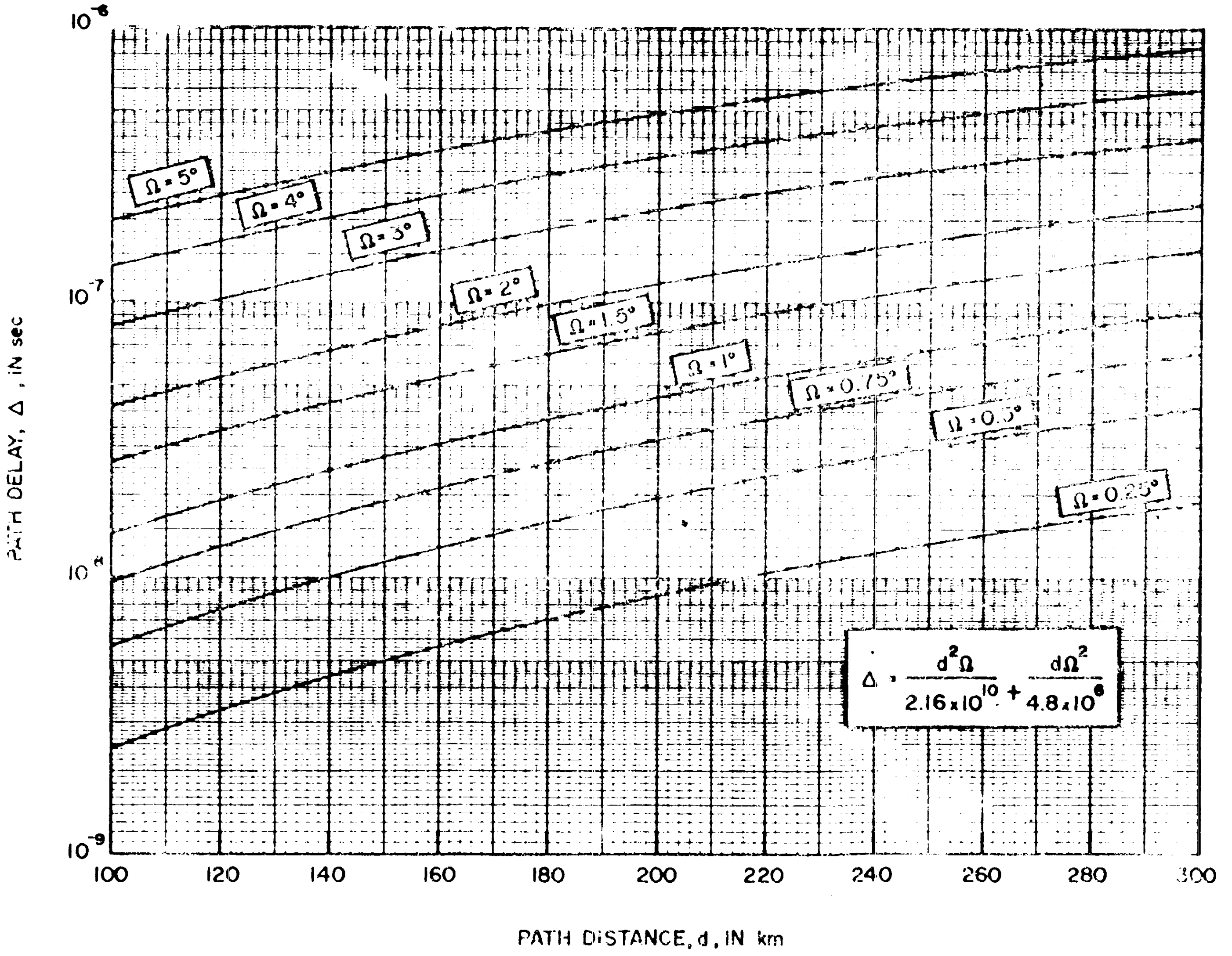

Figure 4.5-17 Multipath Echo Delays as a Function of Antenna Beamwidth and Distance

$$P_I/P_s = 0.192 \frac{B_b^2}{(\delta F)^2} H\left[8\Delta^2(\delta F)^2\right] \qquad (4.5\text{-}35)$$

where

B_b is the baseband width in Hz,

δF is the RMS carrier deviation in Hz,

Δ is the path dely in seconds.

Note that (4.5-35) expresses a numerical ratio and is not in dB.

4.5.26.3 The function $H[8\Delta^2(\delta F)^2]$ is shown on figure 4 of [65], but may be replaced by $64\Delta^4(\delta F)^4]$ for $[8\Delta^2(\delta F)^2] \leq 0.5$. For this condition, (4.5-35) may be simplified and brought into logarithmic form similar to the expressions for other signal-to-noise ratios. Additionally, we replace the RMS carrier deviation δF with the RMS per channel deviation δf (see the definitions of section 4.5.20.12) and obtain the signal-to-intermodultion noise ratio S/I in dB:

$$S/I = -10.89 - NLR - 20 \log B_b - 20 \log \delta f - -40 \log \Delta \, dB, \qquad (4.5\text{-}36a)$$

where

$$20 \log \delta f = 20 \log \delta F - N \qquad (4.5\text{-}36b)$$

4.5.26.4 S/I may also be thought of as a "path noise power ratio"; thus, the following corrections for bandwidth and load factor can be made to obtain the signal-to-voice channel noise ratio, S/N_p in dB, due to path inter modulation:

$$S/N_p = S/I + 10 \log \frac{B_b}{b_c} - NLR \qquad (4.5\text{-}37)$$

Here,

B_b is the baseband width in Hz, as before,

b_c = 3100 Hz is the voice channel bandwidth,

NLR is the RMS noise loading ratio in dB.

By substituting (4.5-36a) into (4.5-37), the final expression for the signal-to-voice- channel intermodulation noise ratio in dB is obtained:

$$S\backslash N_p = -10.89 - 2(NLR) - 10 \log B_b - 40 \log \Delta - 20 \log \delta \\ -10 \log b_c \, dB. \qquad (4.5\text{-}38)$$

This expression is plotted in figures 4.5-18 to 4.5-21 for various values of the RMS per channel devation δf for 60, 120, 180, and 240 voice channels, and using the RMS load factor NLR = -10 + 10 log n from the DCS Standards where n is the number of voice channels. Note again that these graphs are only applicable to the condition $[8\Delta^2(\delta F)^2] \leq 0.5$ as stated above.

4.5.26.5 It should also be noted that the above equations include an emphasis improvement factor, as noted in [65]. On the other hand, diversity improvement is not included and should be applied to reduce the path intermodulation noise as indicated worksheet 5-7a.

4.5.26.6 The foregoing establishes a measuring signal-to-path intermodulation noise ratio. Experimenal work has established that path intermoaulation noise varies directly as transmission loss, and empirical results [64] suggests on the average a 0.7-db increase in noise for every one dB increase in transmission loss. By using this proportionality constant, the design can evauate the dynamic effects of path inter modulation noise.

4.5.26.7 Other methods for predicting path intermodulation noise may be used, such as those by Beach and Trecker [64], or those based on the work of Medhurst [62]. The choice of the Sunde method [65] was made here for its ease of use in approximating system performance. Very little, if any, information has been published on the comparative parative prediction accuracies of these various methods for a variety of path geometries.

4.5.26.8 The above path intermodulation noise calculations apply only to the tropospheric scatter propagation mechanism. One may

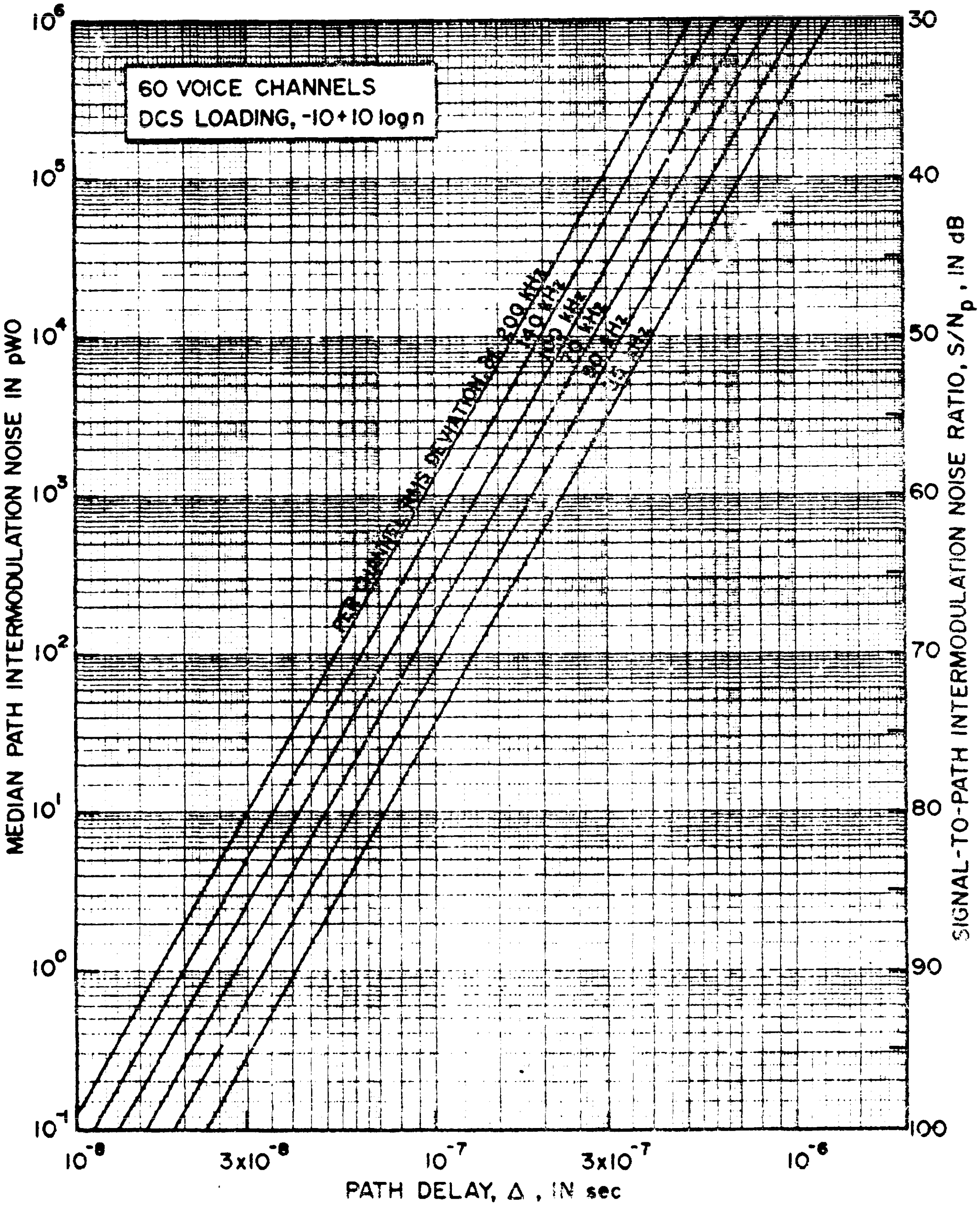

Figure 4.5-18 Path intermadulation as a Function of Per Channel Deviation and Path Delay for 60 Channels

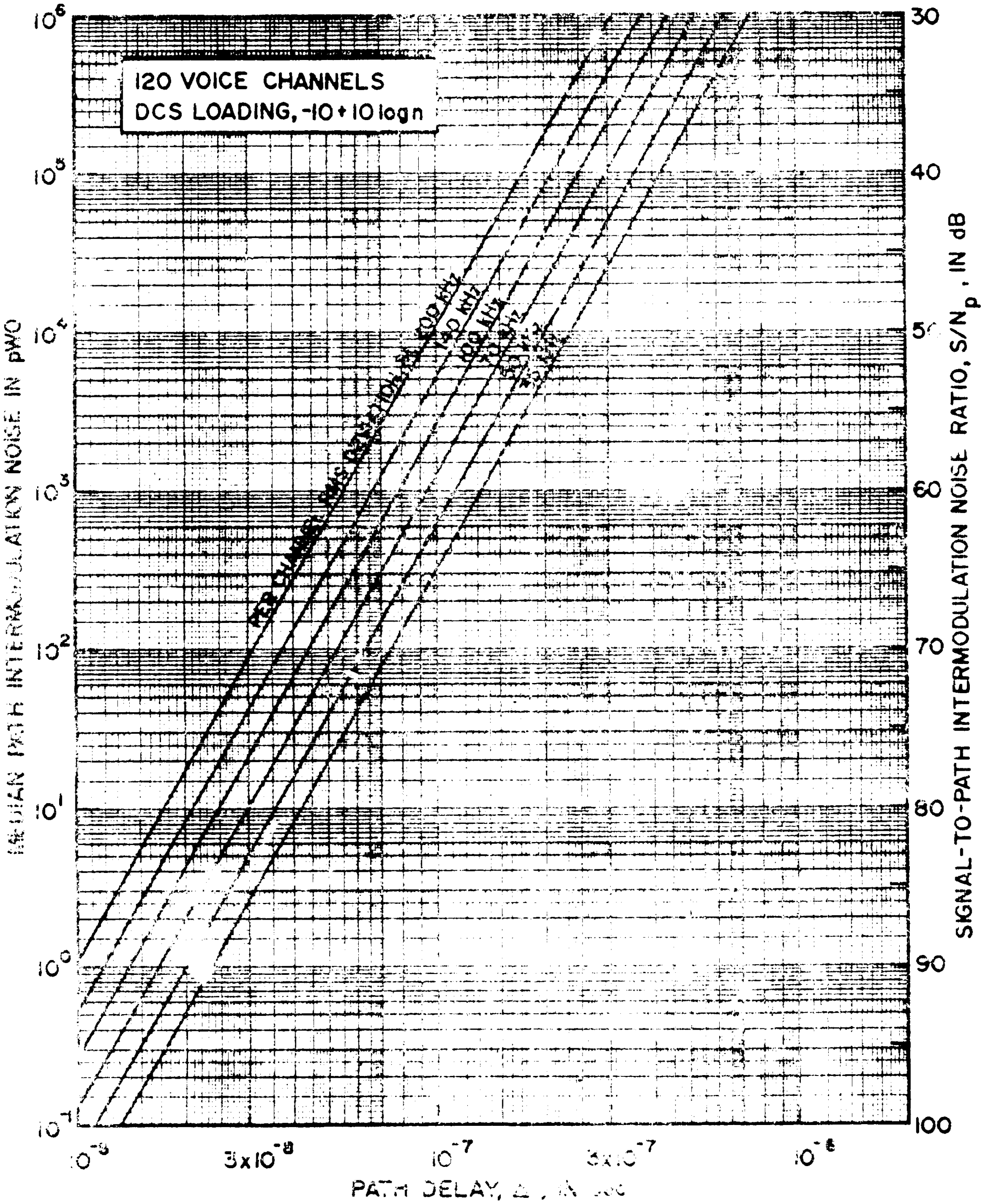

Figure 4.5-19 Path Intermodulation as a Function of Per Channel Deviation and Path Delay for 120 Channels

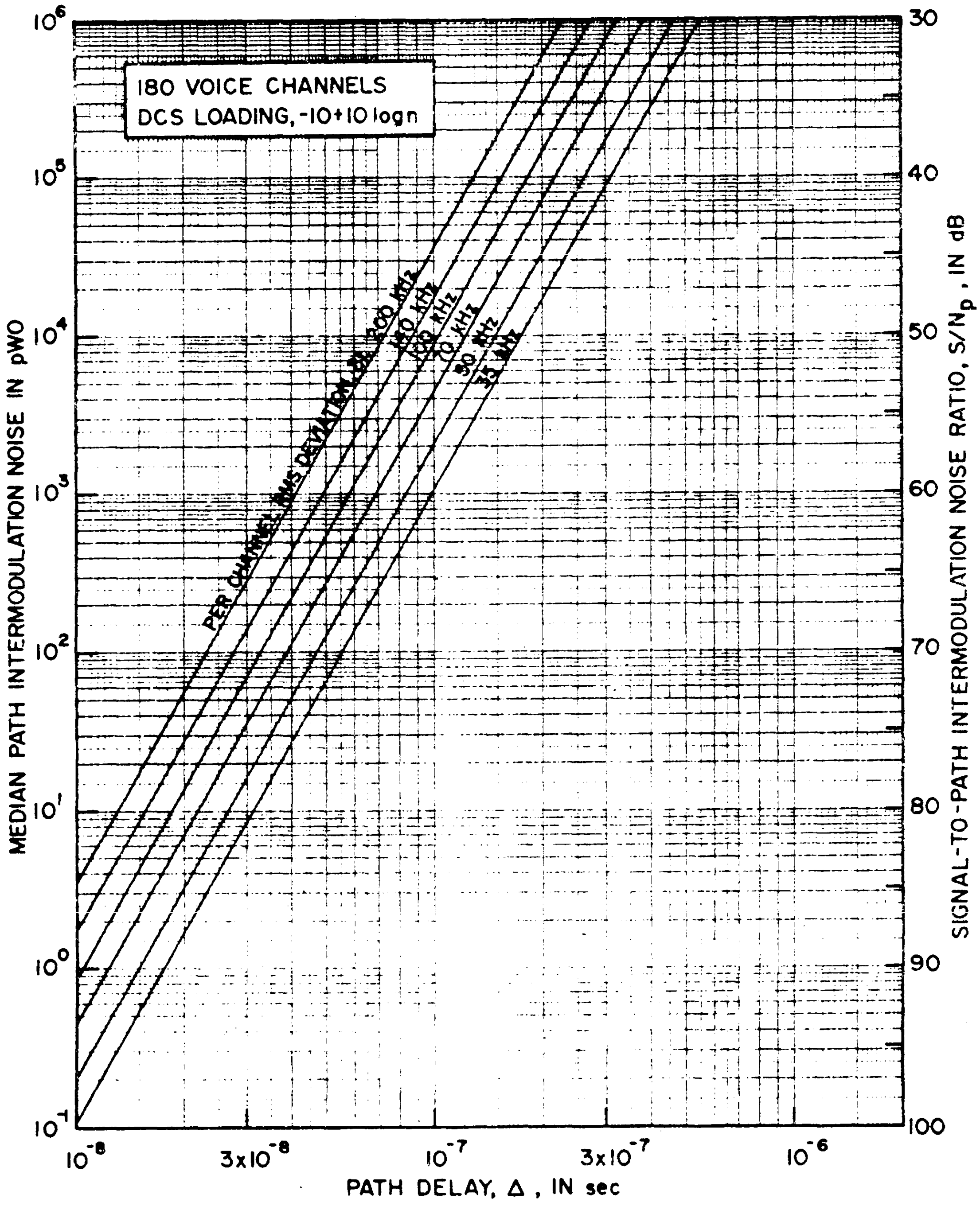

Figure 4.5-20 Path Intermadulation as a Function of Per Channel Deviation and Path Delay for 180 Channels

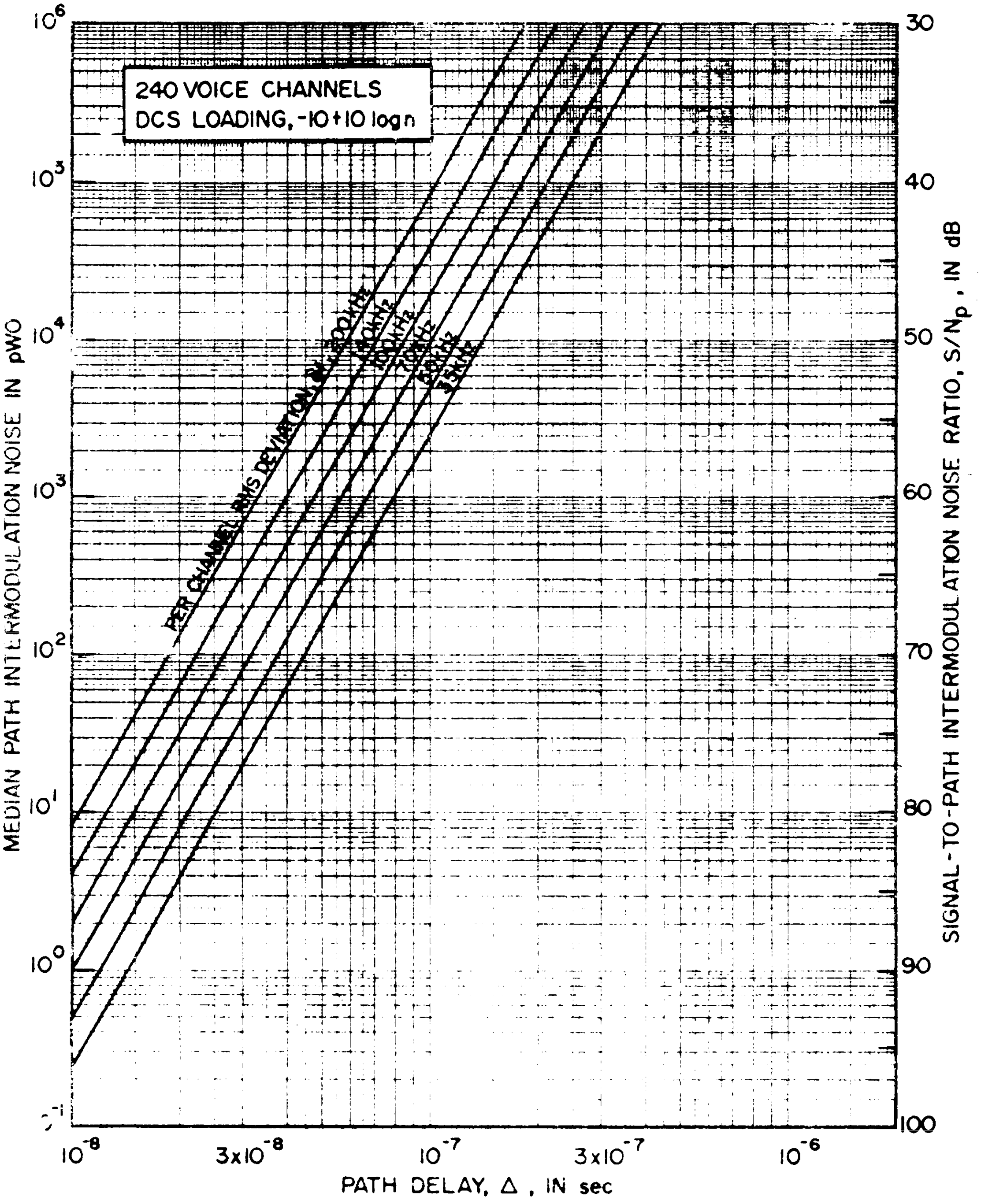

Figure 4.5-21 Path Intermadulation as a Function of Per Channel Deviation and Path Delay for 240 Channels

assume this noise component to be negligible for single and double obstacle diffraction propagation and for smooth earth diffraction.

4.5.27 Time -invariant Nonlinear Noise

4.5.27.1 The sum of the total feeder echo noise and equipment intermodulation noise in this design has been defined as the time-invariant nonlinear noise. Since these noise components do not depend on the path loss variability, their sum, in addition to the path intermodulation noise component, is normally the dominant contribution for relatively high signal levels above the long-term median. Thus, an approximation for long-term median noise calculations may be made by omitting the smaller thermal noise contribution which will be discussed in the following paragraph. Conversely, the total nonlinear noise may be dropped as an approximation in the short-term noise calculation for low signal levels near FM threshold, since in this case the thermal noise contribution will be the dominant factor.

4.5.28 Calculation of Yearly Median Thermal Noise (Worksheets 4.5-7a and -7b)

4.5.28.1 For purposes of system noise calculations, thermal noise is defined as the noise from all sources that is present in a channel when there is no modulated signal present on any of the channels in the system. By this definition, thermal noise includes atmospheric and cosmic noise, and all intrinsic and thermal noise produced in the equipment when no modulation is present. Thermal noise is measured in a channel with all modulation removed from all channels of the system.

4.5.28.2 The signal-to-thermal noise ratio, S/N_t in dB, in an FDM-FM system is a function of transmission loss variability. As the loss on a hop becomes low, i. e., the received signal level becomes high the thermal noise is quite low and as received signal level approaches FM threshold, the thermal noise becomes proportionally higher. Signal-to-thermal noise ratio, therefore, is proportional to received signal level or carrier - to-noise ratio as shown in (4.5-15b), and may also be expressed (using the customary decibel notation) in several other forms as follows:

$$S/N_t = P_r + 20 \log \left(\frac{\delta f}{f_m} \right) - 10 \log \left(kTb_c \right) - F \text{ dB} \qquad (4.5\text{-}39)$$

$$S/N_t = P_r + 20 \log \left(\frac{\Delta F}{f_m} \right) - PF - NLR - 10 \log \left(kTb_c \right) - F \text{ dB}$$

$$S/N_t = C/N + 20 \log \left(\frac{\Delta F}{f_m} \right) - PF - NLR + 10 \log \left(\frac{B_{IF}}{b_c} \right) \text{dB}$$

$$S/N_t + C/N + 20 \log \left(\frac{\delta f}{f_m} \right) + 10 \log \left(\frac{B_{IF}}{b_c} \right) \text{dB.} \qquad (4.5\text{-}42)$$

In this summary of useful forms, (4.5-41) is the same as (4.5-15b). Some of the terms in (39), to (42) have already been defined, and are repeated for convenience.

$$\Delta F = (\delta f) \left(\text{antilog } \frac{PF}{20}\right) \left(\text{antilog } \frac{NLR}{20}\right) \text{ Hz, with} \qquad (4.5\text{-}43)$$

ΔF the peak carrier deviation in Hz (table 4.5-2), and

the peak carrier deviation in Hz(table 4.5-2), and

of the RMS per channel deviation in Hz(table 4.5-2).

S/N_t is the voice channel signal-to thermal noise ratio in dB,

P_r is the received signal level in dBm,

C/N is the predetetrection carrier-to-noise in dB,

N = 10 log n is the receiver front end thermal noise in dbm,

PF is the baseband signal peak factor, 13.5 dB,

NLR is the RMS noise loading ratio in dB (table 4.5-2),

b_c is the usable voice channel bandwidth, 3100 Hz,

B_{IF} is the receiver IF bandwidth in Hz (table 4.5-2),

f_m is the highest modulating frequency in the baseband in Hz (table 4.5-2),

F is the receiver noise figure in dB (from manufacturer's specifications or figure 4.4-62),

k is Boltzmann's constant, 1.3804×10^{-20} millijoules / °K,

T is the antenna temperature, 290° K.

As noted earlier, the product kT (expressed in dBm to correspond to the units for p_r)is-174 dBm/Hz. The terms on the right-hand side of (4.5-39) and (4.5-40) with the exception of P_r, may be calculated for a given set of equipment parameters., This then becomes a constant--a figure of merit--and as P_r is allowed to vary, the voice, channel signal-to-thermal noise ratio varies in proportion. By using this information a single-receiver transfer characteristic (e.,g., fig. 4.5-25) may be constructed. The linear portion of the curve with the slop of -1 may be uniquely determined by the above equation, provided that the path intermadulation compinent is sufficientlty small compared to ther thermal noise.

4.5.29 Determine Long-term Median Total Noise Performance.

4.5.29.1. In the preceding sections, each noise contribution from the several sources has been evaluated. The equipment intermodulation and feeder echo noise contributions, as already noted, are time-invariant, since they are not a function of transmission loss and received signal level. The hop median noise is the sum of the thermal noise calculated for the long -term median, the time-invariant noise, and the path intermodulation noise.

TABLE 4.5-2

IF Bandwidth Required as a Function of Channel Capacity and Per-channed Deviation

	Number of Channels			
	60	120	180	240
Baseband Limits kHz Lower (f_ℓ) Upper (f_m)	12 or 60 252 or 300	12 or 60 504 or 552	60 804	60 1052
Baseband Bandwidth B_b in kHz	240	492	744	992
10 log B_b/b_c	18.9	22.0	23.8	25.1
RMS noise loading ratio, NLR, dBm0	7.8	10.8	12.6	13.8
nlr x pf	11.58	16.38	20.07	23.17
For δf = 70 kHz: Peak carrier deviation ΔF in kHz	811	1147	1405	1622
IF Bandwidth B_{IF} in kHz	2126 or 2222	3302 or 3398	4418	5348
For δ = 100 kHz: Peak carrier deviation ΔF in kHz	1158	1638	2007	2317
IF Bandwidth B_{IF} in kHz	2820 or 2916	4284 or 4380	5622	6738
For δ = 140 kHz: Peak carrier deviation ΔF in kHz	1622	2293	2809	3244
IF Bandwidth B_{IF} in kHz	3748 or 3844	5594 or 5690	7226	8592
For δ = 200 kHz: Peak carrier deviation ΔF in kHz	2317	3276	4014	4634
IF Bandwidth B_{IF} in kHz	5138 or 5234	7560 or 7656	9636	11373

4.5.30 Minimizing the Median Noise Performance (Worksheet 4.5-8)

4.5.30.1 After completing the median noise calculations in the step-by-step procedure in the worksheets through 4.5-7, reduce the RMS per channel deviation and repeat the noise calculations. At this point, compare the total noise from the first and second calculations. If the total noise is less for the second choice, choose a third, lower RMS per channel deviation and again repeat the calculations. Continue this iteration until the total noise increases from the previous result. When this has been attained or when the second choice results in a higher total noise than the first, an approximate minimum total noise has been determined. Choose the deviation that produces the least amount of total noise. This will then be the nearly optimum trade-off in noise components giving the highest median signal-to-total noise performance.

4.5.31 Comparison of Noise Allowance with Predicted Hop Noise (Worksheet 4.5-8; see also sec. 4.5.37- 4.5.39)

4.5.31.1 The designer may now compare the calculated total noise performance with the noise allowance calculated according to the method in section 4.5.18. If the predicted noise is equal to or less than the median allowance, the designer may proceed with the determination of short-term noise performance in the following paragraphs.

4.5.31.2 If the predicted noise is greater than the allowance, adjustments may be made to the hop and equipment requirements. It may become, at this point, a matter of evaluating the cost trade-offs required to meet all of the performance demands. For example, the cost, both initial investment and long-term, of increasing the transmitter power requirements must be weighed Against the willingness of the customer to accept a somewhat lower-quality channel.

4.5.32 Construction of Hop Quieting Curve (Worksheets 4.5-3 and -9)

4.5.32.1 The quieting curve is basically a system dynamic transfer characteristic that can be a useful tool, both for system analysis and for evaluation. It is a plot of single-receiver received signal level or RF carrier-to-noise ratio versus voice channel signal-to-total noise ratio. Construction of the curve begins with the various noise components calculated in the foregoing sections for a predicted median received signal level. Thermal noise and path intermodulation noise must be adjusted for each level of received signal according to the instructions on worksheet 4.5-9. These numbers are then entered on worksheet 4.5-2a. The next step is to sum the noise component. corresponding to each received signal level and then convert to signal-to-noise ratio. These results may then be plotted on worksheet 4.5-3 as illustrated in figure 4.5-25.

4.5.32.2 This completes the quieting curve except for the determination of the diversity-improved FM threshold. This may be obtained from worksheet 4.5-40 For uniformity, the slope of the curve below FM threshold should be drawn with a 4-dB decrease in signal-to-noise ratio for each l-dB decrease in received signal level. This slope may vary depending on the particular squelch circuits of individual equipments.

4.5.33 Estimate Worst-hour Single Receiver Input Power (Worksheet 4.5-10)

4.5.33.1 An absolute minimum value of hourly median received signal level is impossible to predict for a given radio hop. Many hops are subject to atmospheric conditions leading to extreme values of transmission loss that can persist for hours at a time. These anomalous conditions are difficult, if not impossible, to predict from conventional meteorological information; the first indication of trouble may be a complete loss of signal at the receivers. These things do happen!

The designer can only predict a statistical average path performance, not a deterministic performance as exemplified by a receiver quieting curve. This distinction cannot be overemphasized. Increased fade margins on the basis of anticipated prediction errors (see sec. 4.4.27) will provide at least some insurance in anticipation of Murphy's Law [68] in action. ("If anything can go wrong, it will".) The confidence limits discussed here and in section 4.4.32 are an estimate of the system gain (hence system cost) required to provide a given level of that insurance.

4.5.33.2 What is needed, in view of the foregoing caveats, is a reasonable engineering estimate of the "worst hour" value of transmission loss and hence received signal level. As a reasonable figure, and to provide the basis for estimating the short-term link time availability, the hourly median signal level exceeded during 99.99% of all hours with a confidence level of 0.5 will be used. This is designated as Pr(0.9999, 0.5).

4.5.34 Calculate Radio Hop Short-term Noise Performance (Worksheet 4.5-10)

4.5.34.1 Since techniques used for predicting the short-term radio hop performance are somewhat different for predetection and post-detection combiner schemes, the design choice made in section 4.5.21 will dictate the method used.

4.5.34.2 Consider the example of the distribution prepared for hourly medians of received signal level expected during all hours of the year shown in figure 4.4-38. There are 8760 hours in the year so that a fraction of one ten-thousandth of a year can be considered an "hour" without a great loss-in accuracy. If we do this, the "worst hour" will correspond to 0.9999, the next worst to 0.9998, the third worst to 0.9997 and so on. For our example, the following table shows the hourly median received signal levels and single receiver C/N for up to the “worst ten hours” or that hourly median signal level not exceeded for 0.999 of the year. Note that the C/N values given here are based on the reduced-band-width, threshold-extended noise discussed in section 4.5.20.

Table 4.5-3

q	C/N, db	P_r, dBm
0.9990	17.6	-91
0.9991	17.1	-91.5
0.9992	16.6	-92
0.9993	16.1	-92.5
0.9994	15.6	-93
0.9995	15.1	-93.5
0.9996	14.6	-94
0.9997	13.6	-95
0.9998	12.6	-96
0.9999	10.6	-98

4.5.35 Predetection Combiner System

4.5.35.1 In a predetection combiner, the signals from the diversity branches are combined before the signals are demodulated. This means that the single FM demodulator- receives a signal from which most of the variations in C/N have been removed. The curves in figure 4.5- 11 shows the effects on voice channel S/N performance of dual and quadruple diversity and equal gain and maximal ratio combining schemes, based on Rayleigh distributions for each single signal. These curves, however, are valid only if the median received signal levels are well above single-receiver FM threshold. Since it is likely that any real system will operate at low signal levels for part of the time, the performance at signal levels in the neighborhood of the FM threshold needs to be evaluated. Sets of generally applicable curves are shown in figures 4.5-22a and 4.5-23, which can be used to evaluate the short-term distribution of voice channel S/N. Note that each figure is for a different combining scheme. Since we have assumed a quadruple diversity, predetection, maximal ratio combiner, figure 4.5-22a is used for the example. Figure 4.5-24 is a typical, single receiver quieting curve for which the S/N has been normalized to 0 dB at the break in the curve (FM threshold). This normalized a S/N of zero corresponds to the S/N of zero on figures 4.5-22a and 4.5-23. Figure 4.5-25 is the system quieting curve for the example link. Note that at the single-receiver FM threshold (with threshold extension of 7 dB and pre-emphasis improvement of 4 dB), the calculated voice channel S/N is 27.6 dB. This then is the actual value at the zero-ordinate* for the normalized S/N on figure 4.5-24, and the value of C/N at this FM threshold iS 10 db. from table 4.5-3, the worst hour" median received signal level, P_r, was estimated to be -98 dBm. The value of P_r at the single-receiver FM. threshold was calculted to be -98.6 dBm in section 4.5.22, and can also be read as the abscissa on figure 4.5-25. Since C/N = 10dB at P = -98.6 dbm, then C/N = 10.6 db at P_r = -98 dBm.. Note that figure 4.5-22a has curves for various hourly median C/N values from 4 to 16 dB.

4.5.35.2 An ordinate scale has been placed. On the right-hand side of figure 4.5-22b with zero ordinate of the normalized S/N labelled as its actual value of 27.6 db and the 10 pW0 level (S/N=30db) indicated. From this figure, we can estimate that the S/H will fall below 30 db (or the noise will exceed 10^6 pW0) for about 3% of the hour during which the single receiver median C/N is 10.6 db by interpolating between the C/N=10

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this corresponds to the intersection of the slopes of the characteristics ABOVE AND BELOW THE BREAK POINT.

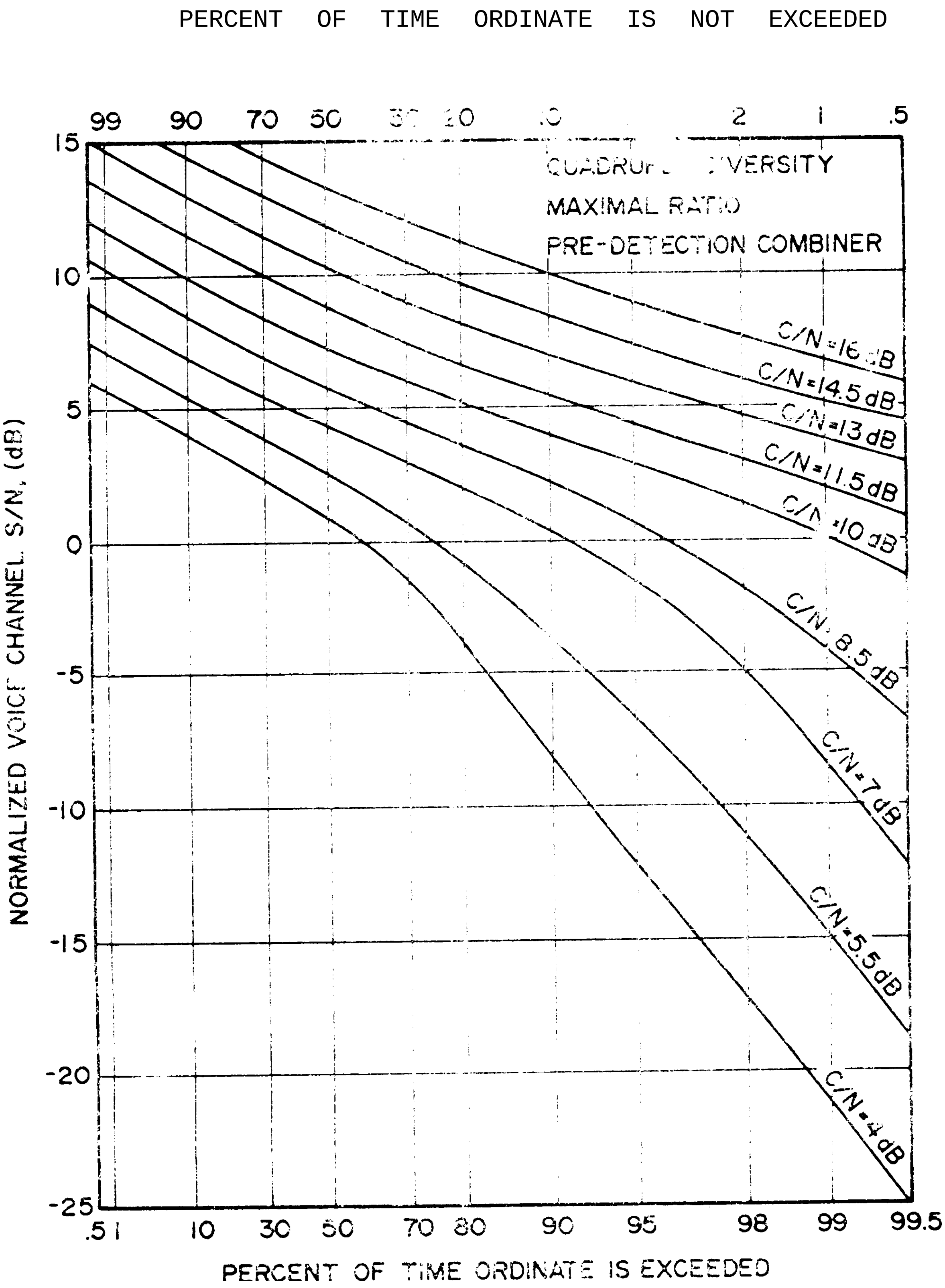


Figure 4.5-22 Within-the-hour Distributions of Voice Channed Noise Level for Operation in the Region of FM thresholdText

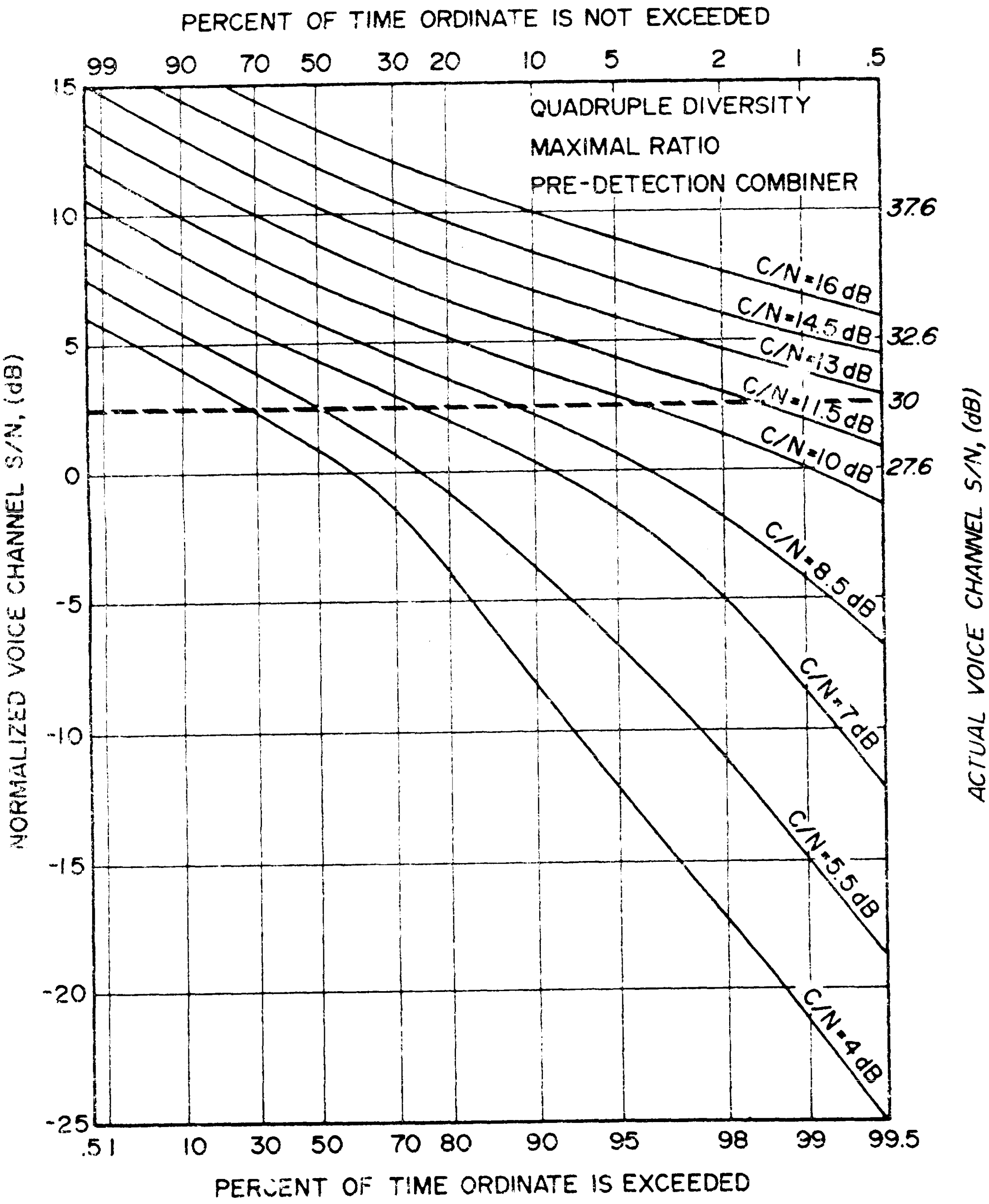


Figure 4.5-22b Within-the-hour Distributions of Voice Channel Noise Level for operation in the Region of FM threshold

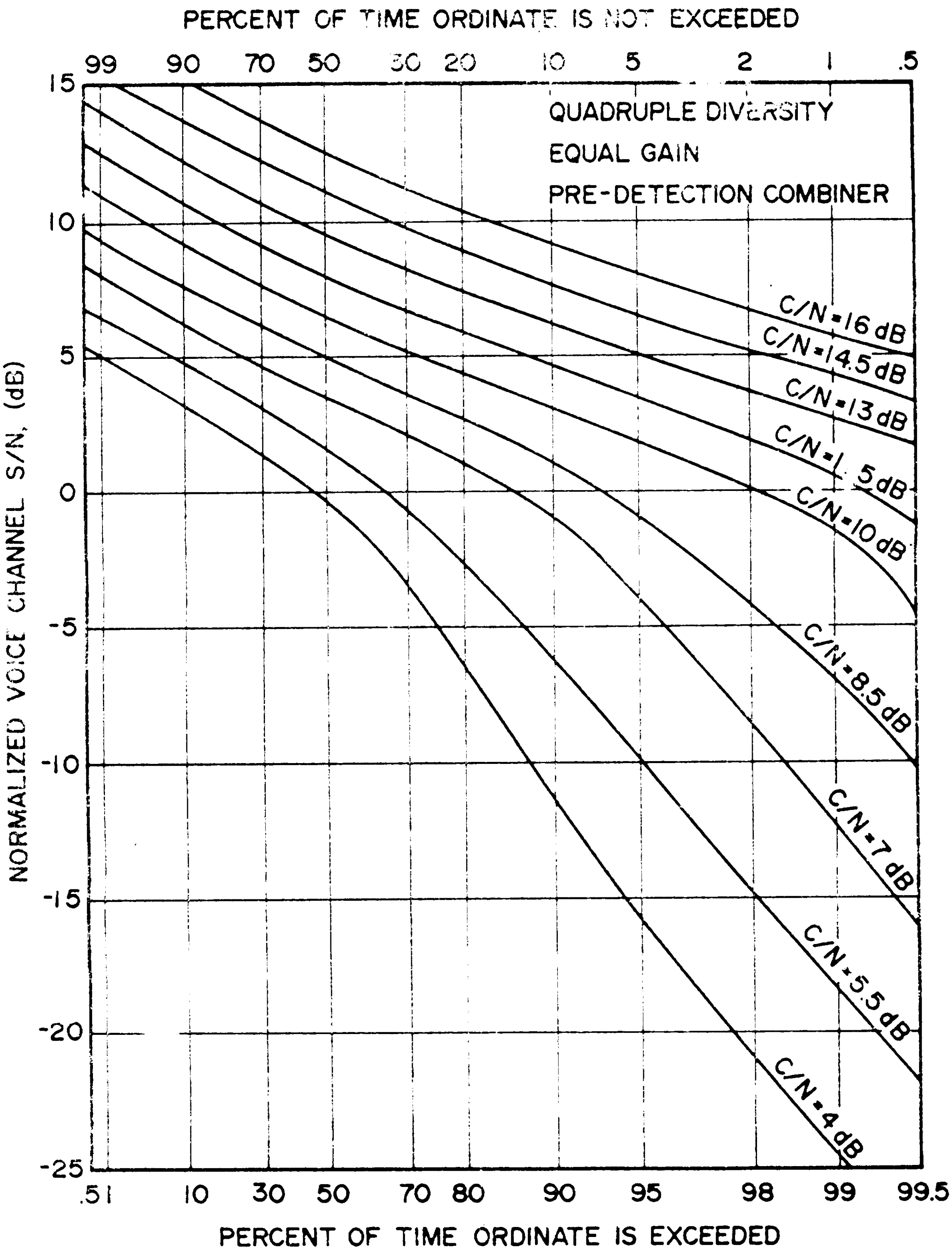


Figure 4.5-23 Within-the-hour Distribution of Voice Channel Noise Level for Opeeration in the Region of FM threshold

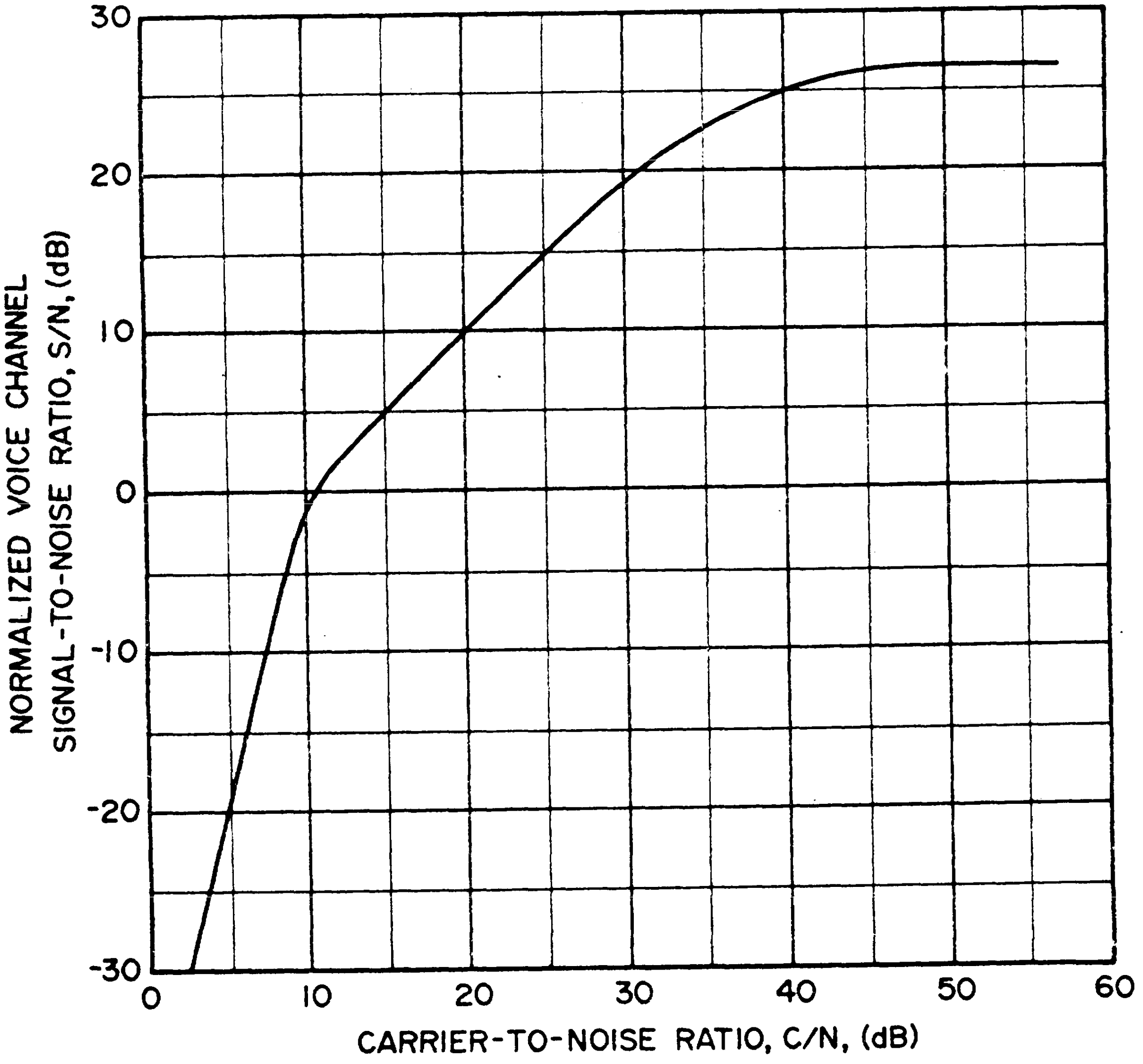
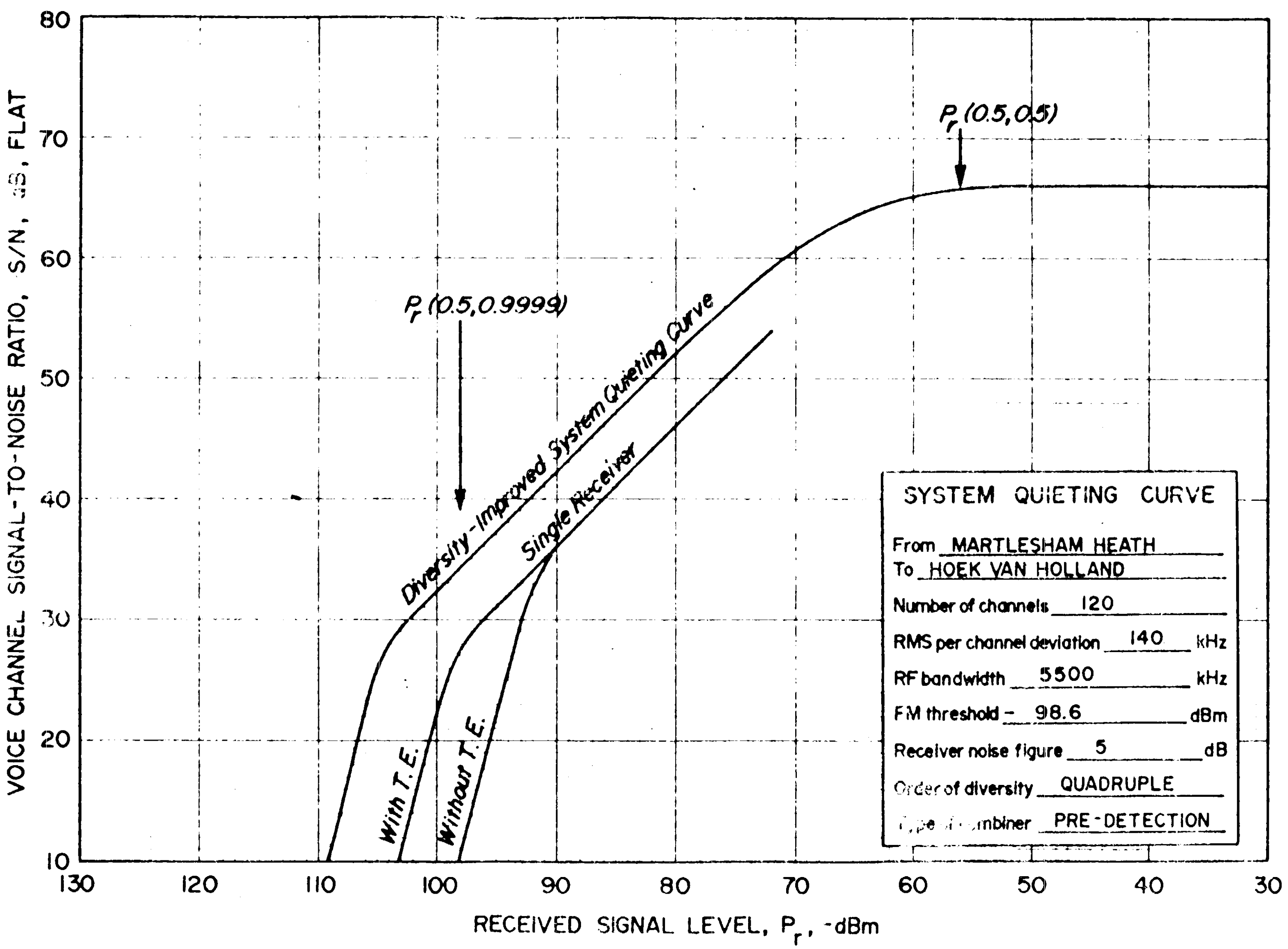


Figure 4.5-24 Generalized Single Receiver FM Quieting Curve



SYSTEM QUIETING CURVE

From MARTLESHAM HEATH
To HOEK VAN HOLLAND
Number of channels 120
RMS per channel deviation 140 kHz
RF bandwidth 5500 kHz
FM threshold - 98.6 dBm
Receiver noise figure 5 dB
Order of diversity QUADRUPLE
Type of combiner PRE-DETECTION

Figure 4.5-25 Example System Quieting Curve and C/N = 11.5 dB curves. Table 4.5-4 shows the results of such an analysis for the worst 10 "hours" of the year.

Table 4. 5-4

Outage Time for The Example Hop During the Worst 10 Hours of the Year (Pre-detection Combining)

q	P_r, dBm	C/N, dB	"Outage Time" %	minutes
0.9990	-91	17.6	-	-
0.9991	-91.5	17.1	-	-
0.9992	-92	17.6	-	-
0.9993	-92.5	16.6	-	-
0.9994	-93	15.6	-	-
0.9995	-93.5	15.1	-	-
0.9996	-94	14.6	-	-
0.9997	-95	13.9	-	-
0.99998	-96	12.6	1	0.6
0.9999	-98	10.6	3	1.8

Note that for C/N values higher than 13 db, the curves do not indicate any outage time since it would be less than 0.005 x 3600 or 18 seconds. It is not likely that any prediction method could offer this resolution so it is assumed that intervals of this length and shorter can be ignored. By summing the outage times for the worst ten hours, an overall hop availability can be calculated. For this example, for 2.4 minutes of the year, the voice channel noise is expected to be greater than 10^6 pWO, giving an overall hop availbility (percent time that the voice channel noise is less than 10^6 pW0) of

$$\frac{8760 -0.04}{8760} \quad \text{or } 99.9995\%$$

at a confidence level of 0.5.

4.5.36 Postdetection Combining System

4.5.36.1 In a postdetection combining system, each if signal from the diversity branches is demodulated individually and the resulting baseband signals are combined. This means that each FM discriminator is fed a signal of constantly changing C/N (hence its output will be a constantly changing S/N), but that the combined signal, which is the baseband output, has had most of the S/N variations removed. The curves shown in figure 4.5-11 show the results expected of a postdetection combiner operating with median C/N values much larger than 10 dB. As with predetection combiners, it is necessary to examine the performance in the region of FM theshold (that is, median C/N values of 10 dB). Again, figure 4.5-24 is the generalized quieting curve and the curves in-figures 4.5-26 and 4.5-27 are used to evaluate the short-term distributions of voice channel S/N. As was done for the predetection calculations, the ordinate values on the right-hand side are placed 30 that the-actual S/N at FM threshold (27.6 dB); is normalized to zero on the left-hand scale. By using figure 4.5-26b, we can estimate that the S/N will fail below 30 dB (or the noise will exceed 10^6pW0) for 10% of the hour or 6 minutes during which the median C/N is 10.6 dB. During the second worst hour, the C/N will be about 12.6 dB and the estimated outage time is 3% of the hour, or 1.8 minutes. During the third worst hour, when the C/N is 13.6 dB, the estimated outage time is 1.5% or 0.9 minutes, and so on as shown in table 4.5-5 From figure 4.5 -26, we see that hourly median C/N values higher than about 15 dB will result in outage times within the hour of less than 0.5%. The estimated total outage time is the total of the individual outage times; for this hop, it will be about 8.7 minutes which gives a hop availability of 99.998% at a service probability of 0.5.

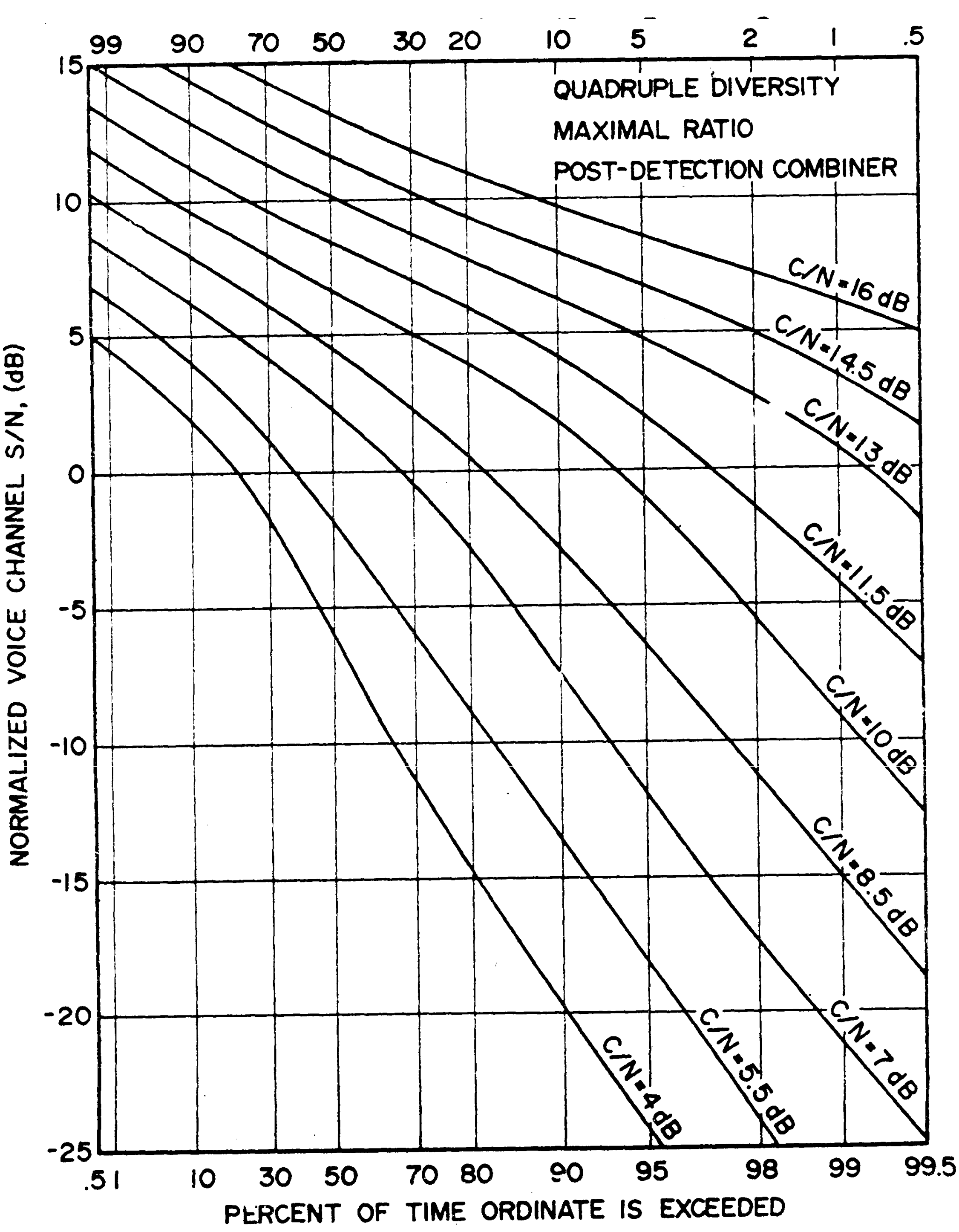


Figure 4.5-26a Within-the-hour Distribution of Voice Channel Noise Level for Operation in the Region of FM Threshold

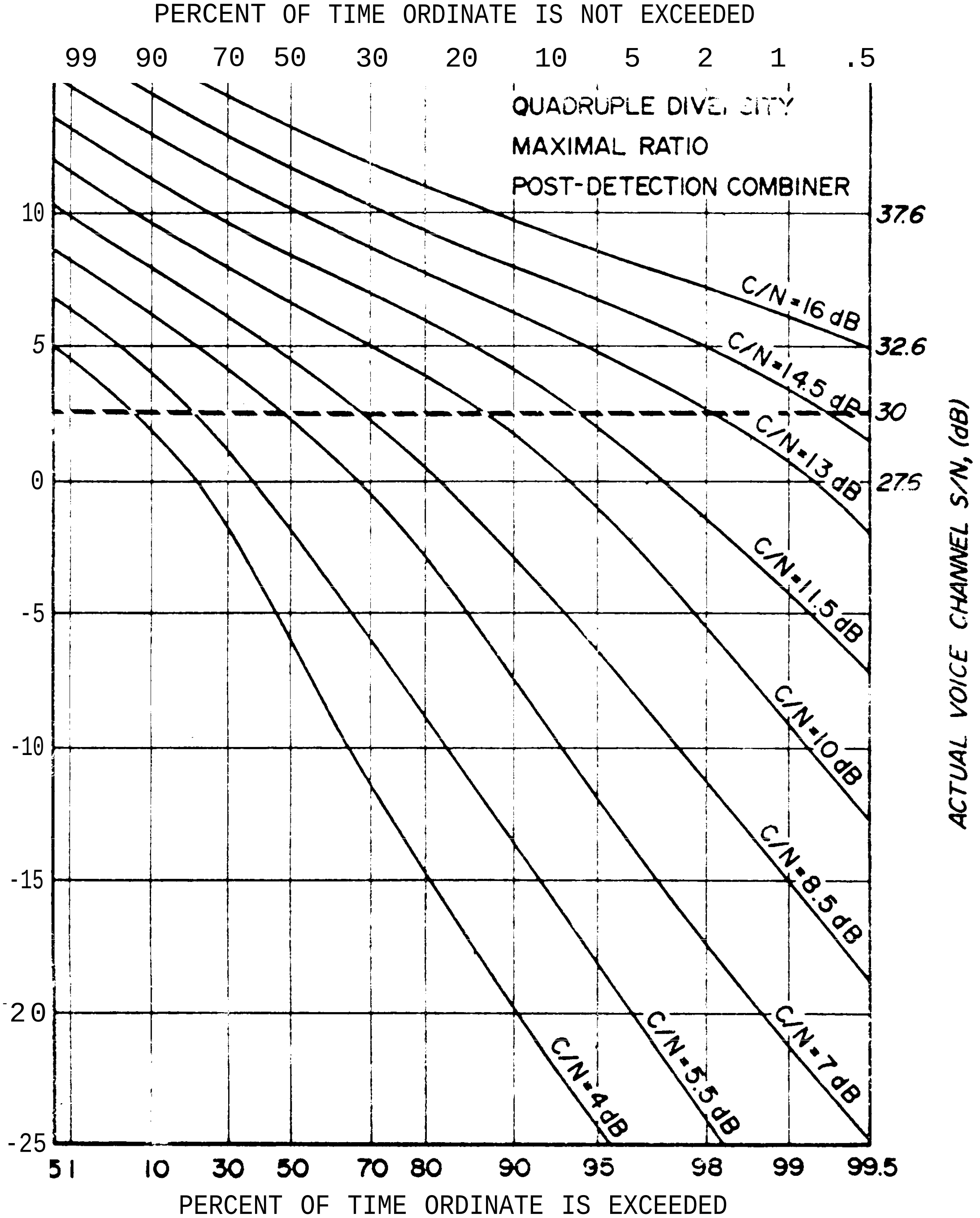
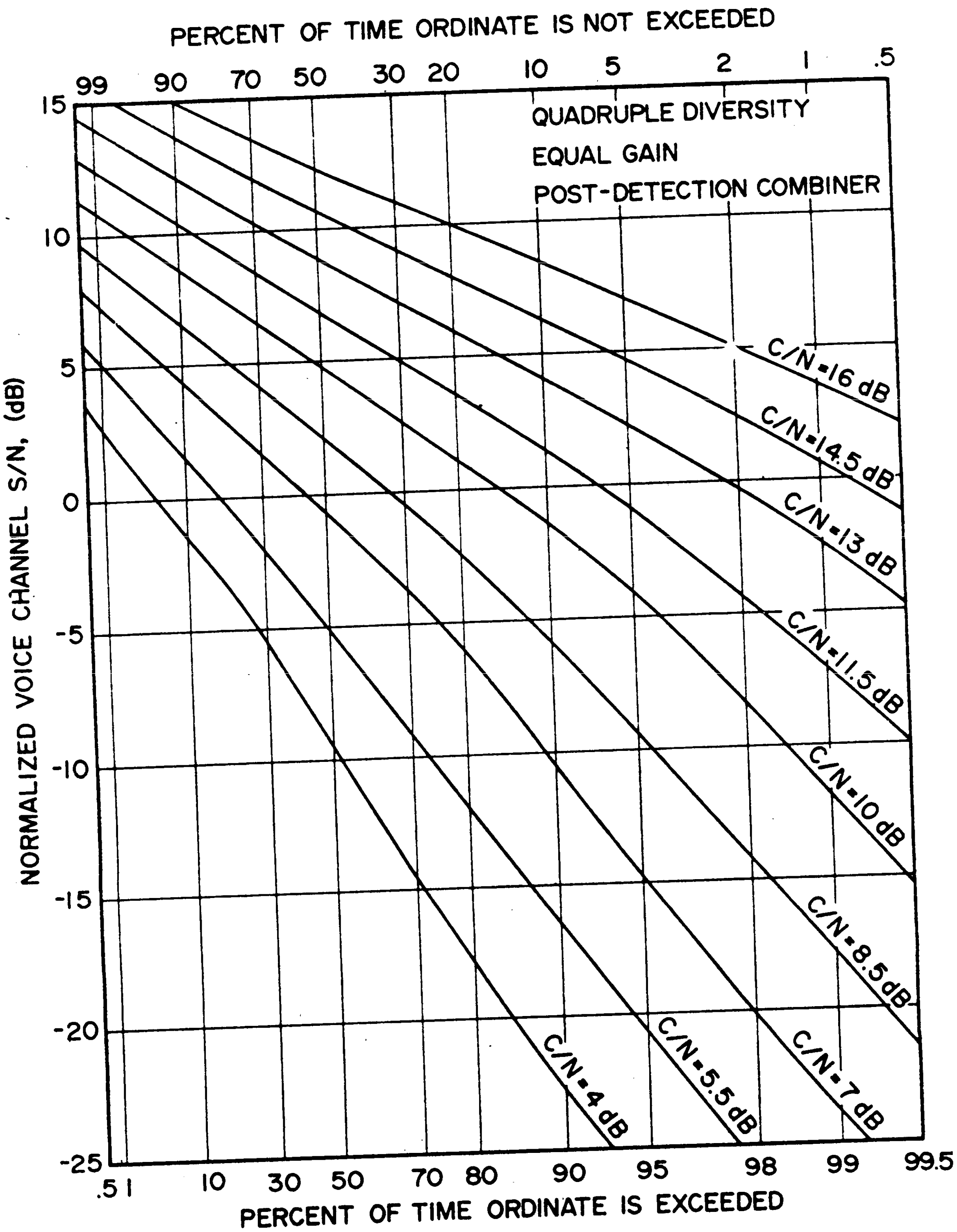


Figure 4.5-26b Within-the-hour Distributions of Voice Channel Noise Level for Operation in the Region of FM Threshold



4.5-27 Within-the-hour Distributions of Voice Channel Noise Level for Operation in the Region of FM Threshold.

Table 4.5-5

Outage Time for the Example Hop During the Worst 10. Hours of the Year (Post- detection Combining)

q	P_r, dBm	C/N, dB	"Outage Time"	
			%	minutes
0.9990	-91	17.6	-	-
0.9991	-91.5	17.1	-	-
0.9992	-92	16.6	-	-
0.9993	-92.5	16.1	-	-
0.9994	-93	15.6	-	-
0.9995	-93.5	15.1	-	-
0.9996	-94	14.6	-	-
6.9997	-95	13.6	1.5	0.9
0.9998	-96	12.6	3	1.8
0.9999	-96	10.6	10	6

4.5.37 Comparison of Expected Performance and DCA Long-term Median and Short-term Noise Allowance

4.5.38 Long-term Median Noise Performance

4.5.38.1 The longi-term noise calculated for a radio hop will occur at the long-term median received signal level at a service probability of 0.5 or P_r is (0.5, 0.5). For the example path (Martlesham Heath to Hock van Holand) this P_r is -56 dBm and the voice channel noise at this received signal level is 501 pW0 as shown on figure 4.5-25.

(Recall that n_T = antilog $\left(\frac{90 - S/N_T}{10}\right)$). As discussed in section

4.5.18, the DCA noise allowance is 594 pW0 so the long-term median noise meets the requirements.

4.5.39 Short-term Noise Performance

4.5.39.1 The two-part short-term requirements were set forth in section 4.5.19, Short-term Noise Allocation. For all transhorizon radio hops, the specifications are the same and are as follows:

1. The hourly median voice channel noise during the worst four hours of the year will not exceed 100,000 pW0 (-40 dBm0).
2. The voice channel noise (measured with a five millisecond averaging time) will not exceed 1,000,000 pW0 (-30 dBm0) for more than a cumulative 22 minutes of the year.

4.5.39.2 Note that from the hop quieting curve, figure 4.5-24, the received signal level above which the S/N is better than 40 dB(or above which the noise is lower than -40 dBm0 or 100,000 pW0) is about -92 dBm. Referring to figure 4.4-38, the distribution of hourly medians of received signal level for the example path, it is seen that this RSL level (-92 dbm) is exceeded for 99.92% of the hourly medians and hence is not exceeded for 0.08% of the hourly medians or for (0.0008) (8760) or about 7 hours during the year. *For* this example during the “worst 7 hours of the year”, the hourly median voice channel noise will exceed 100,000 pW0, and as shown in table 4.5-6, the hourly median noise will considerably exceed this level during the “worst hour” of the year, so the DCA Allowance can be assumed to be approximately satisfied.

Table 4.5-6

q	P_r, dBm	Meadian S/N, dB	Median Noise pW0
.9990	-91	41.2	7.59×10^4
.9991	-91.5	40.7	8.51×10^4
.9992	-92	40.2	9.55×10^4
.9993	-92.5	39.7	1.07×10^5
.9994	-93	39.2	1.20×10^5
.9995	-93.5	38.7	1.35×10^5
.9996	-94	38.2	1.51×10^5
.9997	-95	37.2	1.90×10^5
.9998	-96	36.2	2.40×10^5
.9999	-98	34.2	3.80×10^5

4.5.39.2 Referring back to tables 4.5-4 and 4.5-5, it is seen that for the example link, use of predetection combiners (table 4.5-4) that the time during which the noise in a voice channel exceeds 10^6 pW0 is 2.4 minutes, versus a DCA allowance of 22 minutes. For postdetection combining (table 4.5-5), the time during which the noise exceeds 10^6 pW0 will be about 8.7 minutes versus a DCA allowance of 22 minutes. Thus, either the predetection or the postdetection combining technique will provide the quality of service which is desired by DCA.

4.5.40 Diversity Improved Threshold

4.5.40.1 Tne threshold region of the diversity improved quieting curve will be dependent on the combining scheme used. Basically it is constructed by use of figures 4.5-22, 4.5-23, 4.5-26 and 4.5-27. Use is made of the median values of each distribution for a given combining scheme; hourly median normalized voice channel S/N may be read as a function of hourly median C/N and these values are then plotted on the quieting curve. Such values have been plotted from figures 4.5-22, 4.5-23, 4.5-26 and 4.5-27 in figure 4.5-28 The shape of the threshold region in figure 4.5-28 may be used to complete the diversity improved quieting curve calculated in worksheet 4.5-9.

4.5.41 Trade -off Design for Problem Hops

4.5.41.1 In a few cases, as in the present example, the system designer will encounter a path that does not provide the prescribed performance, particulary short-term. That is to say, the designer, by using the foregoing approach, may not be able to meet the short-term requirements for performances even though median conditions are met. This is mostly likely to occur when the median-to-worst hour transmission loss variability exceeds 35 to 40 dB. If all cost trade-offs and hop and equipment requirements have been completly evaluated and included as much as is practicable, the following approach may be taken. Rather than use the per channel deviation determined by the method in section 4.5.30 that results in minimum median noise, increase the per channel deviation. The result will be an improvement in short-term thermal noise performance, but a degradation in the median performance. This effect was illustrated by the top drawing in figure 4.5.12 by the cross-over of the transfer characteristics for increased received power level. The trade-off is improved short-term performance for somewhat degraded long-term performance. Extreme care must be taken in using this method because the median noise performance can degrade faster than the short-term noise performance improves .

4.5.41.2 Another more dratic measure to improve channel performance would be a reduction in channel capacity. The trade-off involved is between having a few high-quality channels or a larger number of lower quality channels; such a decision should be referred to the customer for resolution.

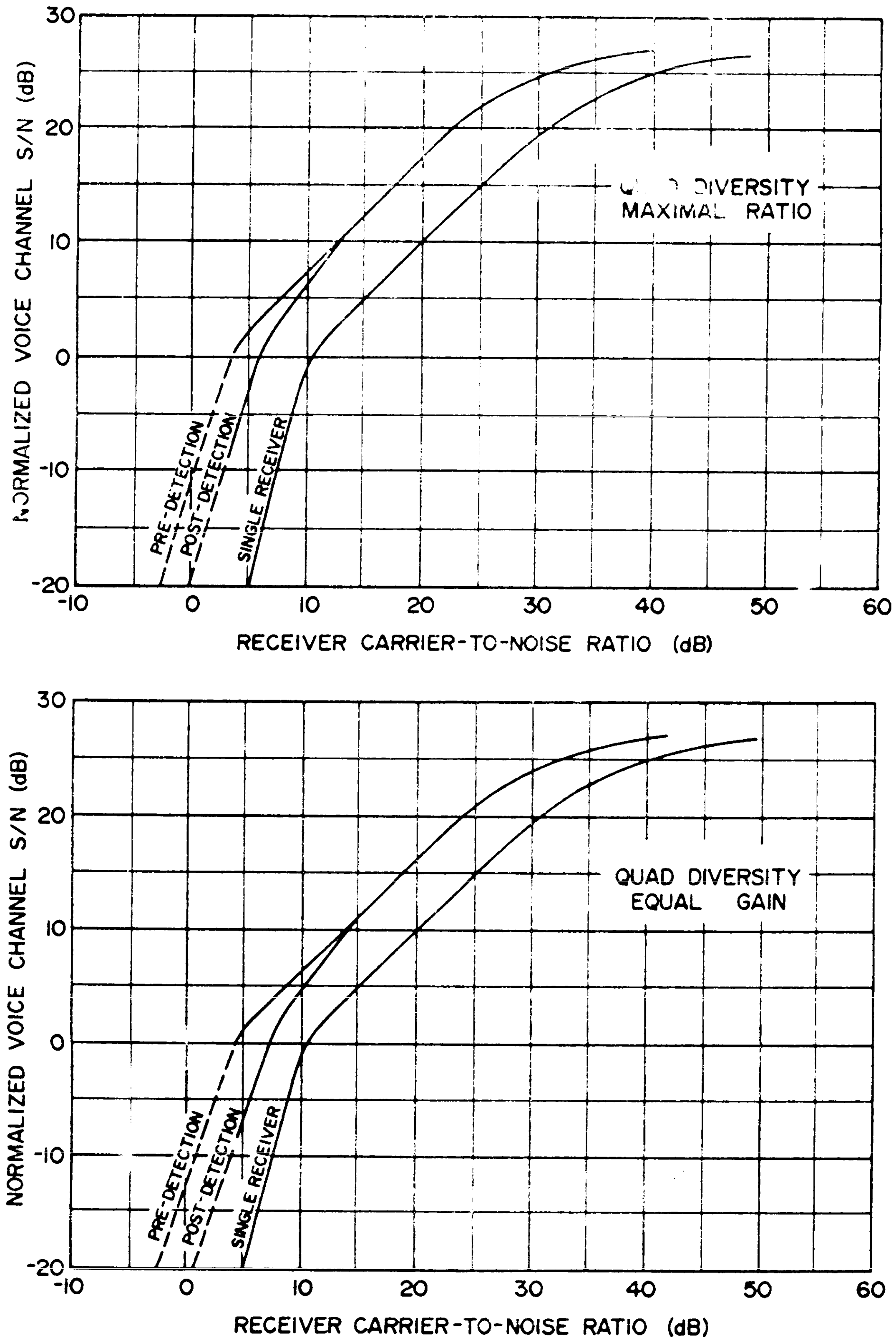


Figure 4.5-28 Combiner improvement Curves for the Threshold Region for Various Combining Schemes

4.5.41.3 It would be well to examine the total system noise performance, i. e., the sum of the median noise powers of all hops in the system. Loss of median noise performance in one hop can be made up by some minor overdesign on other hops in the system. Every effort should be made to maintain end-to-end system performance within the specified requirements.

4.5.42 Compare Calculated Hop Time Availability with Required Time Availability

4.5.42.1 We have developed estimates showing the expected time availability for a single radio hop. The next section deals with the total system noise performance and objectives, and system time availability which will determine the least permissible link time availability. The assumption is usually made that the hop outages will not occur simultaneously so that the system outage time will be the sum of the individual hop outage times. For this reason, some way must be chosen to prorate the outage on a per hop basis. The significant results of the foregoing analyses for each link should be entered on the system summary worksheet 4.5-11.

4.5.43 System Noise Evaluation (Worksheet 4.5-11)

4.5.43.1 After each hop design in the system has been completed as prescribed above, complete the information in the system/hop noise summary worksheet, 4.5-11. It now becomes necessary to examine the overall system noise performance. This may be easily done by summing the calculated median total noise contribution for each hop. This total is compared with the sum of the hop allocations. If the predicted total is less than or equal to the total allocations, the design goal has been achieved. If the calculated noise exceeds the allocation, the individual links should be reviewed for potential noise reduction. It may be possible in some cases to compensate for poorly performing hops with some overdesign on better hops. Every effort should be made in the design to meet both hop and system requirements, but if one may not be feasible, the prime effort should be made to meet the system requirements.

4.5.43.2 Another system parameter that is important to evaluate is the system time availability. For purposes of this discussion, the time availability is interpreted as that time the hop or system total noise is less than 10^b pW0. The complement of this will be called system outage time, which will be considered on a worst-case basis, i.e., system outage time will be the sum of the individual hop outage time. Once the system outage time has been determined, it should be compared with some objective. This objective is somewhat exclusive and subject to varied and argumentative interpretations. A useful interpretation for the purposes of this analysis is as follows. Using CCIR Recommendations 393-1 and 397-1, [4], we will consider the shortest term objective. The 1,000,000 pW0 noise power level will be taken as the failure point. That is to say the system will be unusable if the voice channel noise exceeds 10^6 pW0 and will be usable if it is less. Further, the “0.05% of the most unfavorable month" will be taken to be the worst cumulative 21.6 minutes of that month, and interpreted to mean the worst performance in the year will occur in these 21.6 minutes. This then gives an objective of exceeding 10^6 pW0 during a stimulative total of 21.6 minutes or less during the year which corresponds to 0.00470 of the year or a time availability of 99.996%.

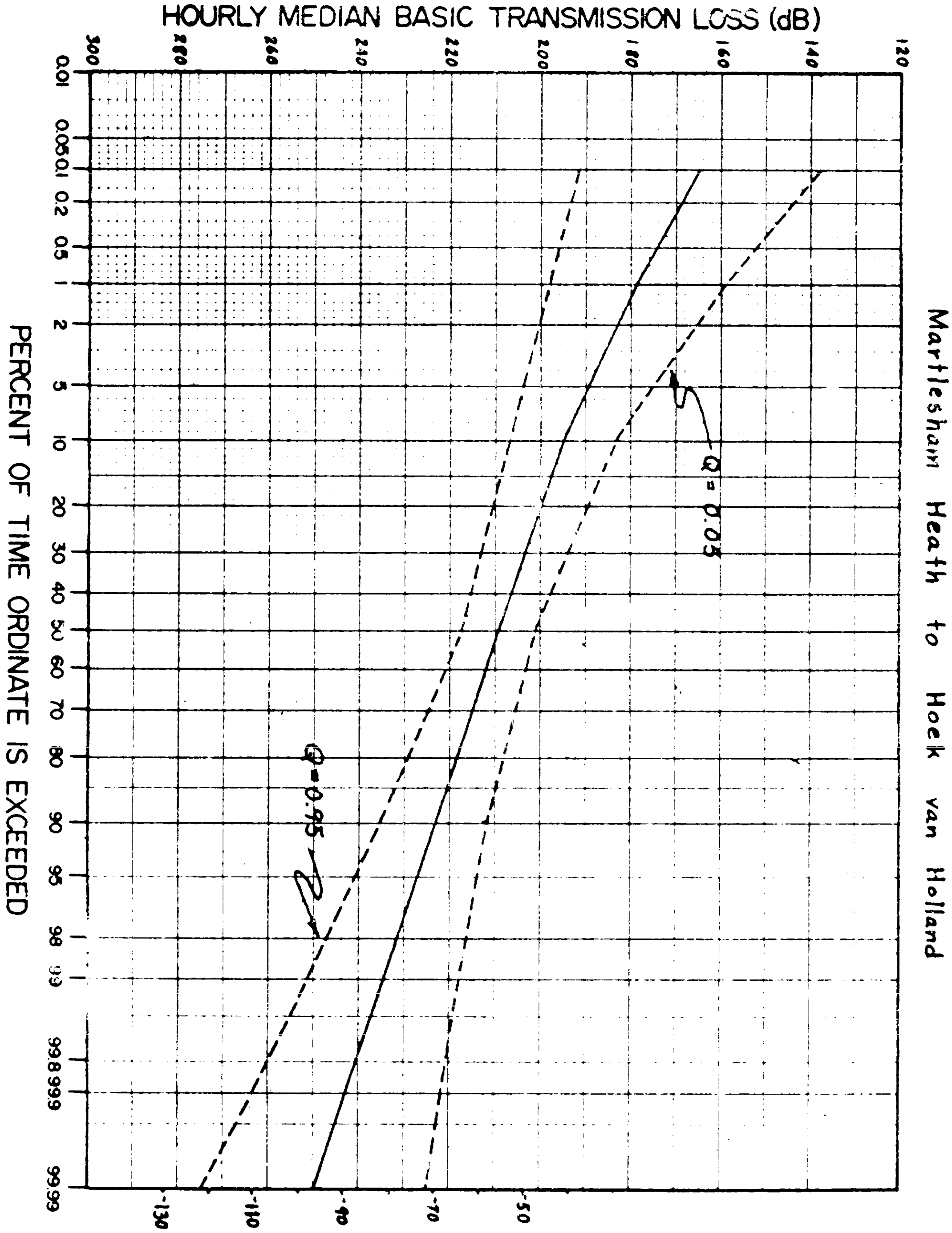
4.5.43.3 System outage time should be compared with this objective and reasonable effort made to meet it without getting prohibitively costy equipment or impracticably high powers. lt must be kept in mind that the calculated outages are only estimates and the objectives are provisional and subject to reconsideration.

HOP **Martlesham Heath** TO **Hoek van Holland**

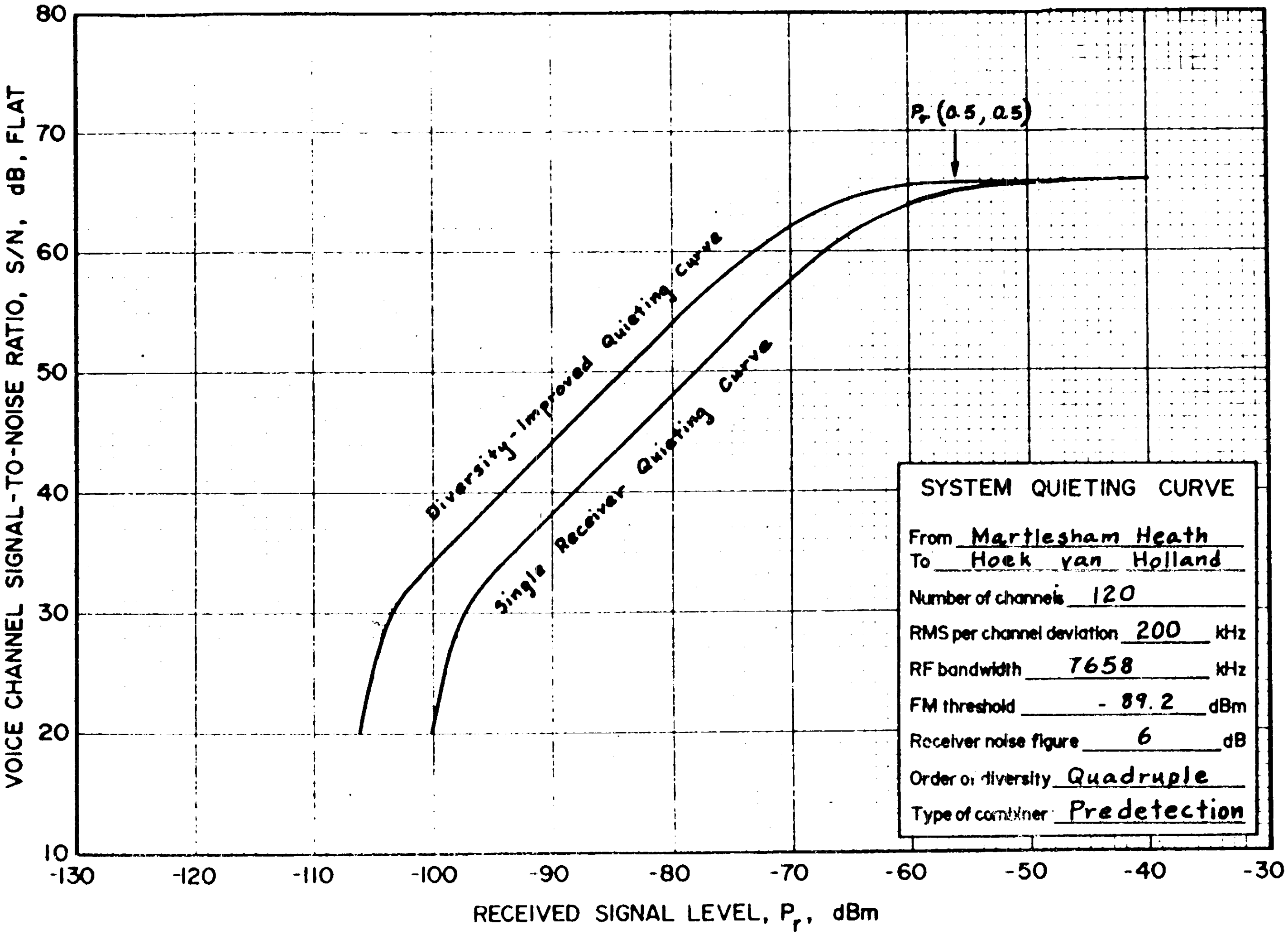
PERCENT OF TIME	MEDIAN VARIABILITY FACTOR Y_0	PREDICTION UNCERTAINTY PARAMETER σ_c	TRANSMISSION LOSS, dB Q=0.05 L_b	TRANSMISSION LOSS, dB Q=0.5 L_b	TRANSMISSION LOSS, dB Q=0.95 L_b	RECEIVED SIGNAL LEVEL, -dBm Q=0.5 P_r	RECEIVED SIGNAL LEVEL, -dBm Q=0.95 P_r
0.01	55.5	19.9	121.1	153.9	186.7	-0.5	-33.3
0.1	44.7	16.3	137.8	164.7	191.6	-11.3	-38.2
1.0	31.2	11.9	158.6	178.2	197.8	-24.8	-44.4
10.0	14.5	7.1	183.2	194.9	206.6	-41.5	-53.2
50.0	0	5.0	201.2	209.4	217.7	-56.0	-64.3
90.0	-14.1	7.0	211.9	223.5	235.1	-71.1	-81.7
99.0	-25.3	10.1	218.0	234.7	251.4	-81.3	-98.0
99.9	-33.5	12.6	222.1	242.9	263.7	-89.5	-110.3
99.99	-40.5	14.9	225.3	249.9	274.5	-96.5	-121.1

FEEDER ECHO NOISE (pWO) N_f	EQUIPMENT INTERMODULATION NOISE (pWO) N_e	PATH INTERMODULATION NOISE (pWO) N_p	THERMAL NOISE (pWO) N_t	TOTAL NOISE (pWO) N_T	TOTAL S/N (dB) S/N_T	RECEIVED SIGNAL LEVEL (-dBm) P_r
13.8	239.3	0	0.04	2.53×10^2	66.0	30
		0	0.12	2.53×10^2	66.0	35
		0	0.37	2.54×10^2	66.0	40
		0.1	1.17	2.54×10^2	66.0	45
		0.2	3.72	2.57×10^2	65.9	50
		0.5	11.7	2.65×10^2	65.8	55
		1.1	37.2	2.90×10^2	65.4	60
		2.6	1.17×10^2	3.70×10^2	64.3	65
		5.8	3.72×10^2	6.25×10^2	62.0	70
		12.9	1.17×10^3	1.42×10^3	58.5	75
		28.9	3.72×10^3	3.97×10^3	54.0	80
		64.8	1.17×10^4	1.20×10^4	49.2	85
		145.1	3.72×10^4	3.75×10^4	44.3	90
		325.1	1.17×10^5	1.17×10^5	39.3	95
		728.2	3.72×10^5	3.72×10^5	34.3	100
		1.63×10^3	1.17×10^6	1.17×10^6	29.3	105
13.8	239.3	3.65×10^3	$.72 \times 10^6$	3.72×10^6	24.3	110

Worksheet 4.5-2a Distribution Parameters (example)



Worksheet 4.5-2b Distribution Graph (example)



SYSTEM QUIETING CURVE

From Martlesham Heath
To Hoek van Holland
Number of channels 120
RMS per channel deviation 200 kHz
RF bandwidth 7658 kHz
FM threshold - 89.2 dBm
Receiver noise figure 6 dB
Order of diversity Quadruple
Type of combiner Predetection

Worksheet 4.5-3 System Quieting Curve (example)

4.1	Number of equivalent voice channels, n	120			
4.2	Voice channel bandwidth, b_c	3100	Hz	(Usable bandwidth)	
4.3	Maximum modulating frequency, f_m	552	kHz	See table 4.2-1	
4.4	Baseband bandwidth, B_b	492	kHz	$B_b = f_m - f_\ell$, where f_ℓ is the lowest frequency in the baseband	
4.5	RMS noise loading ratio, NLR	10.8	dB	-10 + 10 log n (see 4.5.20.12)	
4.6	Numerical RMS noise loading ratio, nlr	3.464		antilog (NLR/20)	
4.7	Peak factor, PF	13.5	dB		
4.8	Numerical peak factor, pf	4.73		= antilog (PF/20)	
4.9	RMS per channel deviation, δf	200	kHz	Start with δf = 200 kHz	
4.10	RMS carrier deviation, δF	692.8	kHz	δF = (nlr) (δf)	
4.11	Peak carrier deviation, ΔF	3276.9	kHz	ΔF = (pf) (nlr) (δf)	
4.12	Receiver IF bandwidth, B_{IF}	7658	kHz	$B_{IF} = 2(\Delta F + f_m)$, or actual values of equipment considered.	
4.13	Low noise preamplifier	yes/no			
4.14	Receiver noise figure, F	6	dB		
4.15	Receiver noise threshold,* kTBF	- 99.2	dBm	-174 + 10 log B_{IF}(Hz) + F	
4.16	FM improvement threshold*	- 89.2	dBm	kTBF + 10	
4.17	**Pre-emphasis improvement, I_p**	4	dB		
4.18	**Combiner type**	pre/post			
4.19	**Median diversity improvement, I_d**	6	dB		
4.20	**Threshold extension**	yes/no			
4.21	**Threshold extension improvement, I_{te}**	7	dB		
4.22	**Equipment NPR**	55	dB		

*If threshold extension is used, use its narrow bandwidth for threshold calculations.

Worksheet 4.5-4 Hop Noise Performance Calculations (example)

5.1	Transmission line length, L_t, transmitter	50	m	(from item (25), worksheet 4.5-1d)
5.2	Mean carrier frequency	4.4	GHz	(from item (23), wordsheet 4.5-1d)
5.3	Percent velocity of propagation, v	60	%	(from figure 4.5-14)
5.4	Velocity of propagation, V	1.8×10^8	m/sec	$V = (3 \times 10^8)(v \times 10^{-2})$
5.5	Echo delay time, τ	5.56×10^{-7}	sec	$\tau = 2L_t/V$
5.6	Radian delay ω_τ	1.927	rad	$\omega_\tau = 2\pi f_m \tau$ (f_m from item 4.3, worksheet 4.5-4)
5.7	Parameter A	0.8784		$A = \delta F/f_m$ (from items 4.3 and 4.10, worksheet 4.5-4)
5.8	S/D - r	5	dB	(from figure 4.5-15)
5.9	Transmit System			
	Antenna return loss, RL_{ANT}	30	dB	(from applicable standards or manufacturer's specifications)
	RF Interface return loss, RL_{RFI}	30	dB	
5.10	Echo amplitude, r	64.7	dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$ ($A_{t\ell}$ from item (31), worksheet 4.5-1d)
5.11	Transmit signal-to-distortion ratio S/D	69.7	dB	$S/D = (S/D - r) + r$
5.12	Transmit signal-to-feeder echo noise ratio S/N_f	80.9	dB	$S/N_f = S/D + 10 \log (B_b/b_c) - NLR$ (from items 4.4, 4.2, and 4.5, worksheet 4.5-4)
5.13	Transmit feeder echo noise $n_{f(trans)}$	8.13	pW0	$n_f = \text{antilog} \left[(90 - S/N_f)/10\right]$

Worksheet 4.5-5 Feeder Echo Noise Calculations (Transmitter) (example)

7.10	Calculate $20 \log \frac{\delta f}{f_m}$	- 8.82	dB			
7.11	Calculate $10 \log kTb_c + F$	- 133.1	dB	$-139.1 + F$		
7.12	Signal-to-thermal noise ratio minus received signal level, $S/N_t - P_r$	124.3	dB	$S/N_t - P_r = -10 \log kTb_c$ $- F + 20 \log \frac{\delta f}{f_m}$		
7.13	P_r (0.5, 0.5)	- 56	dBm			
7.14	Median signal-to-thermal noise ratio, $S/N_t(0.5, 0.5)$	68.3	dB	$(S/N_t - P_r) + (P_r(0.5, 0.5))$		
7.15	Thermal noise, $n_t(0.5, 0.5)$	147.9	pW0	$n_t(0.5, 0.5) = \text{antilog}\ \frac{90 - S/N_t}{10}$		
7.16	Emphasis- and diversity-improved signal-to-thermal noise ratio, $S/N_t(0.5, E, D)$	78.3	dB	$S/N_t(0.5, E, D) = S/N_t(0.5, 05) + I_p + I_d$ (I_p = 4 dB for standard pre-emphasis)		
7.17	Emphasis- and diversity-improved thermal noise, $n_t(0.5, E, D)$	14.8	pW0	$n_t(0.5, E, D) =$ $\text{antilog}\ \frac{90 - S/N_t}{10}$		
7.18	Total median noise, $n_T(0.5)$	268.5	pW0	$n_T(0.5) = n_{it} + n_t(0.5, E, D)$		
7.19	Signal-to-total median noise ratio, $S/N_T(0.5)$	65.7	dB	$S/N_T = 90 - 10 \log n_T$		

Worksheet 4.5-[illegible] Thermal Noise Calculations (example)

8.1	Decrease RMS per channel deviation and recalculate total median noise	Divide by $\sqrt{2}$ in order to decrease it.
8.2	Is total median noise less for second choice of channel deviation?	~~yes~~/no
8.3	If yes, go to step 8.1	
8.4	If no, an approximate minimum has been determined. Select the deviation which results in the least value of total noise and proceed.	
8.5	Compare total median noise, $n_T(0.5)$,	$n_T(0.5)$ 268.5 pW0
	with DCA noise allowance, $n_y(0.5)$.	$n_y(0.5)$ 594.0 pW0
8.6	If $n_T(0.5)$ is greater than $n_y(0.5)$, make adjustments to hop and/or equipment requirements and recalculate total median noise	
8.7	If $n_T(0.5)$ is less than or equal to $n_y(0.5)$, proceed to next step.	

Worksheet 4.5-8 Noise Adjustments (example)

9.1 Calculate and plot diversity-improved dynamic quieting curve in worksheets 4.5-2a and 4.5 ?		
9.2 Enter total feeder-echo noise and equipment intermodulation noise in their appropriate columns in the worksheet		
9.3 Using $P_r(0.5, 0.5)$ in step 7.13 and emphasis- and diversity-improved signal-to-noise ratio in step 7.16, increase both by an equal decibel amount to the nearest whole 5-dB increment of P_r		$P_r(0.5, 0.5)$ = -56 dBm = Long-term median power (PLTM). The next higher integral 5-dB increment (PNHI) = -55 dBm $S/N_t(0.5, 0.5)$ = 78.3 dB. Increase $S/N_t(0.5, 0.5)$ by (PNHI - PLTM). S/N_t = 79.3 dB
9.4 Convert the new signal-to-noise ratio to thermal noise and enter on worksheet 4.5-2a opposite the value PNHI from step 9.3	11.7 pWO	$n_t = \text{antilog} \frac{90 - S/N_t}{10}$
9.5 Convert each succeeding 5-dB increment of noise by multiplying (decreasing P_r) or dividing (increasing P_r) the previous n_t value by 3.16.		
9.6 Using the diversity-improved median signal-to-path intermodulation noise ratio in step 7.7, increase by 0.7 times the dB increment determined in step 9.3		Increase $S/N_p(0.5, E, D)$ = ____ dB by 0.7 (PNHI - PLTM), 0.7(____ dB) or S/N_p = ____ dB
9.7 Convert the new signal-to-noise ratio to path intermodulation noise and enter in worksheet 4.5-2a	0.51 pWO	$n_p = \text{antilog} \frac{90 - S/N_p}{10}$
9.8 Convert each succeeding 5-dB increment of path intermodulation noise N_p by multiplying (decreasing P_r) or dividing (increasing P_r) the previous value of n_p by 2.24		
9.9 Add the noise components in each row to determine total noise	265 pWO	$n_T = n_f + n_e + n_p + n_t$
9.10 Convert the total noise to signal-to-noise ratio	65.8 dB	$S/N_T = 90 - 10 \log n_T$
9.11 Plot S/N_T versus P_r on worksheet 4.5-3		
9.12 Determine diversity-improved threshold from figure 4.5-28 and complete dynamic quieting curve		

Worksheet 4.5-9 Final Noise Estimates (example)

10.1	Median-voice channel noise	268.5 pW0	Section 4.5.38
10.2	DCS allowance for median noise	594.0 pW0	"
10.3	Is 10.1 smaller than 10.2?	yes/~~no~~	"
	If yes, continue		
	If no, adjust system parameters if possible.		
10.4	Number of hours during which hourly median noise exceeds 10^5pW0	3 hours	Section 4.5.39
10.5	DCS allowance fornumber of hours during which hourly median noise may exceed 10^5pW0	4 hours	"
10.6	Is 10.4 smaller than 10.5?	yes/~~no~~	"
	If yes, continue		
	If no, adjust system parameters if possible.		
10.7	Number of cumulative minutes during which noise exceeds 10^6 pW0	0.6 minutes	Section 4.5.39
10.8	DCS allowance for number of minutes during which noise exceeds 10^6pW0	22 minutes	"
10.9	Is 10.7 smaller than 10.8?	yes/~~no~~	"
	If yes, complete system summary chart.		
	If no, adjust system parameters if possible.		

NOTE: If no further adjustment of system parameters is possible, continue but note the failure to meet DCS allowance.

Worksheet 4.5-10 Compliance With DCS Allowances (example)

9.1 Calculate and plot diversity-improved dynamic quieting curve in worksheets 4.5-2a and 4.5-3		
9.2 Enter total feeder-echo noise and equipment intermodulation noise in their appropriate columns in the worksheet		
9.3 Using $P_r(0.5, 0.5)$ in step 7.13 and emphasis- and diversity-improved signal-to-noise ratio in step 7.16, increase both by an equal decibel amount to the nearest whole 5-dB increment of P_r		$P_r(0.5, 0.5)$ = -56 dBm = Long-term median power (PLTM). The next higher integral 5-dB increment (PNHI) = -55 dBm $S/N_t(0.5, 0.5)$ = 78.3 dB. Increase $S/N_t(0.5, 0.5)$ by (PNHI - PLTM). S/N_t = 79.3 dB
9.4 Convert the new signal-to-noise ratio to thermal noise and enter on worksheet 4.5-2a opposite the value PNHI from step 9.3	11.7 pW0	$n_t = \text{antilog} \dfrac{90 - S/N_t}{10}$
9.5 Convert each succeeding 5-dB increment of noise by multiplying (decreasing P_r) or dividing (increasing P_r) the previous n_t value by 3.16.		
9.6 Using the diversity-improved median signal-to-path intermodulation noise ratio in step 7.7, increase by 0.7 times the dB increment determined in step 9.3		Increase $S/N_p(0.5, E, D)$ = ____ dB by 0.7 (PNHI - PLTM). 0.7(____ dB) or S/N_p = ____ dB
9.7 Convert the new signal-to-noise ratio to path intermodulation noise and enter in worksheet 4.5-2a	0.51 pW0	$n_p = \text{antilog} \dfrac{90 - S/N_p}{10}$
9.8 Convert each succeeding 5-dB increment of path intermodulation noise N_p by multiplying (decreasing P_r) or dividing (increasing P_r) the previous value of n_p by 2.24		
9.9 Add the noise components in each row to determine total noise	265 pW0	$n_T = n_f + n_e + n_p + n_t$
9.10 Convert the total noise to signal-to-noise ratio	65.8 dB	$S/N_T = 90 - 10 \log n_T$
9.11 Plot S/N_T versus P_r on worksheet 4.5-3		
9.12 Determine diversity-improved threshold from figure 4.5-28 and complete dynamic quieting curve		

Worksheet 4.5-9 Final Noise Estimates (example)

10.1	Median-voice channel noise	268.5 pW0	Section 4.5.38
10.2	DCS allowance for median noise	594.0 pW0	"
10.3	Is 10.1 smaller than 10.2?	yes/~~no~~	"
	If yes, continue		
	If no, adjust system parameters if possible.		
10.4	Number of hours during which hourly median noise exceeds 10^5pW0	3 hours	Section 4.5.39
10.5	DCS allowance fornumber of hours during which hourly median noise may exceed 10^5pW0	4 hours	"
10.6	Is 10.4 smaller than 10.5?	yes/~~no~~	"
	If yes, continue		
	If no, adjust system parameters if possible.		
10.7	Number of cumulative minutes during which noise exceeds 10^6 pW0	0.6 minutes	Section 4.5.39
10.8	DCS allowance for number of minutes during which noise exceeds 10^6pW0	22 minutes	"
10.9	Is 10.7 smaller than 10.8?	yes/~~no~~	"
	If yes, complete system summary chart.		
	If no, adjust system parameters if possible.		

NOTE: If no further adjustment of system parameters is possible, continue but note the failure to meet DCS allowance.

Worksheet 4.5-10 Compliance With DCS Allowances (example)

NO	PATH	HOP TIME AVAILABILITY (PERCENTILE)	NUMBER OF CHANNELS	C/N FRONT END (dB)	HIGHEST BASEBAND FREQUENCY (MHz)	PER CHANNEL RMS DEVIATION (kHz)	IF BANDWIDTH (kHz)	DIVERSITY IMPROVEMENT (dB)	EMPHASIS-AND DIVERSITY-IMPROVED TOP CHANNEL NOISE POWER, UNWEIGHTED, (picowatts)					TOTAL CHANNEL S/N, FLAT (dB)			PERCENT OF TIME HOP NOISE EXCEEDS 10^6 pWO (flat)	NOISE ALLOCATION
									THERMAL	EQUIPMENT INTERMODULATION	FEEDER ECHO	PATH INTERMODULATION	TOTAL					
		0.5	120	43.2	0.552	200	7658	4	14.8	239.3	13.8	0.5	268.5	66.0			1.14×10^{5}	511 pWO
		0.9999						6	2.1×10^5	239.3	13.8	562	2.10×10^5	36.7				10^5 pWO
		0.5																
		0.9999																
		0.5																
		0.9999																
		0.5																
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		0.5																
		0.9999																

NOTE: If DCS noise allowance is less than predicted performance, state reasons why it could not be achieved

Yearly Median DCS System Noise Allocation__________pWO, based on L = __________km
Yearly Median Predicted System Noise Performance__________pWO
Estimated System Outage Time__________% of year, __________min

Work Sheet 4.5-11 Noise Data Tabulations (example)

CHAPTER 5

FACILITY DESIGN

Section 5.0 INTRODUCTION.

5.0.1 In previous chapters of this manual, guidelines were provided to the design engineer for site selection, performance of surveys and accomplishing the necessary calculations for path performance predictions. This chapter provides a conmmication engineer with guidelines for arranging facilities and equipment on the selected site, developing installation specifications and instructions, and specifying hardware necessary for installation of the facility. The criteria contained in this chapter should be considered only as an illustration. Latest issues of applicable military standards or MILDEP documents should always be consulted for the definitive criteria in current use.

5.0.2 In addition, if unencrypted classified information is typed or otherwise processed, or if unencrypted classified circuits (called “red” circuits) are joining a military communications system at the subject troposcatter or diffraction facility, then the special engineering consideration found in MIL-HDBK-232(C) to reduce possible compromising emanations must be consulted in addition to this handbook.

5.0.3 One further note is that the term “microwave” will be used to refer to facilities designed to exploit the line-of-sight, diffraction, and troposcatter propagation mode.

Section 5.1 SITE PLANNING.

5.1.1 General

5.1.1.1 This section is intended to contain information on all the usual aspects of planning a microwave communictions station. Not everything discussed here will apply in every situation. The most extensive site planning is ordinarily done for an instailation that will be new, a large communications hub, in an undeveloped area and utilized solely for microwave comminications. If the microwave components are to be located at a new, multipurpose site, the microwave engineer need only provide his specialized requirements to the office directing overall planning. If an existing site (and structure) is to accommodate microwave communications, it will be necessary only to modify the site/building plan to include the addition of microwave equipment and plant. Once a particular site or location is chosen for a new microwave radio facility, specifications and instructions for preparation of the site must be such that a general contractor/qualified Government personnel can accomplish the necessary site preparation install the equipment and place it into operation. If the work is to be implemented by contractual actions, the specifications must comply with the appropriate procurement regulations in both format and content, In many cases, the method of implementation is not known at the time the specifications are written; that is, whether the method of implementation will be contractual or organic. Therefore, the specifications should generally be written so that they may be used in either case.

5.1.12 The bulk of the specifications will be in the form of drawings supplemented by written specificaticns. These specifications define those aspects of work that can be adequately described in words or cannot be easily illustrated. The following areas of activity should be covered for total development and construction of a communications station:

a. Site layout and plot plan.

b. Access roads and parking areas.

c. Site preparation, clearing and grading (maximum slope of 5%).

d. Building design.

e. Water supply and sanitation systems.

f. Antenna footings and/or structures.

g. Prime and auxiliary power.

h. Heating, air conditioning and ventilating.

i. Site security fencing and lighting.

j. Real estate requirements.

5.1.1.3 Written specifications must be accurate, complete, and concise. They should define the extent of the work, specify the materials to be used, and establish responsibility for the performance of work. In some cases, part of the work may be performed at more than one site by the same activity, whether Government or contractor. In these cases, the written specifications may have general clauses applicable to all sites and specific clauses applicable to individual sites.

5.1.14 A set of installation specifications will be required for each microwave radio relay station. Individual site specifications will be influenced by the present requirements of the overall system and of the prospects for future expansion of the system. These requirements are derived from system plans and specifications.

5.1.15 The cost of future expansion can be reduced considerably by taking reasonable effort to ensure that: adequate space is available in the building or additional space can be made readily available; the power equipment is adequate for future needs; and the initial equipment is so located that rearrangement, rewiring, and modifications are reduce to a minimum.

5.1.1.6 Where new construction is planned for the exclusive use of the communications facility, considerable thought should be given to the use of the same type and size of buildings at a number of sites with similar missions. Site adaptation of basic definitive design is common practice in the design and construction business and this practice is often used by the U S Government.

5.1.2 Site Plan.

5.1.2.1 Development of site plans require close coordination of all aspects of civil and communications systems engineering to determine the optimum site configurations. The following factors should be considered when optimizing the site layout:

a. Site topography.
b. Available area.
c. Size, number, and type of buildings.
d. Direction and number of transmission paths.
e. Size, number, and height of antennas and supporting structures.
f. Projections or obstructions to radio paths.

5.1.2.2 The preparation of the site plan should be concurrent with the planning of the equipment building layout, since the orientation and location of the tower and equipment building may influence equipment layout design.

5.1.2.3 A typical site layout should concentrate on making the equipment building the center of site operations. The antenna structures should be placed as close to the equipment building as possible, consistent with design codes and standards to minimize the transmission line lengths required between equipment and antennas. Figures 5.1-1 through 5.1-7 are examples of site layouts.

5.1.2.4 The number and direction of transmission paths specified normally determine orientation of the equipment building with respect to the site and the antenna structure or tower. A power generator building may be used separately from the equipment building, but is located sufficiently close to minimize power cable voltage drops between generators and equipment. Sufficient room should be provided between power and equipment building to allow trucks to drive up to their respective entrances. It usually requires less effort and cost to collocate the power generators/ equipment in the same building with the electronics equipment; in this case, the building should have a specially designed room for generators to minimize noise and vibration and any hazards such as toxic fumes and fire. Ordinarily, a generator is secured to the floor through vibration mounts. The engine exhaust pipe to the outside is quieted by a muffler placed close to the engine. Fuel storage areas should be located where the peak RF power density is less than 5.0 watts per square centimeter. In those cases where it is necessary for the personnel to live on site, every effort should be made to provide as much isolation as possible between the living area and the work area. In the case of small installation, this may have to be accomplished in the same building; however, with a large

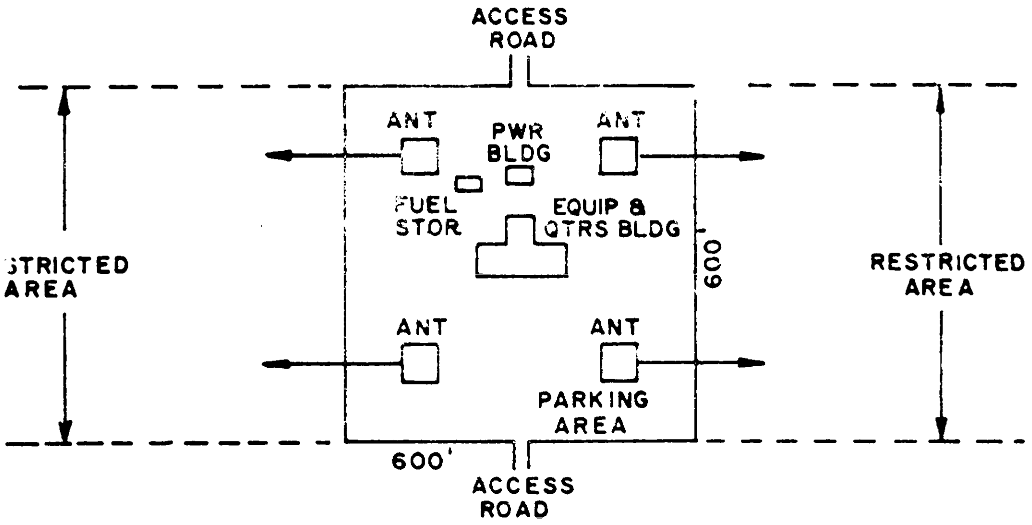


Figure 5.1-1 TWO-TERMINAL TROP SITE, 60-FOOT ANTENNAS

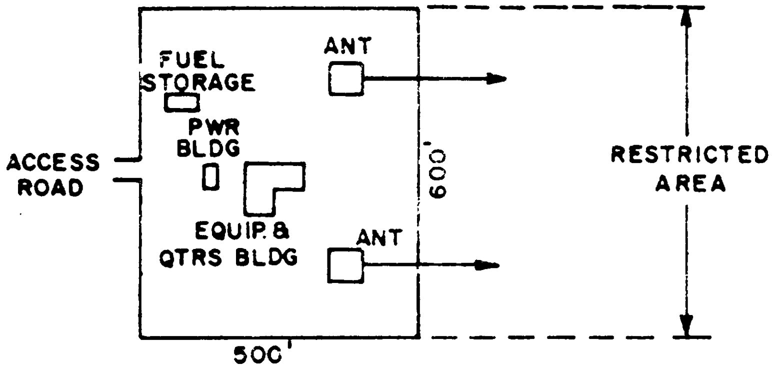


Figure 5.1-2 One terminal tropo site, 60-foot antennas

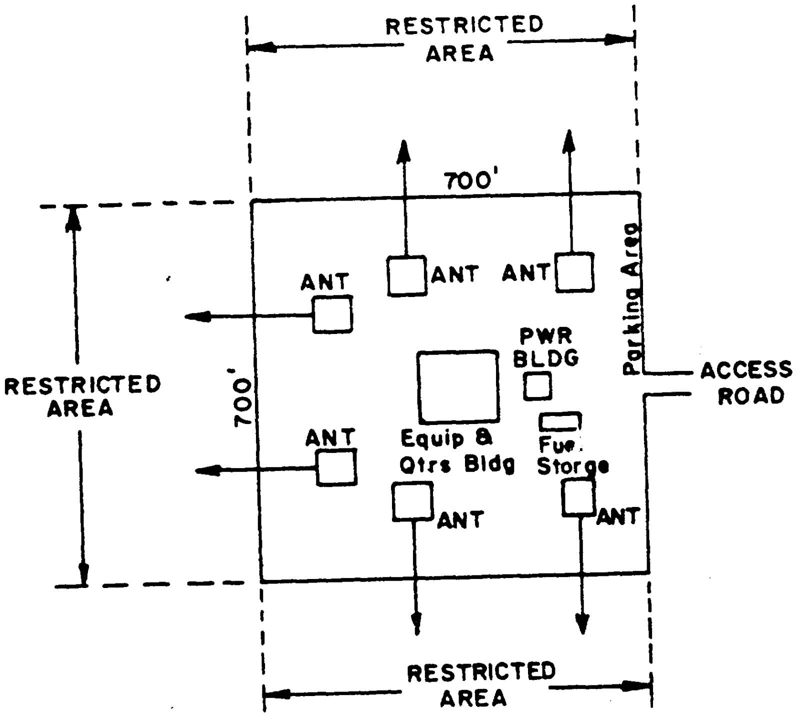


FIGURE 5.1-3 THREE-TERMINAL TROPO SITE, 60-FOOT ANTENNAS

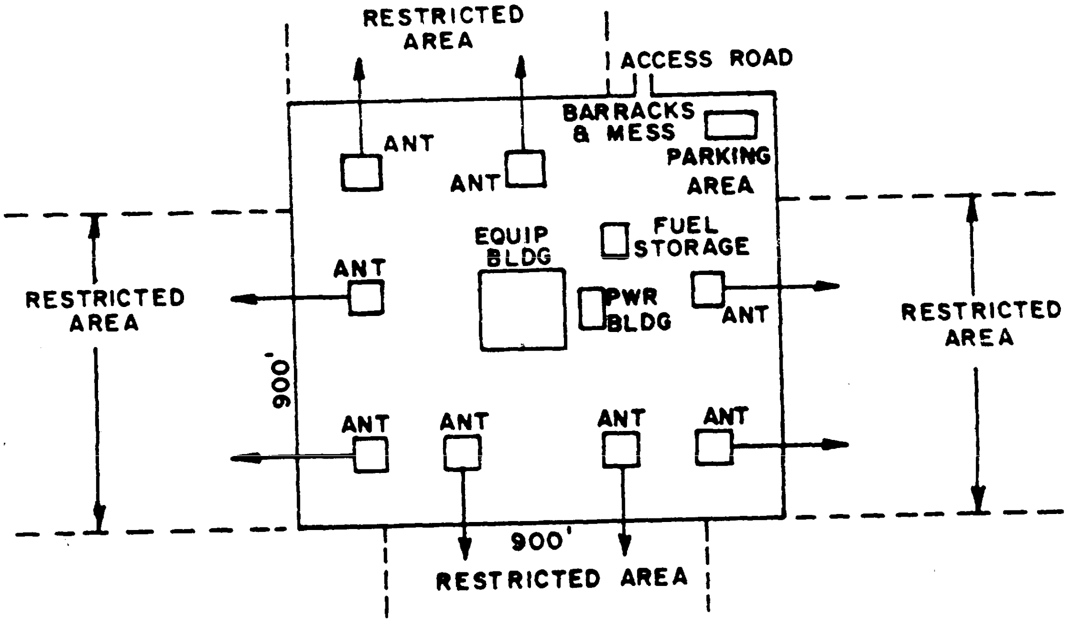


FIGURE 5.1-4 FOUR-TERMINAL TROPO SITE, 60-FOOT ANTENNAS

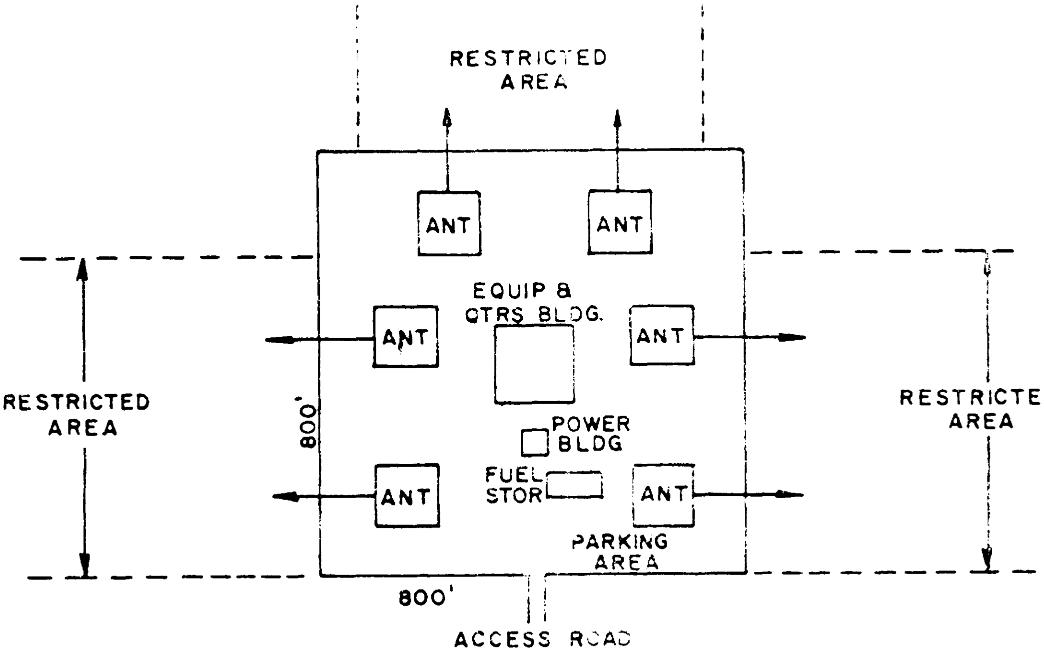


FIGURE 5.1-5 THREE_TERMINAL TROP SITE, 120-FOOT ANTENNA

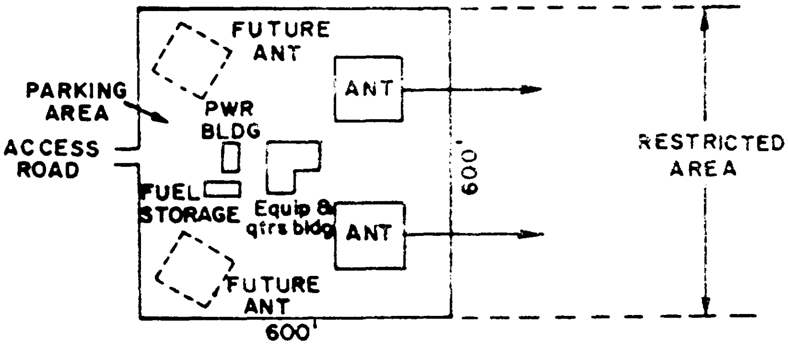
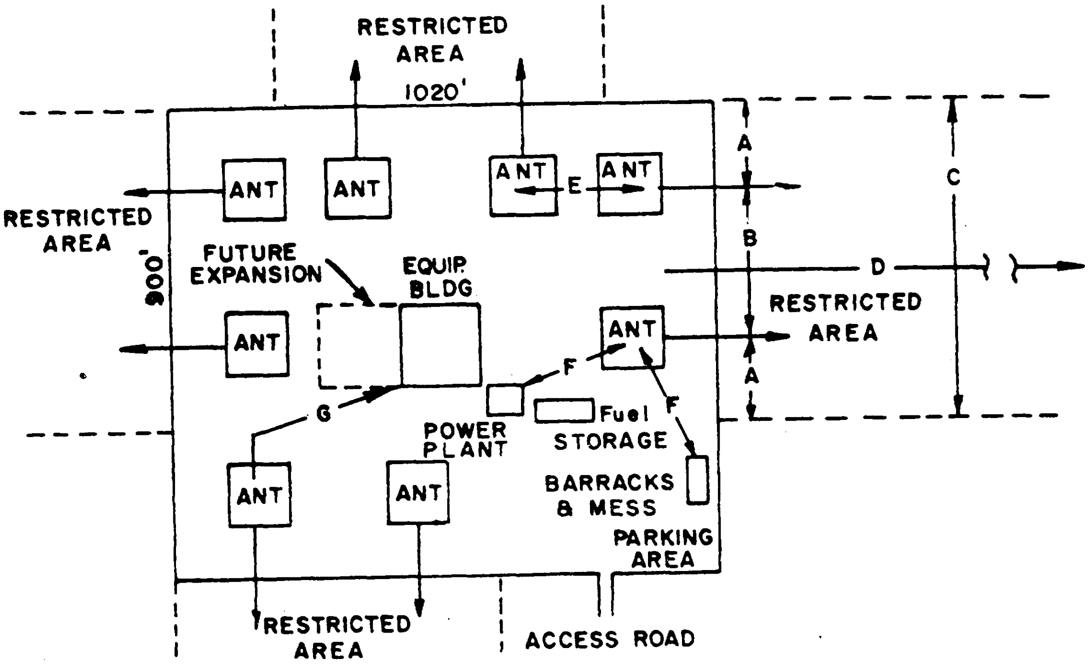


FIGURE 5.1-6 ONE- TERMINAL TROPO SITE, 120-FOOT ANTENNA



ARROWS DENOTE DIRECTION OF PROPAGATION

A = 160 FEET (MINIMUM) FOR 120 FOOT ANTENNA
A = 130 FEET (MINIMUM) FOR 60 FOOT ANTENNA
B = FROM 70 TO 100 HAVE LENGTHS AT OPERATIVE FREQUENCY
D = VARIABLE DEPENDING UPON FREQUENCY, ANTENNA SIZE AND POWER (SEE PARAGRAPH ON RADIATION HAZARDS)
E = 200 FEET (MINIMUM) FOR 120 FOOT ANTENNA
F = 150 FEET (MINIMUM) FOR 60 FOOT ANTENNA
= 150 FEET (MINIMUM FROM CORNER OF BLDG)
G = 500 FEET WAVEGUIDE (MAXIMUM)

Figure 5.1-7 FOUR-TERMINAL TROPO SITE, 120-FOOT ANTENNAS installation, it would be preferrable to have separate buildings. Having separate buildings may require enclosed used walkways areas with high winds and snowdrifts.

5.1.2.5 The topography of the site area often has an important effect upon the site layout. When necessary, compromises in sits layout are effected to keep site preparation and grading within reasonable limits.

5.1.2.6 If microwave station being planned requires attendant personnel, it will be necessary to locate water for their use. An adequate supply of safe water for domestic use and fire protection must be available at all times. Domestic water requirements at an installation include drinking, cooking, washing, bathing, sewage disposal, and possibly a small amount for watering cultivated areas. Most repeater sites do not require or justify elaborate systems and can be supplied by water trailer, community water main, etc. Terminal sites will usually be located in proximity to major compounds and can be supplied by the existing system.

5.1.2.7 The final site plan should show:

a. Site boundary and property lines.

b. Location and dimensions of buildings, tower or antenna structure, foundations, fuel tanks, driveways, walks, retaining walls, drange structures, water supply and sewage disposal (if required), fencing, access roads and parking areas.

c. Base line and bench marks.

d. Elevations, azimutha, and coordinates for the center of each antenna.

e. Underground utilities and services.

f. Existing building,facilities and roads.

g. Magnetic north direction/orientation.

h. A vicinity map.

5.1.2.8 Developing a site plan is the responsibility of the civil engineering authority based upon the communication system requirements as follows:

a. Where service and consequently, facilities are required.

b. Type and volume of equipment space determined by amount and kind of equipment and physical support required.

c. The degree of operation and maintenance required governing personnel requirements.

d. Environmental and power requirements.

P. Location and alignment of antennas.

The communication engineer has the responsibility of gathering this data and translating it into requirements civil engineering can use in preparing the site plan. For existing facilities, a site plan should already exist and should be revised to show new construction. When the project involves the installation of equipment inside an existing, properly identified building, it should not be necessary to include a site plan with the engineering specifications.

5.1.3 Access Roads.

5.1.3.1 A preliminary engineering study, prior to the development of all weather site access roads and parking areas, should take into account vehicular traffic demands. Although the final access road position will depend primarily on site location, layout, and topography, the final design should offer direct routing, adequate right-of-way visibility, good foundation, proper drainage, and degrees of curvature and grade consistent with good highway engineering practice,

5.1.4 Site Preparation.

5.1.4.1 The written specifications should include instructions concerning The clearing of the site and the extent of excavations backfilling, and grading. They should also include instructions for the construction of driveways, walks, retaining walls, and fencing.

5.1.5 Building Design.

5.1.5.1 The size of a building used to house microwave equipment depends upon the station function. In particular, the following factors must be considered:

a. Size and quantity of required equipment and possible future equipment.

b. Necessary working space around equipment.

c. Required space for maintenance purposes.

d. Personnel requirements (desk space, sanitary facilities).

e. Housing of power equipment.

5.1.5.2 At some sites, contemplated use of existing buildings necessitates investigation of load bearing capabilities of the floor. The need for navy antenna mounts the building may require building reinforcement.

5.1.5.3 At remote sites, new buildings may be erected. The type of construction depends upon physical conditions peculiar to the locality, availability and relative cost of construction materials. Other considerations include the required strength and durability of the building and necessary maintenance. Addition factors affecting the Type and strength of a structure are: climatic conditions, temperature range wind velocities, and amount of rainfall and/or snowfall. Transportation and handling cost and site accessibility affect the selection of construction materials. Local codes governing the use of certain materials and methods of construction must be investigated. The availability of skilled labor may be a deciding factor. In areas where a considerable amount of snow and high winds are to be expected, such as mountain top sites, enclosed walkways should be provided between buildings. Also, suitable provisions should be made to ensure that the access roads can be kept open.

5.1.5.4 For small stations, the above requirements can be met by using either sheet metal or masonry construction. Sheet metal building can be prefabricated, easily erected, and readily enlarged or relocated if need be. Masonry building have durability.

5.1.5.5 For each building, an A&E drawing package that includes the following categories of plans should be prepared:

a. Civil Plans-site, grading and utility plan, sections, profiles, details, and boring logs.

b. Architectural Plans-floor plans, elevations, details, schedules, etc.

c. Structural Plans-foundations, roof and wall sections, elevations, construction details, etc.

d. Electrical Plan-electrical distribution, power distribution, control panels, lighting schematics, grounding plans and details.

e. Mechanical Plans-heatinq, ventilation, and air conditioning plans, diagrams, and details.

f. Plumbing Plans-water supply and sanitation facilities plan, diagrams and details.

5.1.5.6 The equipment to satisfy the initial communications requirements determines the floor space requiremants of the station. The kind and quantity of equipment, as well as the type of operation, dictates space to be provided for the electronics bays plus power and other corollary equipments and for personnel. If at all practical, the equipment layout should be planned in such a manner as to afford sufficient space for the installation of equipment capable of handling the maximum projected traffic load. The initial equipment layout should be such that ultimate expansion of the station facility can be accomplished without extensively rearranging already installed equipment. Allowance of space for future equipment can be determined if specific equipments for furure installation are known; otherwise, an estimate based upon the requirements of similar equipments should be made. In a new communications facility, a 100% equipment expansion should be anticipated unless knowedge to the contrary is known. In cases a new communications building is planned, its design should include a capability to enlarge the station from at lease one wall. Specific building design criteria associated with communications station requirements are discussed in the following paragraphs.

5.1.5.7 Buildings of single story, rectangular construction are most common for exclusive utilization by microwave radio communications installation. Equipment building may be physically separated from other site buildings such as power generator building and living quarters. When a single building is employed, one end would normally be used as the equipment room, the center of the building for maintenance and storage, and the opposite end for admistrative functions at the station. A good way to segregate a single, all-purpose, microwave radio communications building is to have one wing for communications equipment, a second wing for power generators, and others for living quarters and offices. Storage and maintenance should be situated close to the communication equipment area. Buildings with multiple stories also afford easy segregation of functions.

5.1.5.8 To determine the space requirements and layouts of the building, floor plans should be developed showing the location of all equipment in the operations and maintenance areas. Requirements for spare parts storage space are determined by the type of equipment and level maintenance to be performed at the station. Consideration should be given to the reduction of spare parts storage requirements resulting from improved equipments, and streamlined maintenance and supply techniques now being employed. Space requirements for administrative and sanitation facilities are determined from the number of personnel programmed for normal operation and maintenance duty at the station.

5.1.5.9 At least one outside door to the equipment room, capable of passing the largest single component that may be moved into the station, is required. A loading ramp or dock must be provided immediately outside this door to facilitate loading and unloading heavy equipment from trucks. If the building floor is at ground level, hardstand should be provided from the drive to the equipment room freight door.

5.1.5.10 Ceilings in the equipment area should be at least ten feet above the floor level for adequate ventilation of standard eight-foot equipment racks. This height also provides proper diffusion of light throughout the equipment area from ceiling luminaries. In case of large installations, a unistrut grid with four foot spacing is normally provided below the ceiling to provide support for the various cable racks or trays that may be required above the equipment bays for the equipment interconnecting cables and power distribution lines.

5.1.5.11 The building floor must be designed to support the heaviest item of equipment likely to be placed upon it as well as the total weight of all equipment on it. Overall, the floor should support the entire weight of all stationary and wheeled equipment, personnel,supplies, storage, and non-load bearing wall , and should provide sufficient perload factors to accommodate the installation of heavier or additional communications equipment for future expansion.

5.3.5.12 Provisions must be made in the walls, ceiling and roof of the equipment building for installation of transmission lines running to the outside of the building. These exit ports require “tailoring” to the installation at each station, and may include RF shielding.

5.1.5.13 Some microwave stations will require the installation of various types of hardware on the roof of the building such as roof ventilators (added by the building construction authority) and roof mounted antennas (specified by the microwave engineer for line-of-sight or near line-of-sight diffraction). A roof plan should be provided showing all pertinent details that will be required by personnel responsible for the installation of the station. There are usually two major factors that will determine the specific location for the placement of antennas on top of the building. The first will be the location of the tower mounted reflector or the adjacent station to which the antenna will be directing a signal, and the second will be the relative location of the microwave equipment within the building. Having the antenna in proximity to the microwave equipment will avoid unnecessarily long waveguide runs.

5.1.5.14 Where a station is required to be equipped with a no-break power system using batteries, a room will have to be provided for a battery bank plus suitable space for a rectifier charger unit.

5.1.15 The design of the interior Lighting will be according to recommendations of the Illuminating Engineering Society (IES) Lighting Handbook. Specific location of the equipment, cable racks, waveguide runs, unistrut grid, work benches, desks and consoles must all be considered in the design of the lighting system. Battery power emergency lighting is required throughout the building.

5.1.6 Station Ground.

5.1.6.1 The DCA Notice 310-70-1, entitled DCS Interim Guidance on Grounding, Bonding, and Shielding, provides guidance for designing a good grounding system. The elements of a ground system for a commumications station are an earth electrode system, power grounding network, safety grounding network, lightning protection grounding network, a facility grounding network and a low frequency signal grounding network.

5.1.6.2 Earth Electrode System. The earth electrode system provides electrical contract with earth and is the common interconnection point for all the various grounding networks. The higher the soil resistivity, the more complex (and expensive) will be the electrode system necessary to achieve low resistance to earth. Two typical configurations of earth electrode system are as follows:

a. ten-foot ground rods installed at 20-foot intervals aronnd the perimeter of the structure provide good utilization of the Effective radius of the rod while providing several points of contract with the earth.

b. In regions of shallow bedrock, vertical ground rods may be ineffective and horizontal grids, wires, or plates must be used. A typical ground system of this type may consist of buried copper radials, extending in all directions from the building center, and a single ground point extended through the floor of the equipment room for connection of the electronic equipment.

5.1.6.3 Power Grounding and Safety Grounding network. This is an integral part of the power system and should be done in accordance with the National Electrical Code.

6.1.6.4 Lightning Protection Grounding network. This is an intergal part of construction of the building or antenna support structure. (See paragraph 5.4.2.3 on lightning protection.)

5.1.6.5 Facility Grounding Network This network is a conductive grid providing multiple low ressistance paths between any two points within the structure and between any point in the structure and the earth electrode system. The facility grounding system is to be separated from the low frequency signal grounding network, described in 5.1.6.6 except for the commnon interconnection made at the main ground plate of the earth electrode system.

5.1.6.6 Low Frequency Signal Grounding. The low frequency signal grounding network is used to furnish a single-point reference for low frequency signals, minimize power frequency noise levels in sensitive low frequency equipments, and provide for fault protection and static discharge of otherwise isolated networks. Low frequency signals are defined as those with frequencies less than one megahertz.

5.1.6.7 Ordinarily, a microwave radio is interconnected with the facility grounding system. Frequency or time division multiplexing, if included with the installation, should have its drop side grounded to the low frequency signal grounding network. The baseband cable between the radio and multiplexer or between radios at a repeater station should have its shield grounded to the low frequency signal grounding network if conducting signal currents with frequencies not exceeding one megahertz, or to the facility grounding system with frequencies over one megahertz. At small repeater stations, it may not be practical to have a separate low frequency signal grounding network;then the baseband cable shield would connect to the facility grounding network regardless of frequency. Whatever method employed, extreme care and sound judgement must be exercised because baseband cables are a critical means by which noise is introduced into radio systems. Grounding conductors will be stranded, insulated copper wire and adequately sized to conduct all currents likely to be imposed. Main grounding leads are usually run on the cable rack, tray or in trenches with signal cables. Taps of smaller size wire are run from the main grounding lead to individual equipments. Connections to this main grounding lead are made with suitable lugs, pressure connectors or clamps.

Section 5.2 EQUIPMENT LAYOUT.

5.2.1 General.

5.2.1.1 Equipment and equipment layout should be standardized among the facilities comprising a communications system insofar as possible. In determing the layout where unencrypted signals bearing classified information are present or processed, the specialized installation guidance found in MIL-HDBK-232(C) must be consulted. Another major consideration should be the necessary access for installation, maintenance and operation. This would Include such considerations as provision of adequate space between rows of equipment to allow for opening of cabinet doors or sliding out modules for maintenance. Another major but less Important consideration is providing the shortest and most direct waveguide run practicable.

5.2.1.2 Other equipment layout considerations include minimizing interbay cabling runs, prevision for future expansion, and providing easy access for maintenance and operational convenience, etc. Sometimes, the electromagnetic incompatibility of various types of equipment or inadequate ventilation for personnel and equipment can be problems. Equipment of the same type or with similar functions are usually grouped together except where impractical due to size and specific requirements of a station. In a typical situation radio/multiplex equipment, crypto equipment, and technical control equipment are each grouped in separte rooms with other rooms being used for administration and maintenance.

5.2.1.3 Human engineering can be another factor of concern in laying out equipment. Equipment should be properly grouped according to their functions and interoperation. Care and thought should be given to the arrangement of meters, test equipment, backfields, indicating lights, etc.

to assure they are placed at the approximate eye level, thus allowing more rapid and convenient use. Equipment should not be mounted at the bottom of a bay, if it can be easily damaged or if its size and shape will interfere with power boxes or other hardware at the bottom of the cabinet or rack. Fortunately, most microwave radio equipment comes fully packaged with all components already mounted within the cabinet or rack.

5.2.1.4 It is adviseable to arrange equipment within the equipment room in such a manner that expansion of the building will not necessitate rearrangement of existing installed equipment. A satisfactory arrangement is to align the equipment in rows on both sides of the building, with sufficient clearance between the rear of the equipment and the wall for *use* as an access/service area, and to provide an aisle between the front panels of facing equipment. The point of entry for antenna waveguide and possible transmission lines for this arrangement will generally be along the sides of the building. The end wall of the equipment room opposite the mechanical, generator, or toilet facilities should be considered as the direction for future building expansion. Therefore, installation of equipment at this room location should be avoided if possible. The end wall location may also be considered for use as an equipment ingress opening, by removal of wall panels, to permit installation or removal of equipment.

5.2.1.5 In determining floor area requirements for the communications equipment, a number of factors must be considered. The most important factor is that of providing sufficient space to suitable house all of the equipment and, at the same time, allow adequate clearance for ventilation and permit ready access for maintenance. When placing each piece of equipment, frequent reference should be made to the back assembly and outline dimensional drawings drawings with special regard to minimum wall clearance requirements, spacing between equipments, power and antenna connection points, minimum radius requirements for the removal of protective housings and opening of maintenance access doors. Approximately three feet of clearance space, at a minimum , should be allowed in front of and to the rear of an equipment bay. If a bay does not permit rear access to equipment, the bay may be installed with no clearance on the back side, i.e., against a wall or back-to-back with other bays, ventilation requirements not withstanding.

5.2.1.6 The operational plan of the station must be studied to determine the communication circuit requirements when placing each component or rack assembly. In small station, it is recommended that the equipment be aligned in a row along one or, if need be, both sides of the building with sufficient space between to accommodate a normal floor traffic pattern. However, this type of layout will generally not be suitable in stations where large quantities of equipment are involved. In the large station, the most practical layout is usually one in which the equipment is aligned in bays across the width of the room, with sufficient space between bays to permit free access to each rack assembly.

5.2.2 Installation Plans.

6.2.2.l After the equipment layout has been determined, installation plans can be developed. Installation plans contain all the information and instructions required to accomplish all aspects of the installation under the cognizance of the microwave communications system engineering activity.

Some typical plans for specifying installations are explained in this section. The format of these engineering plans may vary from agency to agency.

5.2.2.2 Floor plans provide a pictorial representation of equipment placement, as well as administrative, maintenance and storage areas. All required dimensions must be specified on the floor plan with sufficient detail included relative to obstructions, to preclude interference with equipment placement. Section 5.2.3 through 5.2.10 will discuss equipment placement in more detail. Finally, one floor plan is considered optimum and is documented following the practice of the responsible engineering agency (see Section 5.2.11).

5.2.3 Radio Equipment.

5.2.3.1 Power Amplifiers. The power amplifiers and their associated power supplies are positioned close to the wall to provide shortest waveguide runs to their respective antennas. Just how close to the walls they can be positioned will be dependent upon the specific construction of the equipment, whether or not rear access is required for installation and maintenance, room required for installation of duplexer, etc. A dummy load/power calorimeter is positioned between the two power amplifiers to facilitate switching the output of either amplifier into the dummy load and to keep the waveguide runs to a minimum.

5.2.3.2 Exciters- Modulator. The location of these units is not critical. In the illustration, they are placed in the rack row opposite their respective amplifiers; however, they could also be located next to their respective amplifiers, space permitting.

5.2.3.3 Receivers. Location of preselectors and low level preamplifiers should be such that transmission line lengths will be minimized. Otherwise, after preamplification, the location of receivers and base-band amplifiers is not extremely critical in well designed installations. If recorders are to be provided they may be placed in the same rack row.

5.2.3.4 Performance Monitor. These monitors may be either in a fixed configuration or mounted in a movable rack. In the fixed configuration, a location should be selected that will insure that connections to the required test points can be accomplished without unduly long lead. If the monitor is portable, it is only necessary to insure that a convenient space is available for storage, when it is not being used.

5.2.3.5 Duplexers. Duplexers locations are not indicated on the floor plan, but consideration must be given to their location in order to allow a practical installation without long, complicated waveguide runs. In the case of the higher powered transmitters, the duplexers may require water cooling. This is usually provided as part of the heat exchanger system but the necessity for the additional plumbing or pipe runs must also be considered.

5.2.3.6 Spare Klystrons. Where klystron amplifiers are needed, spare klystrons mounted in carriage are normally provided to facilitate rapid replacement when necessary. A convenient space should be provided for their location

5.2.4 Mechaical Equipment.

5.2.4.1 It is desirable to provide a separate room for the mechanical equipment. This includes the heat exchangers, air-conditioning equipment and waveguide dehydration-pressurization equipment. The heat exchangers must be provided with air intake and exhaust ducts to the outside of the building. The size of these ducts dictates that the heat exchangers be located in close proximity to the wall. It must not be overlooked that som types of heat exchangers may require rear access for maintenance purposes. Location of the dehydration pressurization equipment is not critical. However, ease of access for maintenance is desirable and the pressure gages should be readily visible to the maintenance personnel. Location of the air-conditioning equipment will be dependent upon the specific type provided and whether or not intake and exhaust to the outside of the building is required.

5.2.4.2 The efficient of site personnel will be enhanced if it is possible to locate noisy mechanical equipment, like some diesel generators, away in separate housing from working and living areas or otherwise provide noise control. Also, care must be taken to assure that fresh air intakes do not catch fumes or odors from sources such as diesel generators.

5.2.4.3 The batteries of an UPS should be isolated from machinery in a properly designed battery room to prevent damage to the batteries from vibration, pollution, overheating and explosion. The electronic components of an UPS should be in a room separate from the machinery and the batteries to prevent vibration, pollution, overheating and corrosion of the electronic components. See MIL-HDBK-411 for air conditioning criteria.

5.2.5 Multiplex and Technical Control Equipment.

5.2.5.1 In most cases, it is desirable to provide a seperate room for this equipment. Dependent upon the specific facility, the requirements for multiplex or tech control may vary from simple patch facilities in a through repeater to extensive patch and test quality monitoring and line level and adjust facilities in a nodal station.

5.2.6 fault Alarm Equipment.

5.2.6.1 The future DCS System Control (SYSCON) and facility maintenance concepts specifies a five level hierarchial control configuration; certain centers unmanned communications facilities; and centralized maintenance centers. The Tropospheric Scatter Station are excellent candidates for The unmanned communications facilities; Thus it will be essential that the Fault reporting and Alarm System be designed not only for internal use but for Centralized Maintenance Center and the next higher level of SYSCON. This dicates not only the extension of alarms and measurements for monitoring the operation of the equipments but the capability of remote control and data acquisition by cognizant Control and Maintenance Centers. Therefore, the fault-alarm equipment must have those design features that readily permit connections to interface equipments that provide sensing, data acquisition, remote control and telemetry. The same criteria applies in part to manned stations in order to accommodate the SYSCON function.

5.2.7 Orderwire Equipment.

5.2.7.1 A radio orderwire for maintenance purposes should be provided for communications with adjacent sites. This otherwise set is normally located with the radio equipment.

5.2.7.2 A service orderwire for use by the tech control personnel may or may not be required dependent upon the specific system requirements. If it is required, it is normally located in the tech control area.

5.2.8 Other Equipment.

5.2.8.1 In addition to the fixed equipment, there is a need to provide space for test equipment, tools, spare parts, etc. It is desirable to provide a separate maintenance room for this purpose. The space required will, of course, depend upon the amount of radio and multiplex installed, the number of maintenance personnel involved and spare parts stocking requirements,

5.2.9 Power Distribution Boxes.

5.2.9.1 Care should be taken in specifying the size and location of the power distribution box and any additional breakers panels that may be required. They should be located so as to be easily accessible after all the equipment has been installed and sized to provide for future expansion.

5.2.10 Cable Racks.

5.2.10.1 After the equipment layout has been finalized, the location and size of the various runs of cable rack should be determined. Future requirements should also be considered in determining the size of cable racks required.

5.2.11 Installation Plans.

5.2.11.1 After the optimum layout of the equipment has been determined, installation plans and specifications must be developed. Installation drawings contain all the information required to accomplish the installation.

5.2.11.2 While the form of documentation differs from agency to agency, examples of documentation necessary to completely specify the planned installation are given for tutorial purposes:

a. Floor plan.

b. Cable rack installation drawings.

c. Cable termination lists.

d. Cross-connect lists.

e. Power disrtibution drawings.

f. Grounding and bonding plans,

g. Equipment installation drawings.

h. Transmission line layouts.

i. Installation list of materials.

5.2.11.3 Floor Plans. Floor plans provide a pictorial representation of equipment placement as well as administrative, maintenance and storage areas. All required dimensions must be specified on the floor plan with sufficient detail include relative obstructions to preclude interference with equipment placement.

5.2.11.4 Cable Rack Lay-out. Cables for interconnecting and terminating equipments are distributed by one or a combination of three methods: overhead open rack, overhead enclosed tray, or raised floor/floor trenches. selection of the one or a combination of these methods is dictated by the Individual station equipment. Layout drawings should be prepared which depict:

a. Overhead view of cable layout superimposed on floor plan.

b. Detailed two-dimensional and perspective three-dimensional views of cable arrangements such as elbows, splits, tee sections, reducing sections and dropouts.

c. Equipment distribution frames and AC branching panel access details.

d. Rack/cable support and hardware list of materials keyed to layout and details.

5.2.11.5 Cable Termination Lists. All VF and slow speed data signal equipment in a communications station is wired to a distribution frame (DF) as a common terminal for interconnection of circuits ingressing/egressing all conmnications equipment. Information for terminating cables on a distribution frame is provided by cable termination list. Each wire is given a specific punching assignment on a specific distribution frame termination block. A simple radio repeater station likely would not utilize a distribution frame, and the cable list would reflect runs directly from equipment to equipment. The microwave engineer would be concerned with wiring to the DF only to terminate the drop circuits on multiplexing equipment or to cable ordewire and control and fault alarm circuits. See MIL-STD-188-310, Criteris for Engineering Technical Control Facilities, for a description of the breakout of individual circuits and their flow through a communications station.

5.2.11.6 Cross-Connect Lists. Assuming the station is large enough to have a distribution frame, cross-connect lists are used to describe the connection for jumper wires on a distribution frame required to interconnect a particular equipment group in a prescribed manner. Cross-connections could be the responsibility of the operating agency for expansion or replacement of equipment in an existing facility. For a turnkey project, the cross-connections are part of a complete installation.

5.2.11.7 Power Distribution Drawing Power wiring firm the power distribution pannel to each equipment is completely described by the power distribution drawings, including the method to be used by the installer in wiring individual electronic equipments to the power source. They specify such features as:

a. Type and size of wire to be used.

b. Routing of wires.

c. Specific circuit breakers (or fuses) associated with each equipment.

d. Diagrams of each panel board, indicating equipment connected to each circuit breaker, rating of the breaker and the load connected to each breaker.

e. For AC tabulation of total loads on each phase of the panel feeder and the total load on all phases (of more concern to the power engineer than the communications engineer).

f. Materials requied to accomplish installation of power wiring.

g. Required power for each equipment.

5.2.11.8 Grounding Drawings. The station grounding system is shown by a grounding diagram that specifies grounding system routing, cable size, type and position of all ground connectors and materials required to install the grounding systems. Design of the station ground is outline in paragraph 5.1.6.

5.2.11.9 Equipment Installation Drawings. All necessary information to accomplish installation of a equipment is provided by these drawings. They contain installation details peculiar to a specific equipmnt and illustrate the planned procedures for accomplishing each portion of the installation effort. When different equipments require the same basic installation information, a common installation drawing may be used. In either case, materials required to install the equipment should appear.

5.2.11.10 Transmission Line Layout Drawing. This drawing shows the details of the RF transmission line and its routing. It specifies the size components to be used at each point along the route and where bends and flexible sections are located. The location of gas barriers and the arrangement of the pressurizing system should be shown.

5.2.11.11 List of Materials. Accomposite listing of materials required to install the facility should be included in the installation plan.

Section 5.3 PRIME AND AUXILIARY POWER.

5.3.1 General.

5.3.1.1 Power systems shall be engineered to provide continuity of vital communications. The availability/reliability of the power system shall be based upon the operational rquirements of the commnunication systems. The minimum electrical design requirements and perfornance parameters shall be in accordance with MIL-HDBK-411.

5.3.2 Electrical Power Systems. The power systems for Transhorizon C-E facilities shall consist of the following:

a. Primary Source: Commerical or "Class A".

b. Standby Power (when justified), "Class B".

5.3.2.1 Primary Source. Primary power may be furnished by an off-station source such as comerical power or a government owned power system. If reliable primary power is not available from off-station sources, power shall be provided by a prime power plan (Class A) at the C-E facility. prime power plants (Class A) shall be sized according to MIL-HDBK-411 paragraph 4.2.2.b.

5.3.2.2 Standby Power Plant.. Where primary power is provided by an off-station source, a standby power plant (Class B) of adequate capacity to supply the operational load will be provided with exception as noted below. One additional standby generating unit will be provided as a fixed maintenance spare.

a. A back-up power plant is not required when the C-E facility is within 1000 feet of a dedicated prime power plant and has two dicated separate feeders from this plant to the C-E facility. A dedicated prime power plant is:

(1) A power source supplying electrical power only to the C-E facility, or

(2) An off-facility plant, such as a base prime power plant where an engine generator is dedicated to the C-E facility, or

(3) A prime power plant where a host-tenant agreement gives the C-EE facility an acceptable priority in the power restoration sequence when the prime plant fails.

b. The standby power units shall be provided with Auto-start and automatic transfer capability except at installations having 24 hours per day manning by power production personnel.

5.3.3 Fuel Storage Facility. The size of the fuel storage facility shall be determined by local replenishment conditions.

Section 5.4 ANTENNAS AND WAVEGUIDES.

5.4.1 General.

5.4.1.1 The system design considerations in Chapter 4 determines the quantities, types and sizes of antennas and waveguides to be used. The following section will give further information on antennas in Section 5.4.2 and waveguides and other transmission lines in 5.4.3.

5.4.2 Antennas.

5.4.2.1 The size of antennas utilized in a troposcatter or diffraction link depends upon the amount of gain required to compensate for transmission path losses. Diffraction link with modest path losses may have smaller antennas 15 feet or less in diameter while troposcatter links may use 30, 60, or 120 foot billboard-type antennas.

5.4.2.2 The following type of information must be provided by the communication engineer in order for the structural designer to adequately design a suitable antenna support structure and foundation combination.

a. Size and type of antennas required and type of radomes.

b. Azimuth and elevation angles for each antenna.

c. Amount of adjustment required for alignment after installation.

d. Height above ground for each antenna.

e. Location with respect to the building and their corresponding orientations.

f. Beanwidths of the antennas and permissible twist and deflection of the tower that can be tolerated under maximum expected wind and ice loading.

g. Type and number of waveguide runs required and power cabling for feedhorn or radome heaters.

h. Requirements for lightning and painting.

i. Requirements for platforms to allow access to the antennas for maintenance and/or alignment.

j. Required means of access up the tower or antenna support including required personnel safety features.

i. Provisions for future antenna requirements.

l. Climatic details of the area involved.

m. Local restrictions and/or other constraints that may involved.

n. Soil conditions.

5.4.2.3 Whether the antenna support is an antenna-billboard structure or a guyed or sel-supporting tower, the support will need to be considered for painting and lighting, installation near airfield restrictions, personnel safety regulations, and lightning protection. Painting and lighting requirements are imposed by cognizant military or government agencies in the country hosting the facility. Restrictions against installation near airfield is covered by AFM 86-8, Airfield Clearance Criteria, and the applicable host country regulations. Personnel safety for ladders, stairs, and elevated work platforms are specified in OSHA, Volume 1, General Industry Standards and AFM 127-101. Lightning protection for towers should be in accordance with the latest edition of Underwriters Labortories (UL) Pamplet 96A, Lightning Protection Systems.

5.4.2.4 Antenna positioning for tropospheric scatter applications is much more critical than for line-of-sight application. The tropo antennas are much larger than LOS and, once installed, they have very little adjustment range for correction of azimuth and elevation. The beanwidths are on the order of 0.5 degrees to 2 degrees so it is essential that they be positioned very accurately. The geographical coordinates of the antenna locations must be accurately determined in order to calculate the great circle azimuth to establish a baseline for positioning the antennas. It is also necessary to determine the take-off angles to the radio horizons since the antennas must also be positioned in elevation as well as azimuth. The take-off angle is calculated by standard geometric methods modified to compensate for the earth curvature and bending of the radio beam due to atmospheric refraction. The important parameters required are the accurate heights above sea level of both the antenna and its associated radio horizon and the distance between the antenna and the radio horizon. In addition, the minimum monthly surface refractivity values referred to mean sea level must be determined for the area to correct for the bending of the beam. Specific methods for these calculations are provided in Section 4.4.

5.4.3 Transmission Lines.

5.4.3.1 Typically, transmission lines for troposcatter and diffraction links will be waveguides. However, on lower frequency troposcatter links, the waveguides used are larger and cumbersome so coaxial cable is used on all low power connections, such as the connection between receiver and duplexer.

5.4.3.2 Coaxial cable is easier to install than waveguides since most types are flexible or semi-flexible down to a minimum bend radius. Care should be taken to avoid putting kinks in coaxial cable or waveguides.

5.4.3.3 One of the properties which does not apply to coaxial and other transmission lines is the cut-off frequency characteristic. A waveguide does not transmit waves having a frequency less than a critical cutoff value detemined by the waveguide dimensions. The main requirement for conduction is that one dimension must be more than a half wavelength. This requirement makes waveguides difficult to use in high power VHF troposcatter and impractical for low power applications in frequencies other than UHF and SHF.

5.4.4 Waveguide Installation.

5.4.4.1 Rectangular waveguides are comnonly used for tropo application. The installation of waveguidle presents problems that are different from those encountered with two-wire or coaxial transmission lines. The installation should be carfully laid out before the waveguide is ordered. Waveguide runs should be as straight as possible. Exact positioning is a necessity for proper installation.

5.4.4.2 Any abrupt change in waveguide size or shape results in reflections. When it is nessary that the change in direction or size be abrupt, then special devices, such as bends, twists, joints or terminations, must be used.

5.4.4.3 Waveguide may be bent in several ways to avoid reflections.

A. Gradual Bend. One method is to make the bend gradual. It must have a radius of bend greater than two wavelengths in order to minimize any reflections.

b. Sharp bend. In a sharp 90 degree bend, reflections will normally occur. To avoid this, the waveguide is bent twice at 45 degrees, one-quarter wave apart. The combination of the direct reflection at one bend and the inverted reflection from the other bend will cancel and leave the fields as though no reflection had occurred. Special 90 degree bends can also be obtained from the manufacturer.

c. Special bends. For special bends, flexible waveguide can be twisted or bent as the installation requires. Manufacturers will provide the recommended bending radii and twist degrees for their waveguide.

5.4.4.4 All special waveguide components, such as bends and twists, should be kept to a minimum since most will cause discontinuities and increase loss and VSWR. Standard off-the-shelf components should be favored to simplify logistics maintenance.

5.4.4.5 Since it is impossible to mold an entire rectangular waveguide into one piece, the waveguide is constructed in sections at the installation site by joints. The simplest method of connecting two sections of waveguide is the flange-to-flange coupling. When the flanges are connected, an electrical short is created at their junction. The two sections of waveguide can be separated as much as a tenth of a wavelength without excessive loss of energy at the joint. This separation allows room to seal the interior of the waveguide with a rubber gasket for pressurization.

5.4.5 Waveguide Pressurization.

5.4.5.1 To ensure reliability and long life of the system, the waveguide should be continually pressurized with dry gas. A positive pressure is requires to prevent the entry of moisture. In waveguide, moisture will degrade VSWR and increase attenuation. Choice of pressurization equipment depends on the number of systems at each site, the length of waveguide, and the ambient conditions.

5.4.5.2 Most pressurizing units include a valve and a pressure gage mounted on a short section of waveguide. The valve permits addition of gas when the pressure decrease below a predetermined limit. At some locations, it may be beneficial to use a system which automatically keeps waveguide pressure at a pre-set level.

5.4.6 Waveguide Power Handling Capability.

5.4.6.1 Waveguides can handle much higher power than coaxial cable of the same diameter. The maximum power that can be transmitted in a waveguide depends on the maximum electrical field strength that can exist without breakdown. If the electrical field strength at any point in a waveguide exceeds the electric field breakdown strength, dielectric breakdown occurs. The microwave power is dissipated in the walls of the waveguide and in the arc that is formed. The breakdown electric field strength of air varies with different pressures, moisture content, and temperature. For normal conditions, the value of the breakdown field is 30,000 volts (peak) per centimeter.

5.4.6.2 Once the power handling capability of the waveguide specified by the waveguide manufacture matches or exceeds required power of the radio, the system requirements are normally satisfied. However, hiqh noise, smoke or sparking sounds may occur in high power tropo systems due to equipment breakdown or improper installation. Often a defect in the waveguide can be detected by arcing sounds or a warm spot in the waveguide. This defect causes high VSWR which indicates that voltage in the waveguide have exceeded the dielectric breakdown voltage. Time domain reflectometer may be used if defects are not found by inspection. Replacement of the deflective section should reduce these problems.

Section 5.5 ENVIRONMENTAL CONTROL.

5.5.1 General.

5.5.1.1 Environmental control as used in this section includes all equipments used for cooling, heating ventilation, humidification, dehumidification, filtration, pressurization, and distribution of air and the control thereof. Environmental control as defined here is for the communications equipment and all systems, personnel and facilities that directly support these items.

5.5.1.2 This section provides general guidance for the selection of desired environmental conditions. The information herin will have to be supplemented by more specific environmental design criteria based on the requirements of the communications equipment to be installed and the latest applicable conservation directives.

5.5.1.3 When installed equipments operating range requires environmental conditions that are different than those outline in this document, those requirements shall be used as a basis for design; however, every effort should be made to minimize life cycle cost.

5.5.1.4 For further design guidance, refer to the design manual of DOD design and user agencies and the Defence Communications Agency (DCA). The latest edition of American Society of Heating, Refrigeration and Air Conditioning Engineers Guide and Data Book-fundamentals, applications systems, and equipment volumes - should be followed as a basic reference for systems design except where modified by more specific criteria.

5.5.2 Design Conditions - Electronic Equipment Spaces.

5.5.2.1 Outside conditions to be used as a basis for design shall be taken from TM5-785, NAFAC P-89 or AFM 88-8, Engineering Weather Data. The 1% and 99% temperatures for cooling and heating respectively shall be used for those facilities classed as critical. All other facilities shall use the 2-1/2% and 97-% temperatures for cooling and heating, respectively. If conditions are not available from one of these manuals for a particular site, the United States Air Force Environmental Technical Applications Center, Scott AFB IL 62225 should be contacted for the necessary data.

5.5.2.2 Inside Design Conditions:

a. Winter dry bulb temperature shall be 70°F.

b. Summer dry bulb temperature shall be 78°.

c. Relative humidity shall be maintained between 20 and 50 percent and shall utilize a minimum of humidification and dehumidification during the winter and summer, respectively.

d. Supply air shall be filtered by filters with a minimum efficiency of 20 percent when tested by NBS dust spot test method using atmospheric dust.

5.5.3 Design Conditions - Auxiliary Equipment Rooms.

5.5.3.1 Outside design conditions shall be as reference in paragraph 5.5.2.1.

5.5.3.2 Inside Design Conditions:

a. Equipment rooms such as battery rooms, environmental control equipment rooms, and uninterruptible power system rooms may not require as close environmental control as does the electric equipment spaces. If this is the case, dry bulb temperature limitations are 104° F, dry bulb maximum, and 50° F, dry bulb minimum, and force air cooling shall be provided as necessary if environmental conditions can be maintained without the use of mechanical refrigeration.

b. Diesel electric power rooms and diesel electric driven UPS rooms shall be provided with forced air cooling as necessary to limit the dry bulb temperature rise to amaximum of 10° F above ambient.

Section 5.6 ELECTROMAGNETIC COMPATIBILITY.

5.6.1 General.

5.6.1.1 Electromagnetic compatibility (EMC) is a complex subject, often needing specialists to perform the type of EMC study needed to assure that the equipment or equipment layout produces no interferences or radiation hazard.

5.6.1.2 New regulations in DOD that control permissible levels of electomagnetic pollution of the frequency spectrum are arising due to the concern for environmental protection. Radiation hazards are being regulated from concern for occupational safety. The cognizant engineering agency must have knowledge of the legalistic and regulatory aspects of EMC and radiation hazard to meet these requirements.

5.6.1.3 Military specifications on EMC, such as MIL-STD-461 ,462, and 463 are intended to control and achieve an acceptable figure of merit or quality in the development of new communications equipment. They do not eliminate the need for EMC engineering in facility design. In addition to equipment quality, frequency selection, nearness to other facilities and, to some extent, the facility design itself are variables in the interference generation problem.

5.5.2 Noise Sources.

5.6.2.1 Listed below are short comments on EMC considerations of the main interference mechanisms usually involved in a microwave facility. These were discussed in Chapter 4 (Link Design).

a. Direct co-channel interference. A frequency management problem.

b. Adjacent channel interence A Frequency problem but also a problem in collocation to be watched by the facility engineer.

c. Spurious receiver responses. Included under this heading are image, harmonic and direct IF responses as well as the true spurious responses.

d. Transmitter spurious output. Due to the high transmitter powers involved, should be watched with concern.

e. Case susceptibility. High transmitter powers may cause this to be a problem especially when collocated with LOS equipment and/or multiplex and terminal equipment.

f. Conducted interference. RF transmitters, power supply regulators, etc., may cause problems especially when collocated with other facilities using a common source of power.

5.6.2.2 EPIC studies may be organically performed by the engineering activity or by ECAC. Many times a data base output can be obtained from ECAC and the activity may finish analysis with its own specialists. (Reference Section 4.2.29.)

5.6.3 Radiation Hazards.

5.6.3.1 A potential radiation hazard exists in systems which radiate electromagnetic energy at an intensity sufficient to cause injury to personnel, or which develop an unsafe environment for fuel or exposives. High voltage equipment may constitute an additional hazard in form of ionizing (X-ray) radiations.

5.6.3.2 Since there may be no noticeable effects from either RF or ionizing radiation until serious damage has been done, areas where potential hazards exist should be posted or restricted. Recommended limits to personnel exposure to RF radiation are listed in Table 5.6.1. Determining expected levels of ionizing radiation is difficult and the problem can best be avoided by including appropriate requirements in the design criteria. All areas of potential hazard should be checked by qualified personnel to determine the radiation levels.

5.6.3.3 Personnel injury due to excessive RF radiation is a result of heating of the tissues. The temperature rise and resultant damage is a function of many variables but basically by the amount of RF energy actually absorbed and the rate at which heat is conducted away from the tissues involved, Low frequency energy (10MHz) is considered less hazardous since it penetrates more deeply and is dissipated in a larger volume.

5.6.3.4 Personnel injury due to ionizing radiation is usually the result of direct tissue damage not involving heating. The damage can be temporary or permanent. The extent of damage is dependent on the total dose, the dose rate and duration of exposure.

5.6.3.5 RF radiation also constitutes a possible hazard to electro-explosive devices. These devices may be accidentally detonated by induced RF currents in the firing mechanisms. A hazard is also presented to the handling of volatile fuels. MIL-DEP reguations and other guidance documents should be consulted for details concering safe power levels and needed separation distances.

5.6.3.6 Power densities in the vicinity of a transmitting antenna may be calculated. The usual goal in such calculation is that of specifying the maximum distance at which a particular hazard can be expected, and in the case of tropo applications, to provide the design engineer with an estimate of the hazard or restricted areas which must be considerered in determining the antenna locations. Accurate predictions of power density always require accurate input data. Even when such data is available, the prediction of power density in some areas around most antennas is not practical. Consider the parabolic dish antenna (Figure 5.6-1). Radiation from such an antenna can be referred to as in the "far field" (Fraunhofer) or the " near field" (Fresnel). Generally, the boundary between the near field and the far field can be considered to be a distance from the antenna of:

$$D = \frac{2d^2}{\lambda} \qquad (5.6\text{-}1)$$

where:

D = distance

d = diameter of antenna

A = wavelength

All variables above are in the sane units (normally meters). At distances closer to the antenna than the above, the field is more complex and accurate prediction of power density is difficult. This

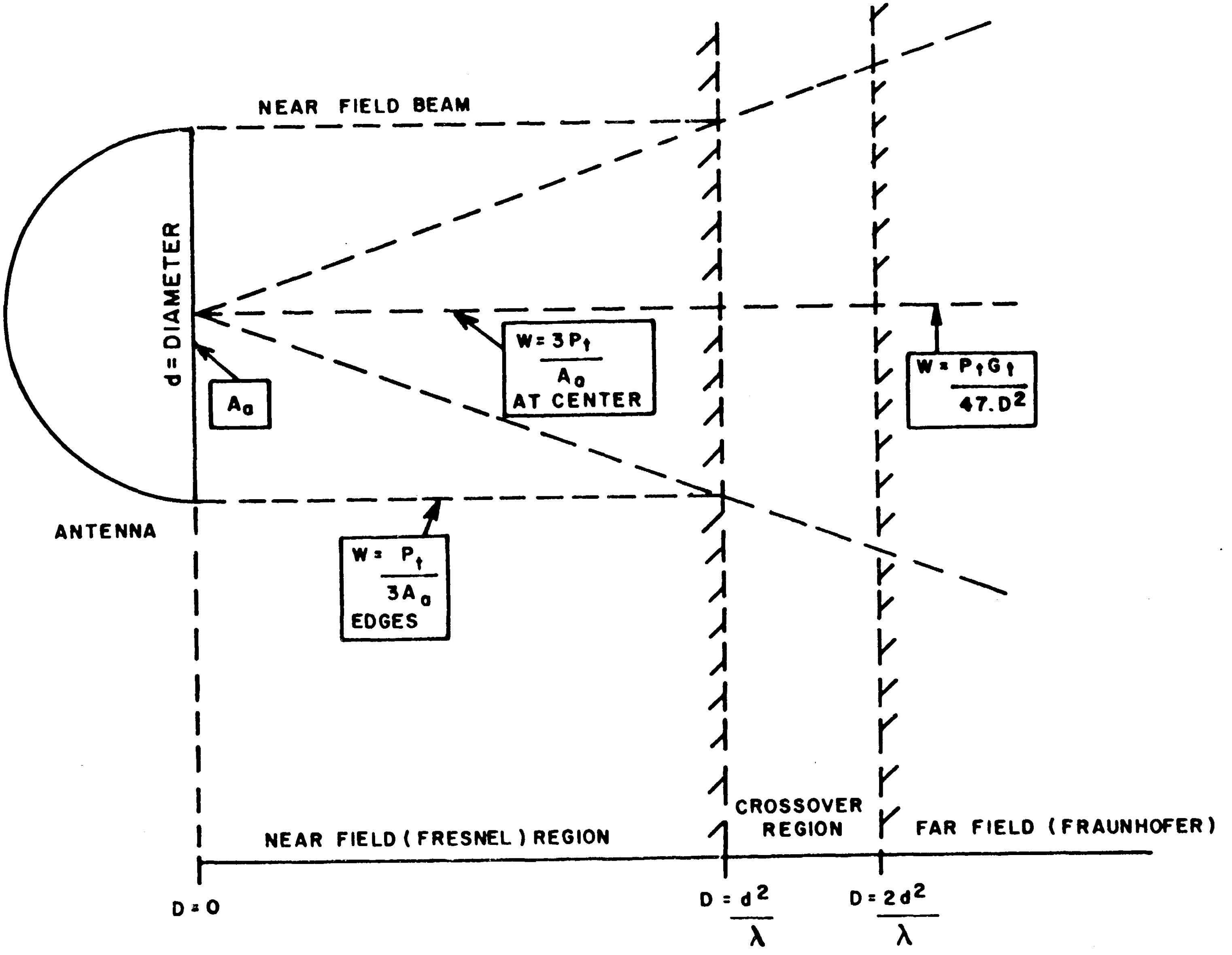


Figure 5.6-1 Distribution of Energy for Simple Parabola

is especially true in the so-called crossover region which is often considered to exist from the start of the far field back to a distance from the dish of:

$$\frac{d^2}{\lambda} \qquad (5.6\text{-}2)$$

The power densities (W) in front of such parabolic dishes is approximately equal to:

$$W = \frac{P_t G_t}{4\pi D^2} \qquad \text{(far field, in beam)} \quad (5.6\text{-}3)$$

$$W = \frac{3P_t}{A_a} \qquad \text{(near field, on axis of beam center)} \quad (5.6\text{-}4)$$

Equations (5.6-4 and 5.6-5) assume the normal 10 dB illumination taper and:

W = Power Density(watts/meter2)

P_t= Power into antenna(watts)

G_t= Numerical Gain of Antenna=Anti $\log\left(\frac{\text{Gain in dB}}{10}\right)$

D = Distance from Antenna(meters)(must be in far field)

Aa=Effective Area of Antenna(meters)

5.6.3.7 The calculation of power densities in the near field of such antennas requires correction factors for the near field phenomenon and is beyond the scope of this document. If a particular situation requires the calculation of power densities in the near field or crossover region, specialized MIL-DEP radiation hazard control personnel can be consulted.

5.6.4 Permissible Exposure Levels.

5.6.4.1 The biological effects of radio frequency radiation on man depend on the portion of the incident field that is absorbed, its distribution in the subject, and his ability to dissipate the absorbed energy. Current permissible exposure levels (Table 5.6-1) are based on the concept of acceptable thermal burden in man and are dependent on time of exposure (for exposures less than six minutes) and frequency. All exposures listed in units of mW/cm^2 are average power density.

5.6.4.2 A plot of Table 5.6-1 is contained in Figure 5.6-2. For exposed time of six minutes, the 10 mW/cm^2 level should not be exceeded for frequencies equal to or greater than 10 MHz and 50 M/cm^2 should not be exceeded for frequencies less than 10MHz. For exposure time of less than six minutes, the product, of the incident power level and time should not exceed 3600 mw-sec/cm^2 for frequencies equal to or greater than 10 Mhz or 18,000 mw-sec/cm^2 for frequencies less than 10 MHz.

- - - - - - - - - - - - -

TABLE 5.6-1
PERMISSIBLE EXPOSURE LEVELS

	FREQUENCY GREATER THAN OR EQUAL 10MHZ	FREQUENCY LESS THAN 10Mhx
Exposure time greater than min (360 seconds)	10 mW/cm^2	50 mW-sec/cm^2
Exposure time less than 6 minutes (360 seconds)	3600 mW-sec/cm^2	18,000 mW-sec/cm^2

NOTE: All exposures limited 100 kv/m maximum(peak E-field).

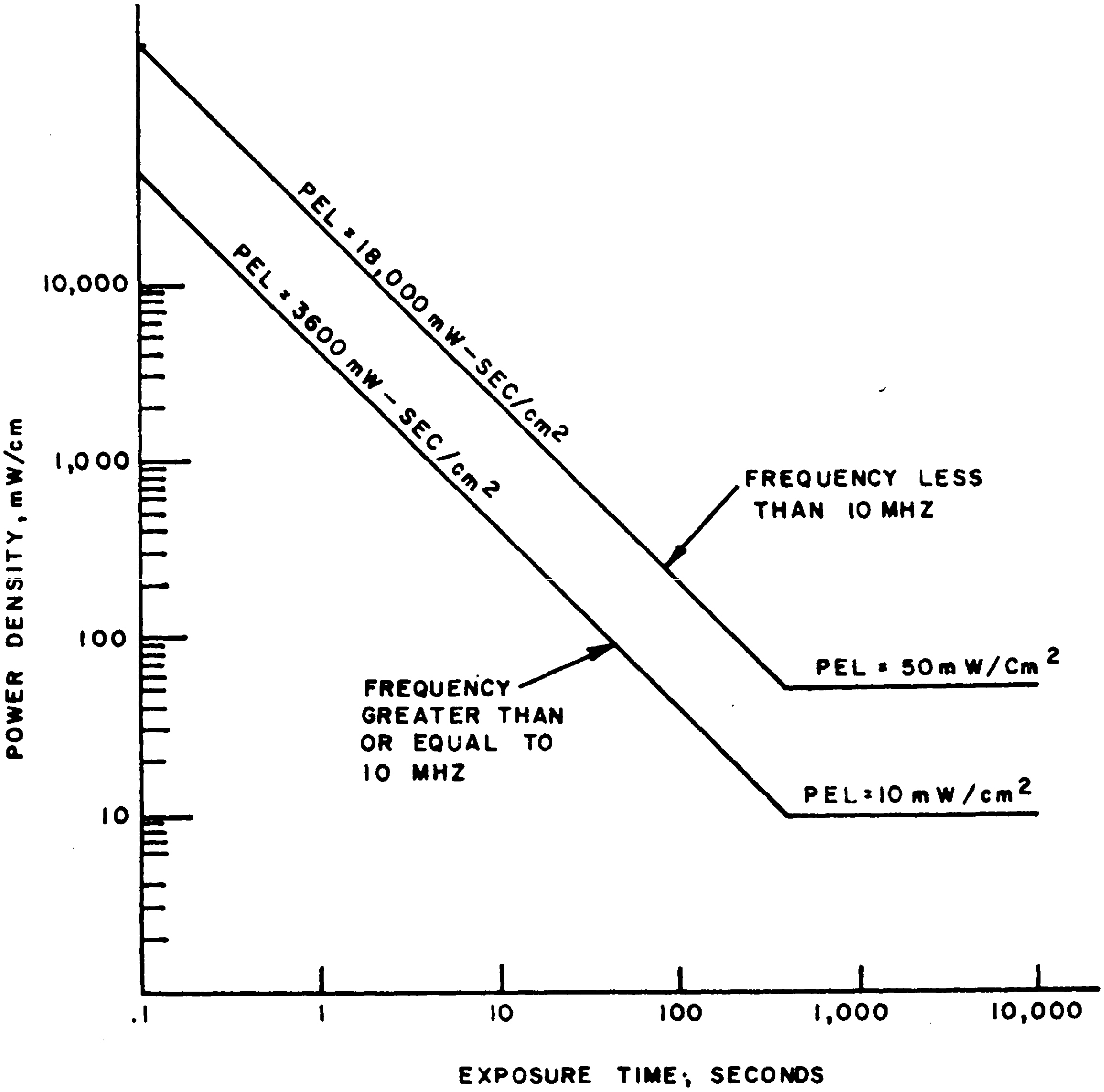


Figure 5.6-2 Permissible Exposure Versus Exposure Time

5.6.4.3 For example, if a known exposure is:

Exposure time = 180 seconds

Exposure average power density = 50 mW/m^2

Frequency =2.6 GHz

To determine if an overexpose would result:

a. Since the frequency is greater than 10 MHz and the time less than 360 seconds, the permissible exposure level (Table 5.6-1) is : 3600mw-see/cm^2.

b. Actual exposure is: 50 mW/cm^2 x 180 seconds = 9000 mW-sec/cm^2. Since the exposure exceeds the permissible exposure level, this is not an allowable exposure.

5.6.4.4 If the exposure level is known and one wishes to detemine the maximum stay time:

Exposure average power density =200 mW/cm^2

Frequency = 5 mhz

a. Since the frequency is less than 10 MHz, the peak exposure level (Table 5.6-1) is: 18,000 mW-sec/cm^2.

b. The allowable exposure time is:

$$\frac{18{,}000\ mW\text{-}sec/cm^2}{200\ mW/cm^2} = 90 \text{ seconds}$$

5.6.4.5 In no case should the peak E-field exceed 100 kV/m or 10^5 V/m. This criteria is normally only appllcable to pulse-type radiation such as radars; however, since tropo sites may be collocated with radars sites, the tropo engineer should be aware of this peak F-field criteria.

5.6.4.6 To determine if 100 kV/m is exceeded, one must obtain peak power. If average power is known, then peak power is the average power divided by duty factor. As a result, peak voltage (E) is :

$$\sqrt{3700 \times \text{peak power}}$$

where: E is in volts/meter (e) and peak power is in mW/cm^2

5.6.4.7 For example:

Average power = 10 mW/cm^2

Duty Factor = 0.0002

then:

$$\text{Peak power} = \frac{10\ mW/cm^2}{0.0002}$$

$$= 5 \times 10^4 mW/cm^2$$

so:

$$\text{Peak voltage} = \sqrt{3700 \times 5 \times 10^4}$$

$$= 1.37 \times 10^4\ V/M$$

Therefore, 1×10^5 V/m is not exceeded, so this is an acceptable level.

5.6.4.8 It should be noted that all of the preceding discussion is concerned with predictions of power density in front of the antenna and the equationa assume a theoretical free space condition. In actual practice, other factors may be involved. Parabolic antennas may have appreciable radiation from side lobes and back lobes and, in addition, ground reflections or reflections from other objectives in the vicinity may appreciably change in the radiation pattern so the precise hazard area may not coincide with the predicted. It is recommended, therefore that the initial predictions only be used as preliminary estimate and that actual measurements by qualified radiation hazard personnel be performed to define the actual hazard area.

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CHAPTER 6

SECTION 6.1 DETERMINATION OF AZIMUTH FROM OBSERVATIONS OF POLARIS

6.1.1 Introduction

6.1.1.1 Polaris is a "fairly bright (second magnitude) star located about one degree from the north celestial pole. It rotates about the pole in a counterclockwise direction (as viewed from the earth) approximately once in 24 hours, and the elevation angle of the star is always within one degree of the observer's latitude. The star is easily located by reference to the Big Dipper (Ursa Major); it is on the extension of a line through the, two stars on the side of the "bowl" most remote from the handle, and there are no other stars of similar magnitude in the vicinity of Polaris. This relationship is shown approximately in the figure below:

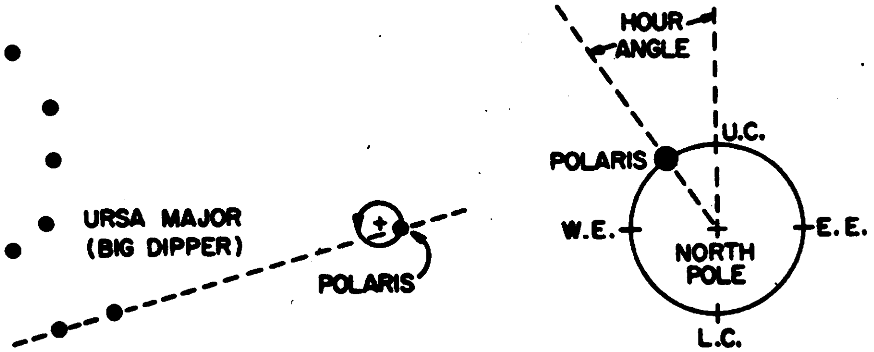

Figure 6.1-1. Polaris location and movement

6.1.1.2 Polaris crosses the (observer's) meridian twice in its daily circuit of the North Pole; once at upper culmination (U. C.) and once at lower culmination (L.C.). The points of maximum easterly and westerly movement are called eastern elongation (E.E) and western elongation (W.E.). At the instant of elongation, the relative horizontal movement is zero.

6. .1.3 The interval between the time of passage of Polaris over the observer's meridian and any other position in its diurnal circle is called the hour angle; usually the point of reference is upper culmination, and the interval may be measured either in units of time or in angular degrees, minutes, and seconds. The mean time hour angle of Polaris west of the observer's meridian is the mean time interval from the local mean the (LMT) of the last preceding U.C.to the local mean time of the observation of Polaris (see preceding figure). An hour angle east of the meridian is the mean time interval from the LMT of observation to the LMT of the next succeeding U.C.of Polaris. These relationships are illustrated in figures 6.l-1 6. 1-2, and 6.1-3.

6.1.1.4 The declination is the angular distance to the star as measure celestial north from the equator; at present it is more than 89°. The term polar distance is sometimes used to denote the angular distance from Polaris to the pole.

6.1.1.5 Azimuth determinations generally require accurate time observations, since the azimuth of Polaris varies with the local mean time; however, azimuths can be determined by observations of Polaris at elongation even if only the approximate time is available. This technique frequently requires observations at an inconvenient time of day, and if clouds *or* fog happen to obscure the star at the time of elongation it becomes necessary to delay subsequent observations until the following night. Considering the present availability of highly accurate watches and the worldwide availability of standard time broadcasts (e.g, WWV (U.S.), JJY (Japan), MSF (England)), it should seldom be necessary to resort to the elongation method. The "hour-angle" method [47], [50] permits azimuth determination at any time during the night, and even when the sun is 20 or 30 minutes above the horizon. Sunrise and sunset periods are, in fact, preferred times for these observations, since no artificial lighting is required for illumination of the theodolite cross hairs, and marks at the site can be easily seen. Very precise azimuth determinations are possible by this method; even at the most unfavorable times when Polais is near culmination, an error of as much as 1 minute in timing causes a bearing angle error of only 0.3 minute of arc at latitude 40°[48].

6.1.1.6 Azimuths can be determined by observation of Polaris from about latitude 10° N to 65° N; for other northern latitudes, and for locations in the Southern Hemisphere, azimuths may be determined by reference to other stars or the sun. Star charts and tables for the reduction of observational data are contained in most ephemerides [49, 50], and the techniques are discussed in surveying manuals, such as those referenced in the preceding paragraph.

6.1.2 Observational Procedure

1. Set watch to exact standard time by monitoring a time broadcast station.
2. Set up the theodolite or transit, and carefully level the instrument.
3. Set up a mark at a distance of 100 to 200 meters from the observation station. If observations are planned for hours of total darkness, provision must be made for lighting the mark. Center the instrument on the mark (0° azimuth).
4. Focus telescope on a distant light or star.
5. Locate Polaris (see fig.6.l-). Bisect the star, and note the exact time (if working alone a stop watch may be useful). Record the horizontal angle from the mark to Polaris.

6. Reverse the telescope, bisect the star, and record time and horizonal angle.

7. With the telescope in the reversed position, again bisect the star and record time and angle.

8. Return the telescope to the direct position and make a fourth observation.

9. Use the average watch time of the four observations to determine the correct local time of the Polaris observation.

10. Determine mean horizontal angle from the mark to Poliaris, and to this apply the azimuth of Polaris at the mean time of observation to obtain the true bearing of the reference mark.

11. Lay off a reference baseline on the site.

6.1.3 Determination of Local Mean Time

6.1.3.l The distinctions between the various time designations are important Apparent time is based upon the real sun, with a day counted from the sun’s meridian passage on one day to the meridian passage on the next. This rate is irregular. Mean solar time is based upon an imaginary sun whose day is uniform. This is the time generally used for civil purposes. while sidereal time is used by astronomers. A sideral day is equivalent to 23 hours 56 minutes 4.091. seconds in mean solar time.

6.1.3.2 Local mean time is identical with mean solar time on the meridian where that time is employed, and standard time is the same as mean solar time on the central metidians of each time zone in the U.S. (e.g., Eastern Standard time is based on the 75th meridian time). Standard time is reckoned from the meridian passing through the observatory at Greenwich, Engand (longitude 0°) ; in this time zone standard time is called Greenwich Civil Time (GCT), Greenwich Mean time (GMT), or Universal time (U.T.). If we consider the apparent movement of the sun from east to west in the celestial sphere (the dome of the sky as viewed from a point on earth) we find that when the sun crosses the meridian at Greenwich it is noon or 1200 hours GCT, but is not yet noon on meridians west of Greenwich, and noon has already passed at meridians east of Greenwich. Standard or mean solar time varies by one hour for each 15° of longitudes thus there is a difference of 5 hours between Greenwich and the 75th meridian in the U.S. Time zone boundaries are arbitrarily set, frequently to conform to political or geographical boundaries and in some parts of the world the "official" time does not conform to a standard number of hours from Greenwich. For example, many countries in Europe which are in the Greenwich time zone have chosen to use Central European Time (based on the 15° E meridian) as their official time. Great caution must therefore be used in converting from the local official time to local mean time or Greenwich Civil Time.

6.1.3.3 Tabular data in the ephemeris are listed for mean time at Greenwich and calculations related to Polaris observations require the local mean time at the point of observation. It is usually convenient to use a watch set to standard time and correct the mean time of observation for the distances east or west of the standard meridian. Corrections are based upon the following relationships:

Longitude (arc)	Time
360°	24 hrs
15°	1 hr
1°	4 minutes
15′	1 minute
1′	4 seconds
15″	1 second
1"	0.067 second.

Note the distinction between minutes and seconds of arc (longitude) and minutes and seconds of time. A station east of a standard meridian will have a later LMT than a station on that meridian, and a station west of the meridian will have an earlier LMT.

6.1.3.4 To illustrate the method of converting from standard time to LMT, consider the following example:

Latitude 40° 30' 00" N, Longitide 92° 30′ 10″ W.
Date: April 20, 1972
Mean watch time of observation: 18 hrs 27 min 55 sec CST.

Since the observation point is 2° 30′ 10″ west of the time zone meridian (900 W), the "sun" time or local mean time is somewhat earlier than it would be if the site were exactly on the 90th meridian. The correction is as follows:

2° = 8 minutes
30′ = 2 minutes
10" = .67 seconds (or .01 min.)

Total correction = 10 min 0.67 sec, or 10.01 min.

Applying this correction, we obtain

18 hr 27 min 55 sec
10 min 0.67 sec
18 hr 17 min 54 sec, or 18 hr 17.91 min LMT

If our site had been east of the meridian by the same amount (longitude 87° 29′ 50″ W) the correction would have been the same, but it would have been added to the time of observation (CST) to obtain LMT. Also, if the watch used is known to be fast or slow at the time of observation this must be taken into account.

6.1.4 Hour Angle Determination

6.1.4.1 After obtaining the LMT of the observation, we can proceed to the calculation of the hour angle. For the example mentioned above, we would refer to the table on page 3 of the Bureau of Land Management ephemeris [-49], and find that on April 20, 1972 the upper culmination (U.C.)occurs at 12:09.0 p.m. and the declination is 89°08’20.48”. This time for U.C.is the mean time on the Greenwich Meridian, and mean time of U.C.on other meridians will be slightly different because of the difference between solar and sidereal time. Referring to the table on page 27, for 90° 30' W longitude the correction is -1 min 01 sec; therefore the local mean time of culmination at our observation point is 12:09.0 - 1.0 = 12:08.0 LMT. Now we draw an hour-angle diagram:*

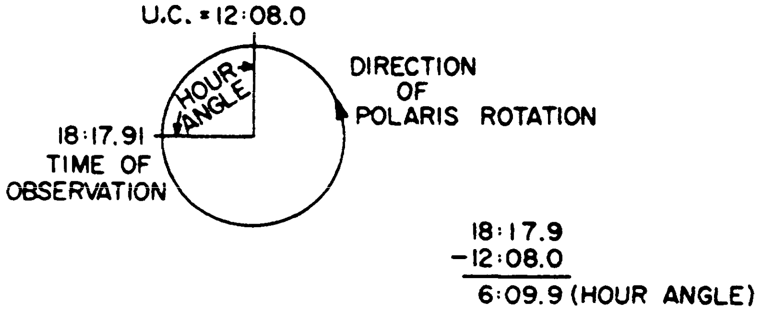

Figure 6.1-2. Hour-angle diagram for example in 6.1.3.4 and 6.1.4.1.

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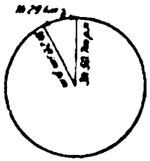
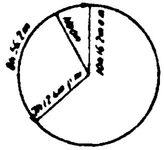
*A number of other examples of hour-angle computations are given in figure 6.1-3.

Examples of computing hour angles of Polaris; all taken out for longitude 117°15′ W.:



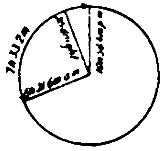
West of the meridian, p. m. obsn., U. C. in p. m.

Feb. 18, 1945, l. m. t. of obsn.		=5h20.1m p. m.
Gr. U. C., same date	=3h 52.0m p. m.	
Red. for long.	= − 1.3	=3 50.7 p. m.
Hour angle, west		=1h29.4m......



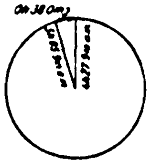
West of the meridian, p. m. obsn., U. C. in a. m.

May 14, 1945, l. m. t. of obsn.		={+12 7h12.4m p. m.
Gr. U. C., same date	=10h17.5m a. m.	
Red. for long.	= −1.3	= 10 16.2 a. m
Hour angle, west		= 8h56.2m



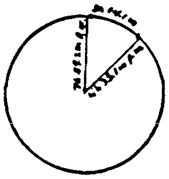
West of the meridian, a. m. obsn., U. C. in p. m.

Nov. 3, 1945, l. m. t. of obsn.		={+12 6h31.6m a. m.
Gr. U. C., Nov. 2	=10h59.7m p. m.	
Red. for long.	−1.3	= 10 58.4 p. m
Hour angle, west		=7h33.2m



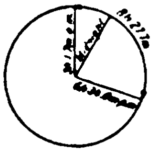
West of the meridian, a. m. obsn., U. C. in a. m.

Aug. 11, 1945, l. m. t. of obsn.		=5h05.9m a. m
Gr. U. C., same date	=4h29.2m a. m.	
Red. for long.	−1.3	=4 27.9 a. m.
Hour angle, west		=0h38.0m



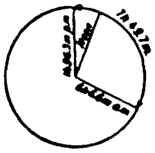
East of the meridian, p. m. obsn., U. C. in p. m.

Gr. U. C., Dec. 20, 1945	=7h 50.5m p. m.
Red. for long.	= −1.3
L. M. T. of U. C., Dec. 20	=7 49.2 p. m.
L. M. T. of obsn., same date	=4 35.1 p. m.
Hour angle, east	=3h 14.1m



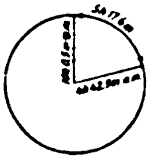
East of the meridian, p. m. obsn., U. C. in a. m.

Gr. U. C., Sept. 2, 1945	= 3h 3.0m a. m.
Red. for long.	= −1.3
L. M. T. of U. C., Sept. 2	={ 3 1.7 a. m. +12
L. M. T. of obsn., Sept. 1	= 6 34.0 p. m.
Hour angle, east	= 8h27.7m



East of the meridian, a. m. obsn., U. C. in p. m.

Gr. U. C., Mar. 19, 1945	= 1h57.6m p. m.
Red. for long.	= −1.3
L. M. T. of U. C., Mar. 19	{= 1 56.3 p. m. +12
L. M. T. of obsn., same date	= 6 6.6 a. m.
Hour angle, east	= 7h49.7m



East of the meridian, a. m. obsn., U. C. in a. m.

Gr. U. C., May 18, 1945	=10h 1.9m a. m.
Red. for long.	−1.3
L. M. T. of U. C., May 18	=10 0.6 a. m.
L. M. T. of obsn.	= 4 42.8 a. m.
Hour angle, east	= 5h17.8m

Figure 6.1-3 Examples of Computing Hour Angles of Polaris, both West and East of Meridian, with Diagrams

6.1.5 Azimuth of Polaris

6.1.5.1 Referring now to page 19 of the ephemeris, we enter the table with the hour angle and the station latitude, and find the azimuth by interpolation:

	Latitude		
Hour Angle	400	40° 30′	42°
6:09.0	67.1*		69.2*
6:09.9	67.082	67.6	69.182
6:19.0	66.9*		69.0*

To this value we make a correction for declination, obtained from the right-hand columns of page 19: +0. 2.

The corrected azimuth is 67.8′, or 1° 07.8′.

If we assume that the mean horizontal angle (mark to star) was 22° 30.1′,

$$\begin{array}{r} 22^\circ 30.1' \\ \underline{+1^\circ 07.8'} \\ 23^\circ 37.9' \end{array}$$

The true meridian is therefore 23° 37.9′ to the east of the line connecting the mark and observation point. With this information available, we can lay off a true reference baseline at the site, as shown in figure 6.1-4

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* Values from ephemeris table.

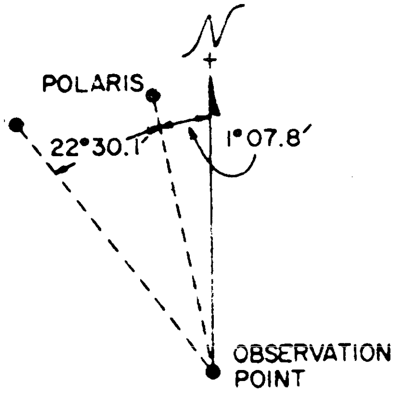


Figure 6.1-4 Example of baseline diagram (not drawn to scale)

6.1.5.2 The method outlined above for observing Polaris and calculating true azimuth is based upon material in the "Manual of Instructions for the Survey of the Public Lands of the United States" [47]. When using other ephemerides (for example, [50]. slightly different procedures are followed. The various ephemerides are revised annually, with the issue for the coming year available in November or December.

6.1.6 Observation of Polaris by the Elongation Method

6.1.6.1 If, because of loss or damage to watches, accurate time is not available, azimuths may be determined accurately by the elongation method. The instrument is set up and leveled well in advance of the time of elongation indicated by the ephemeris (we assume that some crude timepiece is available). Check observations are made at intervals of a few minutes, and when the rate of change of azimuth begins to decrease, the observer is alerted that the time of elongation is approaching. When no change in azimuth is noted over 1 or 2 minutes (Polaris appears to move along the vertical crosshair) observations of the indicated azimuth should be started, and continued until horizontal movement of the star is again evident. Observations should be alternated between direct and reversed position of the telescope; select a set of four readings that embrace the extreme position of the star and use the mean of these readings as the azimuth at elongation. Then enter the table on page 22 of the ephemeris [49] with the station latitude and determine the star to pole azimuth at the time of elongation. Then calculate the true bearing (mark to pole) as in the hour-angle method.

6.1.6.2 There is a period of about 15 minutes on either side of the point of elongation when the azimuthal change is only about 1′ of arc, so nearly continuous observation during this period is recommended.

6.1.7 Checking of Azimuth

6.1.7.1 It is recommended that the calculations for azimuth from the observational data be made independently by two members of the survey party.

SECTION 6.2 DETERMINEATION OF ELEVATION BY ALTIMETER SURVEYS

6.2.1 Altimeters and Atmospheric Pressure

6.2.1.1 Altimeters are essentially aneroid barometers calibrated to indicate altitude instead of pressure. The pressure-height relationship is based upon an assumed "standard" atmosphere; these so-called standard conditions will seldom, if ever, be found in the real atmosphere, so that some error is nearly always present. A commonly used relationship for Scale calibration of surveying altimeters is based upon the assumption of a completely dry, isotklermal atmosphere with a uniform temperature of 10°C(50°F’) and a sea-level pressure of 29.90 inches of mercury [51]. Since the sea-level pressure sometimes exceeds this value, an altimeter calibated on this assumption will sometimes show negative values of altitude; this is avoided on other instruments by placing the scale zero at 1000ft (pressure 31.026 inches) so that readings will aways be positive with the latter scale calibration, however, the indicated altitude is usually about 1000 ft higher than the true altitude.

6.2.1.2 Pressure always decreases with altitude, roughly at the rate of about one inch per 1000 ft; thus at 5000 ft above sea level the actual atmospheric pressure will be around 25 inches of mercury. Barometers (and altimeters) indicate the total weight of air above the point of observation; this varies with the temperature and humidity of the air masses and is greatly influenced by moving weather systems. Altimeter surveys should be conducted only during stable weather conditions, when winds are light and the pressure and temperature are reasonably steady over the survey area; operations should be suspended in stormy weather or when winds are high or gusty.

6.2.1.3 In spite of the limitations outlined above, the surveying altimeter is very useful for determining differences in elevation between two points, one of which is a benchmark or other location of known elevation. By making corrections for temperature and humidity differences (which affect the density of the air) horizonal and temporal changes in pressure, and scale calibration temperature, very rapid and accurate surveys can be obtained. It should be noted that the "scale calibration" correction is completely separate from the <u>air</u> temperature correction; the scale is engraved under laboratory conditions with a temperature of about 24° C (75° F), and when used in the field under different temperature conditions a slight scale change occurs.

6.2.1.4 The following general precautions are applicable to most surveying altimeters:

a. Handle the instrument as you would a good watch--do not drop or jolt it, and pack in a padded case when shipping or moving in a vehicle.

b. Never expose the altimeter to the direct rays of the sun--use in the shade, or shield with the body during observations. Avoid placing the instrument on hot pavement, rocks, metal roofs, etc.

c. Always read the instrument in the same position (normally horizontal) and be careful to avoid parallax errors -- if the dial has a reflector ring, make the reading when the pointer and its image appear coincident.

d. If there is a large change in temperature between two observation points, allow a period of time before the second reading to permit the instrument to reach thermal equilibrium.

e. Tap the case of the altimeter lightly with a finger or pencil eraser before reading; this helps reduce errors caused by mechanical lag or friction in the mechanism.

f. When several altimeters are used by a field party, it is a good practice to make compartive readings at least once each day and record the values in the field notebook. Any large change in the differences between instruments is reason to suspect possible instrumental damage.

g. Avoid frequent resetting of the dial pointers in the field. It is better to make corrections to field readings based upon the most recent benchmark-to-altimeter comparison.

h. After checking an altimeter at a benchmark, observations at the various points in the field should be made as quickly as possible. Even when the general pressure systems are static there are regular diurnal variations that must be allowed for -- a sort of atmospheric tide. These diurnal pressure variations have a 12-hour period with maxima at 1000 and 2200 local time, and minima at 0400 and 1600 [53]. In the tropics these are the most important pressure fluctuations and are very regular from day to day; in temperate and higher latitudes the diurnal effect is freqently masked by the larger pressure changes caused by moving pressure systems, but the "tidal" effect is still present.

6.2.2 Altimeter Surveys

6.2.2.1 There are a number of ways in which altimeter surveys can be conducted; the choice depends Largely upon the personnel and number of instruments available, as well as the accuracy required from the particular survey. Two procedures will be described, the single-base method and the two-base method [48], [52].

6.2.2.2 In the single-base survey, two altimeters are required. One remains at a benchmark *or* other point of known elevation, with readings of the altimeter made at regular intervals -- say every

5 or 10 minutes. The other instrument referred to as the roving altimeter, is read at the various points along the path where elevations are desired. At both stations, temperature and humidity measurements are obtained with small battery-powered psychrometers, or with the sling-type psychrometer packed in the case of many surveying altimeters. The indicated differences in elevation are corrected by a factor determined by the mean temperature and humidity over the path from benchmark to field point at the time of the field observations; tables or nomograms for the corrections are included with the altimeters. The corrected difference in elevation is then combined with the known elevation of the base station or benchmark to obtain the desired elevation of the field point. (Corrections may also be required for the scale temperature.)

6.2.2.3 The two-base method eliminates the need for temperature and humidity corrections, although the temperature must still be checked to determine if scale temperature corrections are necessary. One station is established at a low point in the area, and a second station at a high point; the points of unknown elevation are between these two stations. The elevations of the base stations must be known; if possible they should be located at benchmarks. A third altimeter is carried to the field sites where elevations are desired. All three altimeters are read simultaneously, either by prearranged schedule or by radio coordination. It is assumed that the atmospheric properties change linearly between the base stations at a given time, and that the ratio between the known base-station elevation difference and the altimeter-indicated difference is equal to the ratio between the unknown elevation difference from base station to field point and the difference indicated by simultaneous altimeter readings. For example,

$$\frac{\text{Upper base - Lower base (Elevation)}}{\text{Upper base - Lower base (Altimeter)}} = \frac{\text{Field Pt. - Lower base (Elevation)}}{\text{Field Pt. - lower base (Altimeter)}}$$

$$\frac{1000\text{ ft} - 400\text{ ft}}{1200\text{ ft} - 500\text{ ft}} = \frac{x - 400}{800 - 500}$$

$$\frac{600}{700} \quad \frac{x-400}{300}$$

x - 400 = 300 x 6/7; or X = 257 + 400 = 657 ft (Elevation of field pt.)

Use of a computation sheet, such as that shown in figure 6.2-1, is recommended. The average error of elevation obtained with the two-base method is about 3 ft with the two base stations separated by 10 miles horizontally and 1000 ft vertically [48].

6.2.2.4 There will be occasions when limitations of personnel or equipment may require a single-altimeter survey. In this case, take a reading at a benchmark then a reading at the field point, then another reading at the benchmark. If the two benchmark altimeter readings vary by more than a few feet repeat the sequence; in any case, it is preferable to take a series of readings and use the average elevation difference in determining the elevation of the field point.

6.2.2.5 There are recording altimeters available which reduce the manpower demands of the single-or two-base surveys. A recording microbarograph is also very useful on a field survey to obtain a continuous record of the pressure variations related to diurnal effects or moving pressure systems; with the aid of this record one can eliminate or recheck observations made during periods of rapidly changing pressure, or even correct field observations for the dynamic pressure component.

6.2.2.6 The effect of these dynamic pressure changes on survey accuracy can be significant, as shown by the following example: Between 1000 and 1200 local time, while an altimeter survey was in progress, the barograph shows a pressure fall of 0.10 inches. (Changes of this magnitude occur frequently in many parts of the world.) Using the rule-of-thumb relationship that a change in elevation of 1000 ft results in a pressure change of about one inch of mercury, a change of 0.10 inch is equivalent to an elevation difference of about 100 ft. Therefore during the 2-hour period while the survey was in progress, the dynamic pressure component was causing the equivalent of a 25-ft elevation difference (at a point) each 30 min.

6.2.2.7 Another source of altimetry error is related to the horizontal gradient of pressure, which is indicated by the spacing of isobars on weather maps. A survey proceeding on a line perpendicular to the isobars in the vicinity of a moderately intense storm system might incur errors on the order of 1 to 3 ft per mile, related to this horizonal difference in the pressure field. Under such circumstances however, the surface winds could be expected to be 15 mph or more, and if the rule mentioned previously of taking surveys only during very light wind conditions is followed, the horizontal pressure gradient error should be relatively minor.

TWO-BASE ALTIMETER SURVEY COMPUTERS

Observer J. Porter Date 10 Sept. 71

(1) Upper Base Station Elevation 1000 (Location) B.M. 2-Longhill

(2) Lower Base Station Elevation 400 (Location) Airport Runway 6

(d) Difference (1 - 2) 600

(4) Altimeter Reading, Upper Base 1200

(5) Altimeter Reading, Lower Base 500

(6) Difference (4 - 5) 700

	Site #A	Site # B	Site # C
(7) Altimeter Reading; Field Site	800	570	
(8) Altimeter Reading: Lower Base (5)	500	500	500
(9) Difference (7 - 8)	300	70	
(10 Divide (3/6)	0.857	0.857	0.857
(11) Multiply (10 x 9)	257.10	59.99	
(12) Elevation; Lower Base (2)	400	400	400
(13) Elevation; Field Site (11 + 12)	657	460	

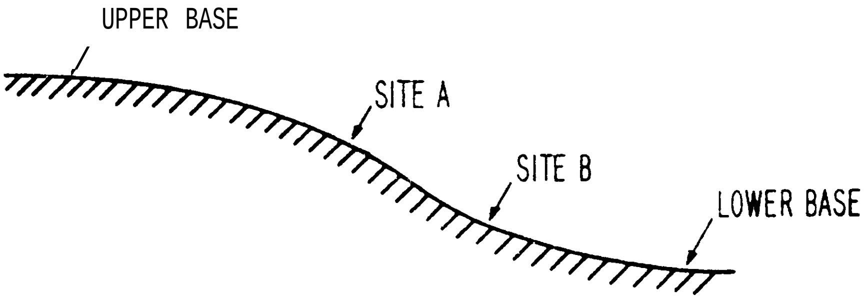


Figure 6.2-1. Example of computation sheet for two-base altimeter survey.

SECTION 6.3 DIFFRACTION OVER A SINGLE ISOLATED OBSTACLE WITH GROUND REFLECTIONS

6.3.1 The Geometric Optics Method

6.3.1.1 Diffraction over an isolated obstacle was discussed in section 4.4.20, where ways of approximating the effects of reflection and diffraction from foreground terrain were indicated. Where the effects of reflection are expected to be of great importance, such as in the case of propagation over a large body of water, the following geometric optics method may be used.

6.3.1.2 Figure 6.3-1 illustrates four distinct ray paths over a knife edge (which may be rounded); the first ray is not reflected from the ground, the second and third are each reflected once, and the fourth ray is reflected once on each side of the obstacle Each ray is subject to a diffraction loss f(v,p) and a phase lag $\Phi_j(v, p) -90\, v^2$ at the knife edge, where j = 1, 2, 3, 4. Both $f_j(v,p)$ and $\Phi_j(v, p)$ depend on the parameters v and p given in section 4.4.20. When the isolated obstacle is an ideal knife edge, the diffraction loss depends only on the parameter v, which may also be written:

$$v_j = \pm 2\sqrt{\Delta_j/\lambda} \cong \pm\sqrt{2d\,\alpha_{oj}\beta_{oj}/\lambda} \qquad (6.3\text{-}1)$$

where Δ_j, by figure 6.3-1, is

$$\Delta_1 = r_{10} + r_{20} - r_{00}, \quad \Delta_2 = r_{11} + r_{12} + r_{20} - r_{02}$$
$$\Delta_3 = r_{10} + r_{21} + r_{22} - r_{03}, \quad \Delta_4 = r_{11} + r_{12} + r_{21} + r_{22} - r_{04} \qquad (6.3\text{-}2)$$

6.3.1.3 Path differences used to calculate v_j in (6.3-1) can be closely approximated by the following formulas:

$$\Delta_j = d_r\theta_j^2, \quad d_r \doteq d_1\, d_2/(2d), \quad \theta_j = \theta + \theta_{jr} \qquad (6.3\text{-}3)$$
$$\theta_{1r} = 0, \quad \theta_{2r} = 2d_{11}\,\psi_1/d_1, \quad \theta_{3r} = 2d_{22}\psi_2/d_2, \quad \theta_{4r} = \theta_{2r} + \theta_{3r}$$

BEYOND-HORIZON KNIFE-EDGE DIFFRACTION WITH GROUND REFLECTIONS

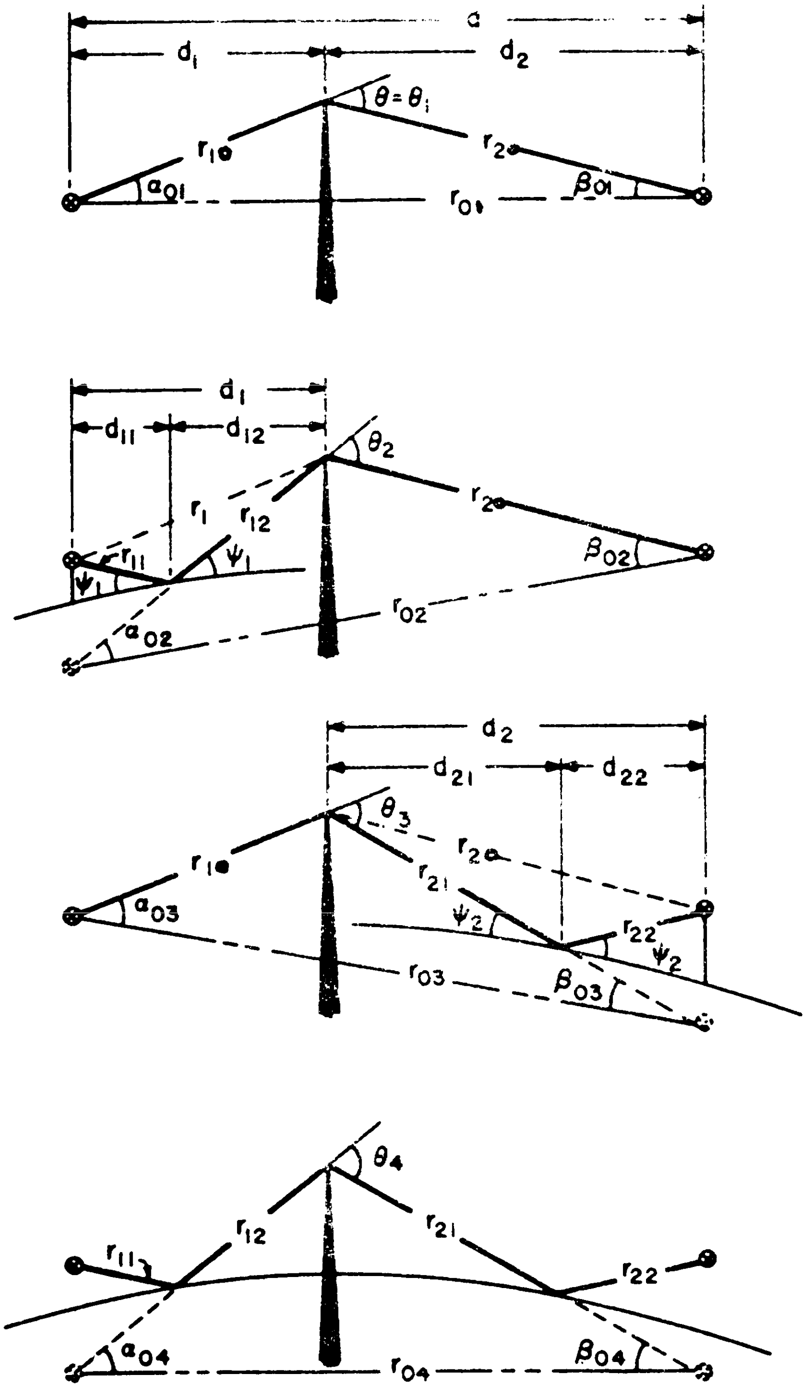


Figure 6.3-1 Beyond-horizion Knife-edge Diffraction with Ground Reflections (Knife-edge normal to Ray Path)

Here the notation has been somewhat simplified, and $d_{1,2}$ is the same as the $d_{L1,2}$ used in section 4.4.7. The grazing angles ψ_1, ψ_2 and the diffraction angle $\theta \equiv \theta_1$ are identified in figure 6.3-1. Also, $\theta = \alpha_{o1} + \beta_{o1}$.

6.3.1.4 The total phase lag for an isolated rounded obstacle path relative to a reference free-space path of length r_{oj} is given by

$$\Phi_i(v, \rho) - 90\, v_i^2 = \phi(v_i, 0) + \phi(0, \rho_i) + \phi(v_i\, \rho_i) \text{ degrees} \qquad (6.3\text{-}4a)$$

where the function $\phi(v, 0)$, $\phi(0, \rho)$, and $\phi(v\rho)$ are plotted on figures 6.3-2 and 6.3-3. For an ideal knife edge, where the radius of curvature of the crest is zero, $\rho = 0$, and (6.3-4a) reduces to

$$\text{for } v > 0,\ \Phi_j(v, 0) - 90\, v_j^2 = \phi(v_j, 0) \text{ degrees} \qquad (6.3\text{-}4b)$$

$$\text{for } v \le 0,\ \Phi_j(v, 0) - 90\, v_j^2 = \phi(v_j, 0) - 90\, v_j^2 \text{ degrees.} \qquad (6.3\text{-}4c)$$

The above formulation has been adopted from [27] which includes references to earlier work.

6.3.1.5 The three components of the received field which are affected by reflection from the earth's surface depend also upon the complex ground reflection coefficients $R_{e2} \exp[-i(\pi - c_2)]$ and $R_{e3} \exp[-i(\pi - c_3)]$, defined in [16; Annex III.1], and upon ray path differences Δ_{2r} and Δ_{3r}:

$$\Delta_{2r} = r_{11} + r_{12} - r_{10} \cong 2\, \psi_1^2\, d_{11}\, d_{12}/d_1$$

$$\Delta_{3r} = r_{21} + r_{22} - r_{20} \cong 2\, \psi_2^2\, d_{21}\, d_{22}/d_2 \qquad (6.3\text{-}5)$$

For overland propagation at frequencies above about 500 MHz the phase shifts c_2 and c_3 may be neglected ($c_2 = c_3 = 0$), and the complex reflection coefficients are then approximately equal to -1. For paths over sea water, figures 6.3-4 and 6.3-5 give the magnitude R_e and

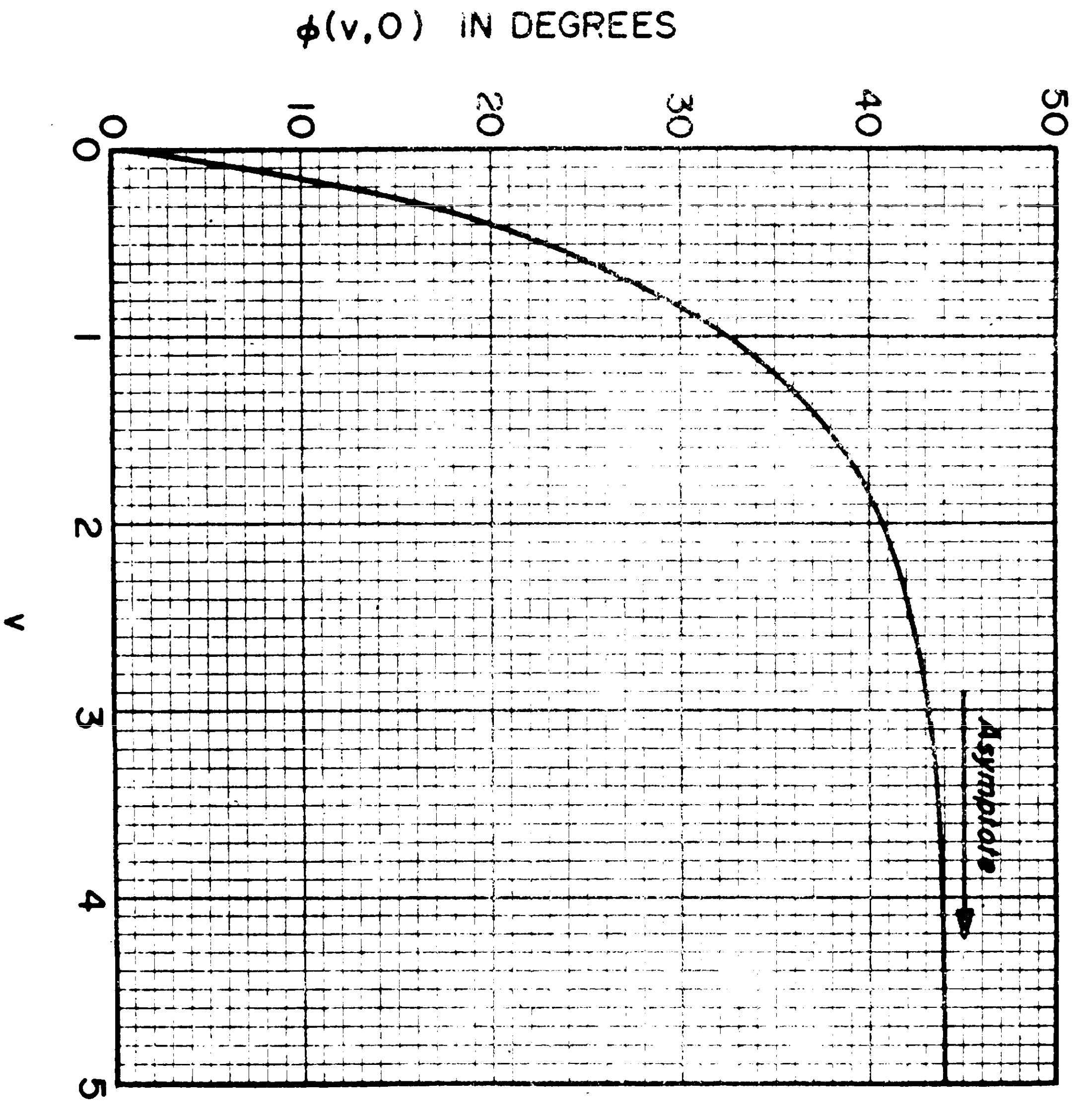


Figure 6.3-2 The Phase Function $\phi(v,0)$ (after Dougherty and Maloney [27]).

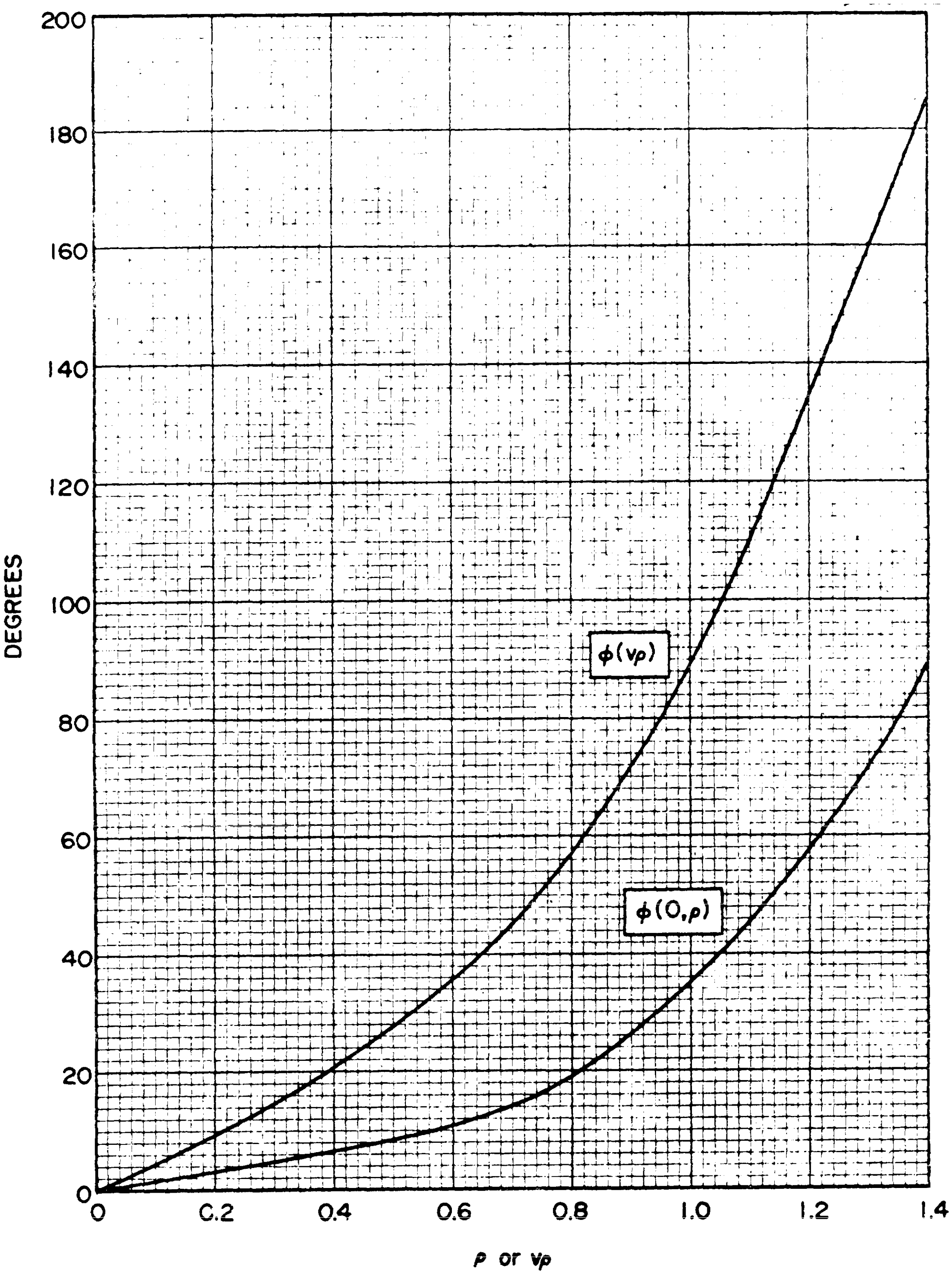


Figure 6.3-3 The Phase Functions φ(0,p)and φ(vp) (after Dougherty and Maloney [27])

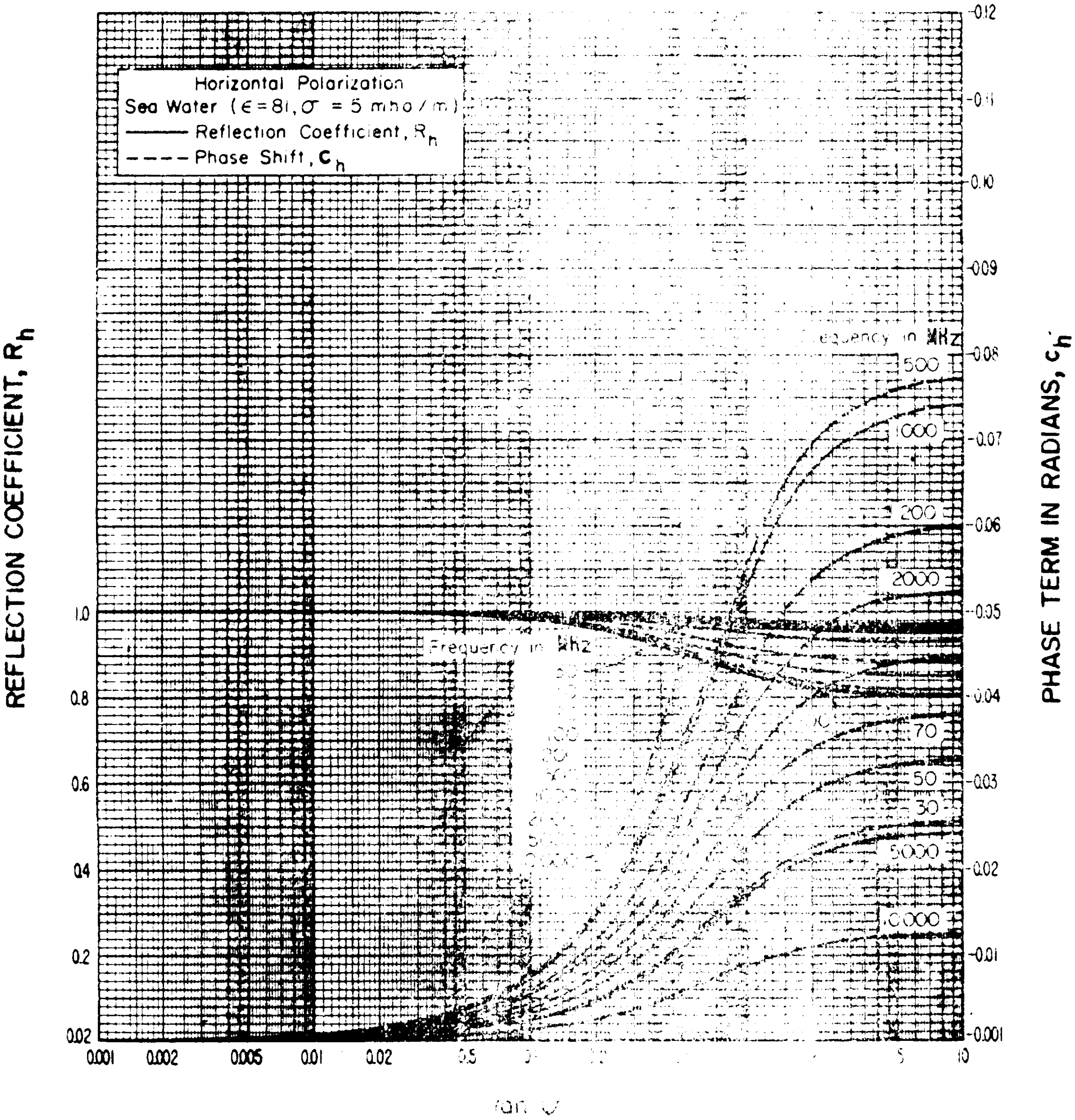


Figure 6.3-4 Reflection Coefficient Magnitude and Phase Term for Horizontal Polarization Over Sea Water

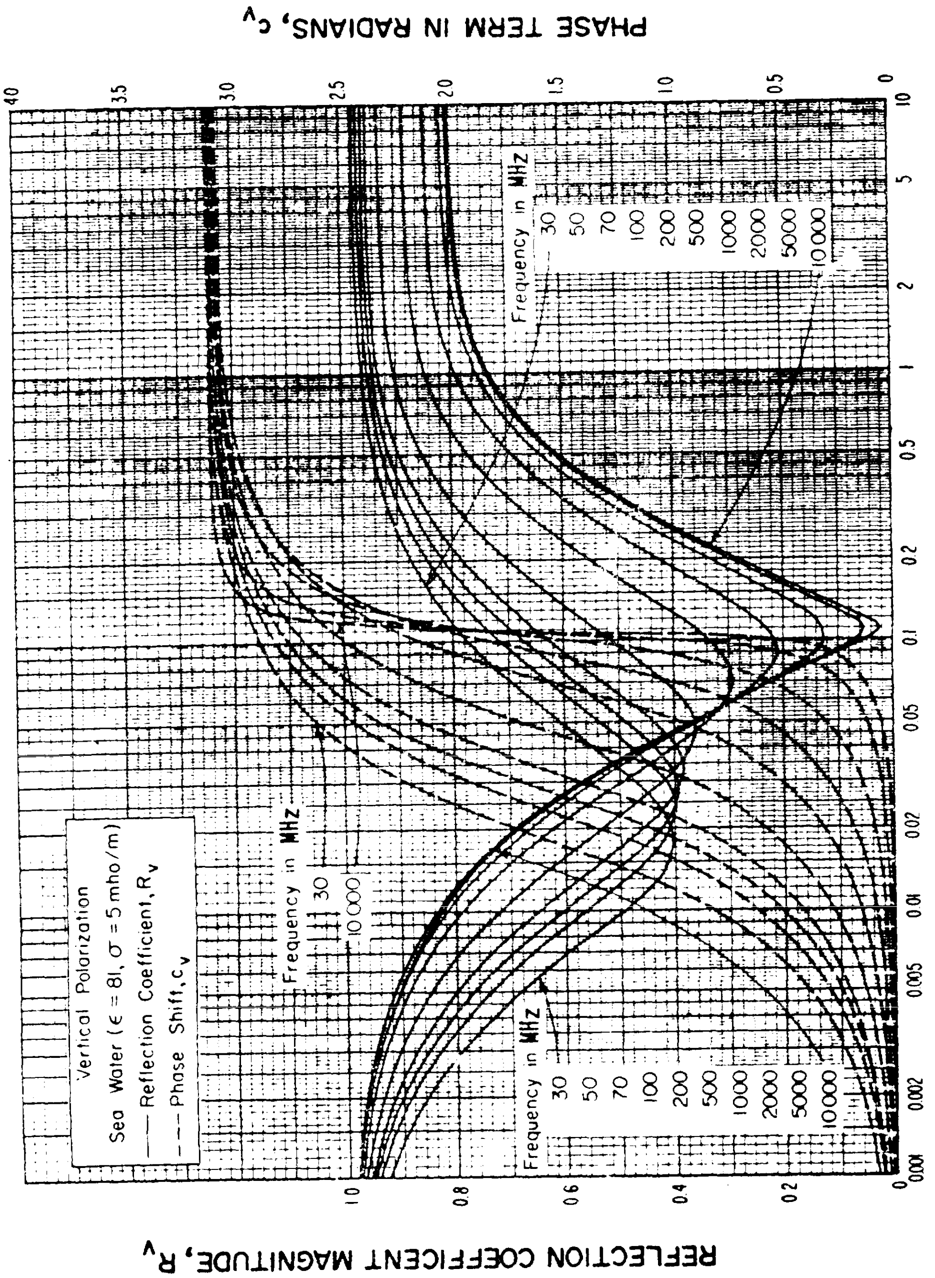


Figure 6.3-5 Reflection Coefficient Magnitude and Phase Term for Vertical Polarization Over Sea Water.

phase term c (in radians) for horizontal and vertical polariazation, respectively. In these graphs the subscript h and v refer to the two polarizations.

6.3.1.6 Introducing the propagation constant $k = 360 / \lambda$ in degrees/meter and expressing the ray path differences $k\Delta_{2r}$ and $k\Delta_{3r}$ in electrical degrees, the attenuation relative to free space is then

$$A = 20 \log \left\{ \left| f_1 \exp[-i(\Phi_1 - 90 v_1^2)] + R_{e2} f_2 \exp[-i(\Phi_2 - 90 v_2^2 + k\Delta_{2r} + \pi - c_2)] + R_{e3} f_3 \exp[-i(\Phi_3 - 90 v_3^2 + k\Delta_{3r} + \pi - c_3] + R_{e2} R_{e3} f_4 \exp[-i(\Phi_4 - 90 v_4^2 + k\Delta_{2r} + k\Delta_{3r} - c_2 - c_3)] \right| \right\} \text{dB.} \quad (6.3\text{-}6)$$

For propagation *over* land one may approximate the magnitudes R_{e_2} and R_{e_3} by +1 in (6.3-6), and neglect the phase terms C_2 and C_3.

6.3.1.7 For the general case of a rounded knife-edge, the magnitudes $f_j \equiv f_j(v, \rho)$ are determined from

$$\log f_j(v, p) = -A_j(v, \rho)/20, \quad (6.3\text{-}7)$$

where $A(v, \rho)$ was defined in (4.4-33)of section 4.4.20, and shown graphically on figure 4.4-12. The total phase lag $\Phi_j \equiv \Phi_j(v, \rho)$ relative to a reference free space path of length r_{oj} was defined in (6.3-4a). The components for $A(v, \rho)$ from (4.4-33) and $\Phi(v, \rho)$ from (6.3-4a) are shown graphically in figures 4.4-11, 4.4-13, 6.3-2 and 6.3-3, respectively.

6.3.1.8 For the ideal knife-edge, $\rho = 0$, and the f_j and Φ_j may also be calculated from:

$$f_j = +\tfrac{1}{2}\sqrt{(1 - C_j - S_j)^2 + (C_j - S_j)^2}, \quad \tan \Phi_j = \frac{C_j - S_j}{1 - C_j - S_j}$$

$$C_j = \int_0^{v_j} \cos\left(\frac{\pi t^2}{2}\right) dt, \quad S_j = \int_0^{v_j} \sin\left(\frac{\pi t^2}{2}\right) dt. \qquad (6.3\text{-}8)$$

Pearcey [74], and the NBS AMS 55 Handbook of Mathematical Functions [69] give complete tables, series expansions, and asymptotic expressions for the Fresnel integrals C_j and S_j. Furthmore, if v is larger than 3:

$$f_j \cong 0.22508/v_j, \quad \Phi_j - 90\, v_j^2 \cong 45 \text{ degrees.} \qquad \{6.3\text{-}9)$$

Figure 6.3-6 is a nomogram which may be used in the case of an ideal knife-edge in the determination of $f(v_j)$ and $\Phi(v)$ for both positive and negative values of v. This nomogram is based on the representation of Fresnel integrals by the Cornu spiral.

6.3.1.9 After θ, d, d_1, d_2, d_{11}, d_{12}, d_{21}, d_{22}, Ψ_1, and Ψ_2, as shown in figure 6. 3-1 have been determined, the following procedure may be used

1. Calculate θ_j and Δ_j for j= 1, 2, 3, 4, using (6.3-3).
2. Calculate v_j, C_j, S_j, f_j and $\Phi_j - 90v_j^2$ using (4.4-33), (6.3-1) (6.3-7), (6.34a), and the appropriate figures 4.4-11 4.4-13, 6.3-2, and 6.3-3. Also see the discussion in the preceding paragraph on the determination of C_j and S_j.

Asymptotic and approximate algebraic expressions for these curves are given in [16, vol.II, sec.III, 2], and in [27].

3. Calculate Δ_{2r} and Δ_{3r} from (6.3-5).
4. For sea water paths, determine R_{e2} and R_{e3} from figures 6.3-4 or 6.3-5; otherwise assume that $R_{e2}=R_{e3}=-1$.
5. Substitute these values in (6.3-6).

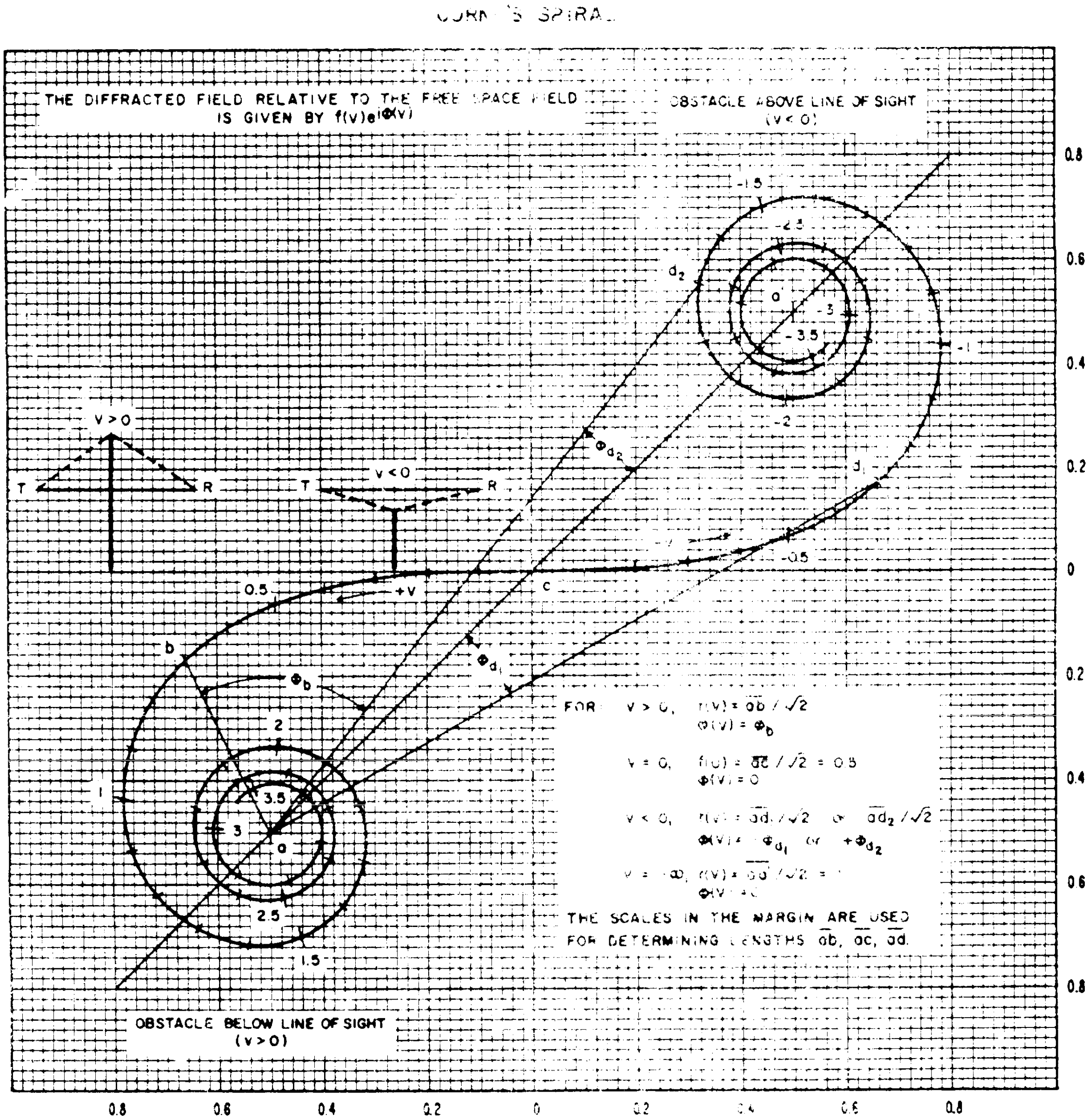


Figure 6.3-6 Nomogram for determination of $f(v_j)$ and $\varnothing(v_j)$.

To check the calculation of each V_j, the approximation given in (6.3-1) may be used, with the following formulas for $\alpha_{oj} = d_2\theta_j/d$ and $\beta_{oj} = d_1\theta_j/d$:

$$\alpha_{01} = d_2\theta/d \qquad \beta_{01} = d_1\theta d$$

$$\alpha_{02} = \alpha_{01} + 2d_{11}\psi_1 d_2/(d_1 d) \qquad \beta_{02} = \beta_{01} + 2d_{11}\psi_1/d$$

$$\alpha_{03} = \alpha_{01} + 2d_{22}\psi_2/d \qquad \beta_{03} = \beta_{01} + 2d_{22}\psi_2 d_1/(d_2 d)$$

$$\alpha_{04} = \alpha_{02} + \alpha_{03} - \alpha_{01} \qquad \beta_{04} = \beta_{02} + \beta_{03} - \beta_{01}. \qquad (6.3\text{-}10)$$

6.3.1.10 A special case will be described for which (6.3-3) and (6.3-5) may be simplified. Assume that each reflecting surface may be considered a plane. Let h_t and h_{tm} be the heights of the transmitting antenna and the knife edge above the first plane, and let h_{rm} and h_r be the heights of the knife edge and the receiving antenna above the second reflecting plane. Assume that Δr is very small for every Δ. In terms of the heights h_t, h_{tm}, h_{rm}, h_r, the parameters θ, d_1, and d_2 and the parameter $d_r \equiv d_1 d_2/(2d)$ can then be expressed by:

$$\Delta_{2r} = 2h_t h_{tm}/d_1, \qquad \Delta_{3r} = 2h_r h_{rm}/d_2$$

$$\Delta_1 = d_r\theta^2, \qquad \Delta_2 = d_r(\theta + h_{tm}\Delta_{2r})^2$$

$$\Delta_3 = d_r(\theta + h_{rm}\Delta_{3r})^2, \qquad \Delta_4 = d_r(\theta + h_{tm}\Delta_{2r} + h_{rm}\Delta_{3r})^2. \qquad (6.3\text{-}10)$$

Section 6.4 BLANK WORKSHEETS

Channel requirements for traffic

from site____________ to site____________

(a) Current Requirements

Type of Channel	Number of Channels	Baseband per Channel	Quality	Equivalent voice channels per information channel	Number of equivalent voice channels	Baseband Spectrum
Voice (Telephone)						
Voice (Facsimile)						
Voice (VFTG Tone Pack)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						
High Quality Audio						

Totals ________ ________

Link channel requirements rounded to the next higher nominal value[1] ________

Transmitter RF bandwidth[2] ________

(b) Requirements for Future Expansion

Voice (Telephone)						
Voice (Facsimile)						
Voice (VFTG Tone Pack)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						
High Quality Audio						

Totals ________ ________

Link channel requirements rounded to the next higher nominal value[1] ________

Transmitter RF bandwidth[2] ________

---

[1] Nominal values are 24, 48, 60, 72, 120, 180, 300 and 600.

[2] Estimate using figure 4.2.7.

Worksheet 4.1-1 Format for Recording Channel Requirements for FDM-FM Systems.

Path: ____________ to: ____________

Nominal Frequency: ________ Path Distance (d)____________ km

Assumed effective earth's radius a =4250 km for worst-hour conditions (k= 2/3)

Radio Hoizon Distance: d_{L1}______ km. d_{L2}________ km(from profile or visual inspection)

Assumed Antenna Height (above ground): h_{g1}_____ m. h_{g2}___ m.

1. Takeoff Angles: θ_{e1} ________ θ_{e2} ________ radians

($\theta_{e1,2} = -0.000686\sqrt{h_{g1,2}}$ for smooth terrain).

2 Angular Distance (θ): __________ radians (1° = 0.01745 radians)

3. ($\theta = d/r + \theta_{e1} + \theta_{e2}$)

θd: ____________________

For Two-Horizon Paths:

4. Enter Figure 4.2-6 with θd and the frequency (MHz).

5. Read Diffraction Loss (A_d): ______________ dB .

6. Calculate: $A_s = 73 + d/16$ dB= ______________ dB.

7. Attenuation (A_r) : __________ dB (smaller value of items 5 and 6).

For Single-Horizon Paths:

8. Calculate: $v = 2.583\,\theta\sqrt{fd_{L1}\,d_{L2}/d}$ = ____________.

(d in km; f in MHz; θ in radians).

9. Enter Figure 4.2-5 with parameter "v"; estimate A_r:

Attenuation (A_r): __________ dB.

Worksheet 4.2-1 Route Comparison-Path Loss Calculation

10. Basic Transmission Loss in Free Space (L_{bf}): __________ dB (from Figure 4.2-2).

11. Free-space Antenna Gain: (from Figure 4.2-4)

Transmitting (diameter _____ meters): G_1 ___________ dB.

Receiving (diameter __________ meters): G_2 ___________ dB.

$G_1 + G_2$ ___________ dB.

12. Path Antenna Gain (G_p): _________ dB (from Figure 4.2-3).

13. Radiated power (P_t): ____________ dBm.

14. a. No.of channels desired (N): _________

b. Baseband width = __________ kHz (from table 4.2- 1}.

c. Required r.f. bandwidth (b_{rf}): ________ MHz (from Figure 4.2-7)

d. $B_{rf} = 10 \log b_{rf}$ dB + 60 = ___________ dB.

e. Receiver Noise Figure (F): __________ dB. (from equipment specifications)

f. Hourly Median Pre-detection Wanted Carrier-to-Noise Ratio for FDM-FM systems:

From Figure 4.2-8, obtain $R_r(g)$: ______ dB directly for quadruple diversity

For dual diversity increase $R_r(g)$ by 3 dB: __________ dB.

For non-diversity increase $R_r(g)$ by 7 dB: __________ dB.

g. For digital systems, use $R_r(g)$ = 20 dB

Operating Noise Threshold (P_m):

$$P_m = (B_{rf} - 204) + F + R_r(g) = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ dBW}$$

15. Maximum permissible attenuation (A_m) from (4.2-20), or:

$$A_m = (P_t - P_m) - (L_{bf} - G_p) \text{ dB} \qquad \_\_\_\_\_\_\_\_\_\_\_\_ \text{ dB.}$$

16. Evaluate difference ($A_m - A_r$) = _____________ dB.

Worksheet 4.2-1 (continued)

	Route No. ____		Route No. ____	
	Site ____	Site ____	____	Site ____
Site Coordinates				
Site Elevation (MSL) - meters				
Path Length (km)				
Horizon Angle (radians)				
Type of Path				
Estimated worst-hour Path Attenuation (dB)				
Required Transmitter Power (kw)				
Antenna Diameter (meters)				
Tower Height (meters)				
Distance to: (km) Dirt Auto Road				
Paved Auto Road				
Power Line				
Airstrip				
Jet Airport				
Railroad Siding				
Military Base				
Hotels-Restaurants				
Coastline				
Water Supply				
Communications Center				
Supply Depot (Fuel, etc.).				
Link to Center (LOS, cable)				
Annual Temperature Extremes (°F/C)				
Annual Precipitation (in./mm)				
Maximum Snow Depth (ft/meters)				
Extreme Wind Velocity (knots)				
Land Owner (Govt., Private)				

Worksheet 4.2-2 Site Comparison Data.

Site Name and Number ____________________

Latitude ____________ Longitude ____________ (Degrees, Min, Sec)

Map reference (most detailed topographic) ____________

Nearest town (postoffice) ____________

Access route: (all Year?) ____________

Property owner; local contact:

Site sketch ______ Site photograph _____ General description _______

Reference baseline __________ By Polaris ______ Other ____________

Antenna No. __________ True bearing ____________

Ground elev. MSL ________ Takeoff angle(beam centerline) ____

Takeoff angles to 45° right and left of centerline ________
(Significant changes in horizon)

Critical Points: (include horizon)

Distance _______ Map elev. ________ Survey elev. __________

Tree height _______ Required clearance _______

Description:

Horizon sketch ______ Horizon photograph _______

Power availability:

a. Nearest transmission line ________ b. Voltage ________

c. Frequency _____ d. Phase _____ e. Operating utility ____

Drinking water source _______ Estimated depth to groundwater _____

Sewage disposal ____ Type and depth of soil on and near site _____

Nearest airport _________ railroad ________ highway ____________

navigable river ________

Worksheet 4.3-1 Checklist for Site Survey (page 1 of 2)

Local communications facilities:telephone___ telegraph____radio____

Nearby radio transmitters______________relay stations______________

Other interference sources_________________________

Local transportation facilities: airlines________railroads__________

truck________bus________

Warehouse and storage facilities________

Local suppliers (hardware/lumber, concrete, etc.)________

Local contractors____

Fuel sources (oil, gas, propane)____________

Local housing accommodations: temporary__________permanent__________

Local military or civil contact___________

Meteorological data from local sources: (averages for each month)

Precipitation___________ (Also extreme 1- and 24-hour)

Snow depth______________ (Also maximum for period of record)

Prevailing wind direction and speed__________

Extreme wind gust and direction______________

Dewpoint or relative humidity (mean diurnal change)___________

Worksheet 4.3-l Checklist for Site Survey (page 2 of 2)

No.	PATH	TERMINAL	CARRIER FREQUENCY (MHz) f	PATH DISTANCE (km) d	SEA LEVEL REFRACTIVITY N_0	HORIZON ELEVATION (km) h_{L1} h_{L2}	DISTANCE TO HORIZON (km) d_{L1} d_{L2}	ANTENNA SITE ELEVATION (km) e_{s1} e_{s2}	SURFACE REFRACTIVITY N_{s1} N_{s2}	AVERAGE SURFACE REFRACTIVITY N_s	EFFECTIVE EARTH RADIUS (km) a	ANTENNA HEIGHT ABOVE GROUND (km) h_{g1} h_{g2}	ANTENNA HEIGHT (km above msl) h_{s1} h_{s2}	HORIZON TAKEOFF ANGLE (rad) θ_{e1} θ_{e2}	DISTANCE BETWEEN HORIZONS (km) D_s	ANGULAR DISTANCE (rad) θ	θd	α_0 β_0	PATH ASYMMETRY FACTOR S

Worksheet 4.4-1a Atmosphere and Path Parameters.

PATH	TERMINAL	EFFECTIVE ANTENNA HEIGHT (km)		RADIUS OF CURVATURE (km)	DIFFRACTION PARAMETERS		INDEX OF CURVATURE		ATMOSPHERIC ABSORPTION	FREE SPACE TRANSMISSION LOSS	DIFFRACTION ATTENUATION, SINGLE OBSTACLE	DIFFRACTION ATTENUATION, SMOOTH TERRAIN	DIFFRACTION ATTENUATION, IRREGULAR TERRAIN	BASIC TRANSMISSION LOSS, FORWARD SCATTER	SCATTER ATTENUATION	ATTENUATION, MIXED MODES	REFERENCE ATTENUATION	REFERENCE BASIC TRANSMISSION LOSS
		h_o	h_{e1} h_{e2}	r	$v\rho$	v	ρ		A_a	L_{bf}	A_h	A_{rd}	A_{kd}	L_{bsr}	A_s	A_{ds}	A_{cr}	L_{bcr}

Worksheet 4.4-1b Transmission Loss Calculations.

No.	PATH	TERMINAL	DIFFRACTION PARAMETERS			DIFFRACTION ATTENUATION	EFFECTIVE RADIUS (km)	DIFFRACTION PARAMETERS					NORMALIZED ANTENNA HEIGHT	DIFFRACTION PARAMETERS			
			$A(v,o)$	$A(o,\rho)$	$U(v\rho)$	$A(v,\rho)$	a_1 a_2	K	b	C_{01} C_{02}	$K(a_1)$ $K(a_2)$	$B(K,b^\circ)$	$\bar{h}_1$ $\bar{h}_2$	$G(\bar{h}_1)$ $G(\bar{h}_2)$	B_o	x_o	x_1 x_2

Worksheet 4.4-1c Diffraction Loss Calculations.

No	PATH	TERMINAL	DIFFRACTION PARAMETERS										SCATTER ATTENUATION FUNCTION	SCATTER PARAMETERS			
			$G(x_0)$	$F(x_1)$ $F(x_2)$	$C_1(K,b)$	d_3 d_4	α_3 α_4	C_{03} C_{04}	$K(\alpha_3)$ $K(\alpha_4)$	B_1 B_2	B_3 B_4	$C_1(K_1,b)$ $C_2(K_2,b)$	$F(\theta d)$	r_1 r_2	η_s	H_0	$R(0.5)$

Worksheet 4.4-1d. Diffraction and Scatter Loss Calculations.

SITE NAME AND ANTENNA DESIGNATION	SITE AND ANTENNA ABBREVIATION	LATITUDE	LONGITUDE	TOWER BASE ELEVATION ABOVE M.S.L. (M)

Worksheet 4.5-1a Site Information.

ANTENNA IDENTI-FICATION NUMBER	- SITE	PATH	POINTING AZIMUTH FROM TRUE NORTH	HEIGHT ABOVE GROUND (M)	FREQUENCY (GHZ)	POLARI-ZATION (V OR H)	TYPE	DIAMETER (FT)	ANTENNA GAIN (dB)	BEAMWIDTH (DEGREES)	FUNCTION (RX OR TX)

Worksheet 4.5-1b Antenna Information Summary

NO	PATH	TERMINAL	PROFILE NUMBER	TOWER BASE ELEVATION ABOVE msl (m)	TOWER HEIGHT (m)	DISTANCE (km)	FREQUENCY (GHz)	MEDIAN TRANSMISSION LOSS (dB)	FEEDER LENGTH (m)	FILTER AND FEEDER LOSS (dB)	TOTAL LOSS (dB)	ANTENNA SIZE (ft)	HIGHEST ANTENNA HEIGHT ABOVE GROUND (m)	ANTENNA GAIN ABOVE ISOTROPIC (dB)	NET PATH LOSS (dB)	TRANSMITTER POWER (dBm)	MEDIAN RECEIVED CARRIER LEVEL (dBm)	IF BANDWIDTH (MHz)	RECEIVER NOISE FIGURE (dB)	NOISE THRESHOLD $10 \log(kTB_{IF}f)$ (dBm)	WORST HOUR RECEIVED CARRIER LEVEL (dBm)			

Worksheet 4.5-1c Equipment Information Summary.

Site Identification

(1) ____, ____ (Name) (Abbreviation)	(2) ____, ____ (Name) (Abbreviation)

Site Location and Physical Parameters

(3) Latitude ____° ____' ____" ____	(4) Latitude ____° ____' ____" ____
(5) Longitude ____° ____' ____" ____	(6) Longitude ____° ____' ____" ____
(7) Altitude ____ m above msl	(8) Altitude ____ m above msl
(9) UTM Coord. ____	(10) UTM Coord. ____
(11) Azimuth to (2), ____° ____' ____" True	(12) Azimuth to (1), ____° ____' ____" True
(13) Proposed antenna height above (7), ____ m	(14) Proposed antenna height above (8), ____ m
(15) Proposed antenna horizontal diversity separation ____ m	(16) Proposed antenna horizontal diversity separation ____ m
(17) Proposed antenna type, ____	(18) Proposed antenna type, ____
(19) Size, ____ ft, ____ m	(20) Size, ____ ft, ____ m
(21) Expected antenna gain ____ dB above isotropic	(21) Expected antenna gain ____ dB above isotropic
(23) Design center carrier frequency, ____ GHz	(24) Receiver noise threshold, kTBF, ____ dBm
(25) Required waveguide length, ____ m	(26) Required waveguide length, ____ m
(27) Proposed waveguide type ____	(28) Proposed waveguide type ____
(29) Waveguide loss per standard length ____ dB per ____	(30) Waveguide loss per standard length ____ dB per ____
(31) Waveguide loss, ____ dB (including connectors)	(32) Waveguide loss, ____ dB (including connectors)
Circulator and/or Diplexer Losses	Circulator and/or Diplexer Losses
(33) Transmit, ____ dB	(34) Receive, ____ dB

Worksheet 4.5-1d Path and Equipment Parameters

(35) Net fixed losses, (31) + (32) + (33) + (34), ______________dB

(36) Loss in antenna gain, L_{gp}, ______________dB

(37) Effective path antenna gain, (21) + (22) - (36), ______________dB

(38) Proposed transmitter power, ______________watts, ______________dBm

(39) Path length, d, ______________km

(40) Median reference basic transmission loss, ______________dB

(41) Worst hour basic transmission loss, ______________dB

(42) Net loss, (35) + (40), ______________dB

(43) Net gain, (37) + (38), ______________dBm

(44) Expected median receiver input power, (43) - (42), ______________dBm

(45) DCA allowable yearly median noise, $n_y(0.5)$, ______________pW0

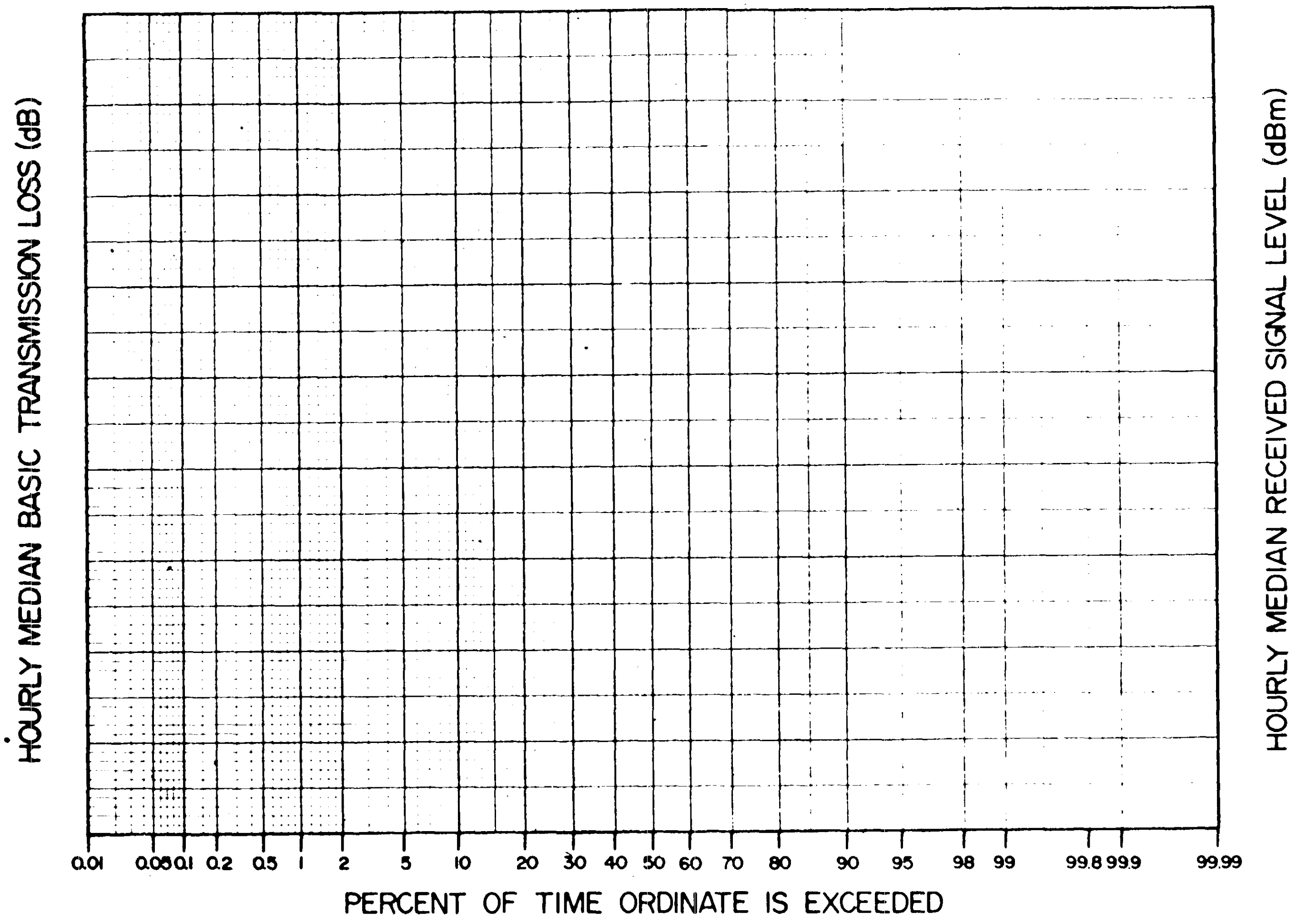
Worksheet 4.5-1d

HOP____________________TO____________________

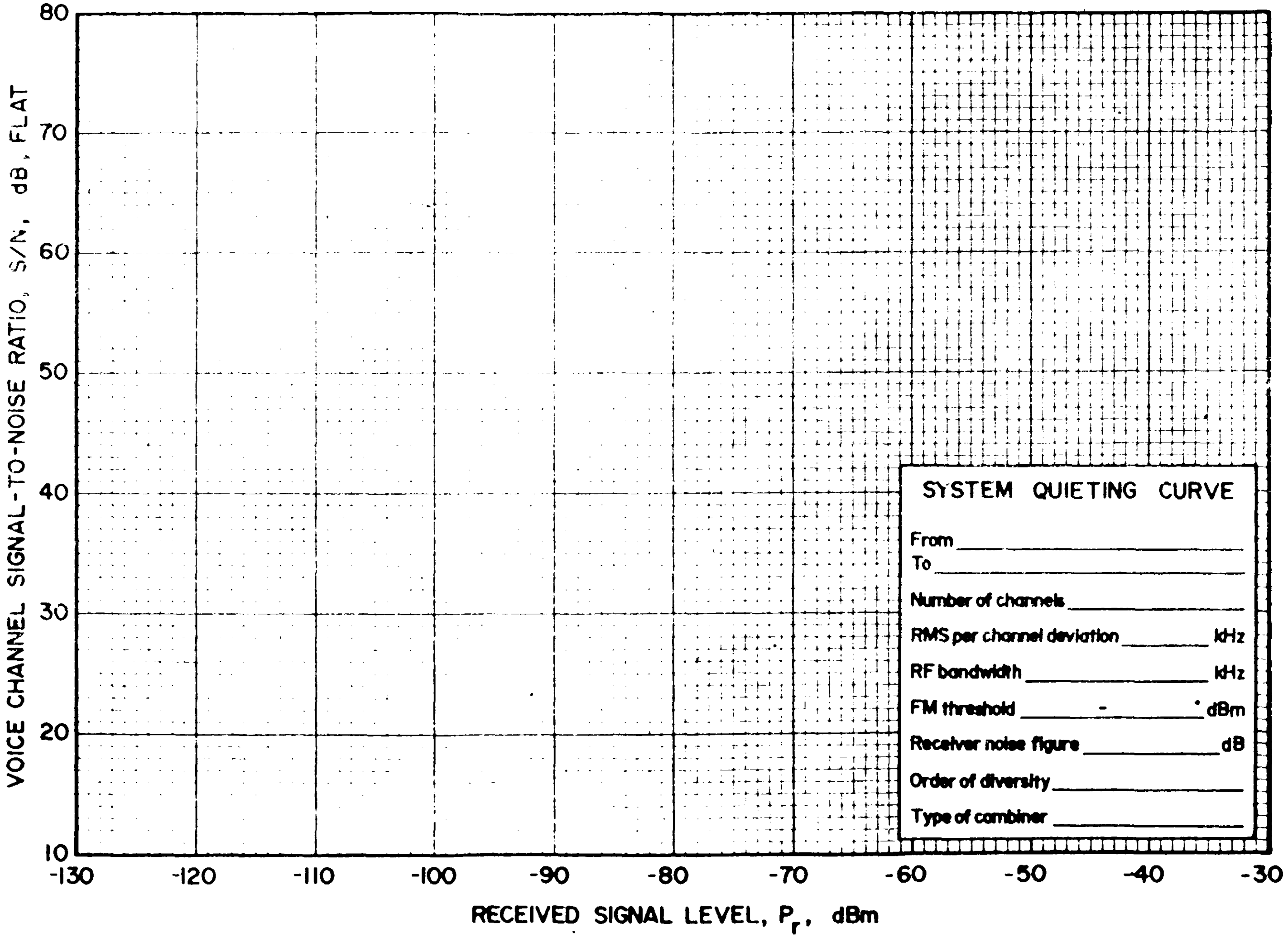
	PERCENT OF TIME	MEDIAN VARIABILITY FACTOR	PREDICTION UNCERTAINTY PARAMETER	TRANSMISSION LOSS, dB Q=0.05	TRANSMISSION LOSS, dB Q=0.5	TRANSMISSION LOSS, dB Q=0.95	RECEIVED SIGNAL LEVEL, -dBm Q=0.5	RECEIVED SIGNAL LEVEL, -dBm Q=0.95		
		Y_0	σ_c	L_b	L_b	L_b	P_r	P_r		
	0.01									
	0.1									
	1.0									
	10.0									
	50.0									
	90.0									
	99.0									
	99.9									
	99.99									

	FEEDER ECHO NOISE (pWO)	EQUIPMENT INTERMODULATION NOISE (pWO)	PATH INTERMODULATION NOISE (pWO)	THERMAL NOISE (pWO)	TOTAL NOISE (pWO)	TOTAL S/N (dB)	RECEIVED SIGNAL LEVEL (-dBm)
	N_f	N_e	N_p	N_t	N_T	S/N_T	P_r
							30
							35
							40
							45
							50
							55
							60
							65
							70
							75
							80
							85
							90
							95
							100
							105
							110

Worksheet 4.5-2a Distribution Parameters



Worksheet 4.5-2b Distribution Graph



SYSTEM QUIETING CURVE

From ____________________

To ____________________

Number of channels ____________________

RMS per channel deviation __________ kHz

RF bandwidth ____________________ kHz

FM threshold __________ - __________ dBm

Receiver noise figure ______________ dB

Order of diversity ____________________

Type of combiner ____________________

Worksheet 4.5-3 System Quieting Curve

4.1	Number of equivalent voice channels, n	______				
4.2	Voice channel bandwidth, b_c	3100	Hz	(Usable bandwidth)		
4.3	Maximum modulating frequency, f_m	______	kHz	See table 4.2-1		
4.4	Baseband bandwidth, B_b	______	kHz	$B_b = f_m - f_\ell$, where f_ℓ is the lowest frequency in the baseband		
4.5	RMS noise loading ratio, NLR	______	dB	-10 + 10 log n (see 4.5.20.12)		
4.6	Numerical RMS noise loading ratio, nlr	______		antilog (NLR/20)		
4.7	Peak factor, PF	13.5	dB			
4.8	Numerical peak factor, pf	4.73		= antilog (PF/20)		
4.9	RMS per channel deviation, δf	______	kHz	Start with δf = 200 kHz	______	______
4.10	RMS carrier deviation, δF	______	kHz	$\delta F = (nlr)(\delta f)$	______	______
4.11	Peak carrier deviation, ΔF	______	kHz	$\Delta F = (pf)(nlr)(\delta f)$	______	______
4.12	Receiver IF bandwidth, B_{IF}	______	kHz	$B_{IF} = 2(\Delta F + f_m)$, or actual values of equipment considered.	______	______
4.13	Low noise preamplifier	yes/no				
4.14	Receiver noise figure, F	______	dB			
4.15	Receiver noise threshold,* kTBF	______	dBm	$-174 + 10 \log B_{IF}(Hz) + F$	______	______
4.16	FM improvement threshold*	______	dBm	kTBF + 10	______	______
4.17	Pre-emphasis improvement, I_p	4	dB			
4.18	Combiner type	pre/post				
4.19	Median diversity improvement, I_d	______	dB			
4.20	Threshold extension	yes/no				
4.21	Threshold extension improvement, I_{te}	______	dB			
4.22	Equipment NPR	______	dB			

*If threshold extension is used, use its narrow bandwidth for threshold calculations.

Worksheet 4.5-4 Hop Noise Performance Calculations

5.1	Transmission line length, L_t, transmitter	________	m	(from item (25), worksheet 4.5-1d)		
5.2	Mean carrier frequency	________	GHz	(from item (23), wordsheet 4.5-1d)		
5.3	Percent velocity of propagation, v	________	%	(from figure 4.5-14)		
5.4	Velocity of propagation, V	________	m/sec	$V = (3 \times 10^8)(v \times 10^{-2})$		
5.5	Echo delay time, τ	________	sec	$\tau = 2L_t/V$		
5.6	Radian delay ω_τ	________	rad	$\omega_\tau = 2\pi f_m \tau$ (f_m from item 4.3, worksheet 4.5-4)		
5.7	Parameter A	________		$A = \delta F/f_m$ (from items 4.3 and 4.10, worksheet 4.5-4)	________	________
5.8	S/D - r	________	dB	(from figure 4.5-15)	________	________
5.9	Transmit System					
	Antenna return loss, RL_{ANT}	________	dB	(from applicable standards or		
	RF Interface return loss, RL_{RFI}	________	dB	manufacturer's specifications)		
5.10	Echo amplitude, r	________	dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$ ($A_{t\ell}$ from item (31), worksheet 4.5-1d)		
5.11	Transmit signal-to-distortion ratio S/D	________	dB	$S/D = (S/D - r) + r$	________	________
5.12	Transmit signal-to-feeder echo noise ratio S/N_f	________	dB	$S/N_f = S/D + 10 \log (B_b/b_c) - NLR$ (from items 4.4, 4.2, and 4.5, worksheet 4.5-4)	________	________
5.13	Transmit feeder echo noise $n_{f(trans)}$	________	pW0	$n_f = \text{antilog} [(90 - S/N_f)/10]$	________	________

Worksheet 4.5-5 Feeder Echo Noise Calculations

6.1	Transmission line length, L_r, receiver		m	(from item (26), worksheet 4.5-1d)		
6.2	Mean carrier frequency		GHz	(from item (23), worksheet 4.5-1d)		
6.3	Percent velocity of propagation, v		%	(from figure 4.5-14)		
6.4	Velocity of Propagation, V		m/sec	$V = (3 \times 10^8)(v \times 10^{-2})$		
6.5	Echo delay time, τ		sec	$\tau = 2L_r/V$		
6.6	Radian delay, ω_τ		rad	$\omega_\tau = 2\pi f_m \tau$ (f_m from item 4.3, worksheet 4.5-4)		
6.7	Parameter A			$A = \delta F/f_m$ (from items 4.3 and 4.10, worksheet 4.5-4		
6.8	S/D - r		dB	(from figure 4.5-15)		
6.9	Receive system					
	Antenna return loss, RL_{ANT}		dB	(from applicable standards or		
	RF interface return loss, RL_{RFI}		dB	from manufacturer's specifications)		
6.10	Echo amplitude, r		dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$ ($A_{t\ell}$ from item (31), worksheet 4.5-1d)		
6.11	Receive signal-to-distortion ratio S/D		dB	$S/D = (S/D - r) + r$		
6.12	Receive signal-to-feeder echo noise ratio S/N_f		dB	$S/N_f = S/D + 10 \log (B_b/b_c) - NLR$ (from items 4.4, 4.2, and 4.5, worksheet 4.5-4)		
6.13	Receive feeder echo noise, $n_{f(rec)}$		pW0	$n_f = \text{antilog}[(90 - S/N_f)/10]$		

Worksheet 4.5-6 Feeder Echo Noise Calculations (Receiver)

7.1	Total feeder echo noise, n_f	______	pW0	$n_f = n_{f(trans.)} + n_{f(rec.)}$	______	______
7.2	Signal/equipment intermodulation, S/N_e	______	dB	$S/N_e = NPR + 10 \log \frac{B_b}{b_c}$		
7.3	Equipment intermodulation noise, n_e	______	pW0	$n_e = \text{antilog} \frac{90 - S/N_e}{10}$		
7.4	Path delay, Δ	______	sec	Figs. 4.4-48 and 4.5-17		
7.5	Median path intermodulation noise, $_p(0.5, E)$*	______	pW0	Figs. 4.5-18, 19, 20, 21	______	______
7.6	Signal-to-path intermodulation noise ratio, $S/N_p(0.5, E)$	______	dB	$S/N_p = 90 - 10 \log n_p(0.5, E)$	______	______
7.7	Diversity-improved signal-to-path intermodulation noise ratio, $S/N_p(0.5, E, D)$*	______	dB	$S/N_p(0.5, E, D) = S/N_p(0.5, E) + I_d$ (I_d = 3 dB for dual diversity = 6 dB for quad. diversity)	______	______
7.8	Diversity-improved median path intermodulation noise ratio, $n_p(0.5, E, D)$	______	pW0	$n_p(0.5, E, D) = \text{antilog} \frac{90 - S/N_p(0.5, E, D)}{10}$	______	______
7.9	Total intermodulation noise, n_{it}	______	pW0	$n_{it} = n_f + n_e + n_p(0.5, E, D)$	______	______

---

*The symbols E and D in these terms denote that pre-emphasis and diversity improvement are included.

Worksheet 4.5-7a Path Intermodulation Noise Calculations

7.10	Calculate $20 \log \frac{\delta f}{f_m}$	-______	dB		______	______
7.11	Calculate $10 \log kTb_c + F$	-______	dB	$-139.1 + F$		
7.12	Signal-to-thermal noise ratio minus received signal level, $S/N_t - P_r$	______	dB	$S/N_t - P_r = -10 \log kTb_c - F + 20 \log \frac{\delta f}{f_m}$	______	______
7.13	$P_r\ (0.5,\ 0.5)$	______	dBm			
7.14	Median signal-to-thermal noise ratio, $S/N_t(0.5,\ 0.5)$	______	dB	$(S/N_t - P_r) + (P_r(0.5,\ 0.5))$	______	______
7.15	Thermal noise, $n_t(0.5,\ 0.5)$	______	pW0	$n_t(0.5,\ 0.5) = \text{antilog}\ \frac{90 - S/N_t}{10}$	______	______
7.16	Emphasis- and diversity-improved signal-to-thermal noise ratio, $S/N_t(0.5,\ E,\ D)$	______	dB	$S/N_t(0.5,\ E,\ D) = S/N_t(0.5, 05) + I_p + I_d$ (I_p = 4 dB for standard pre-emphasis)	______	______
7.17	Emphasis- and diversity-improved thermal noise, $n_t(0.5,\ E,\ D)$	______	pW0	$n_t(0.5,\ E,\ D) = \text{antilog}\ \frac{90 - S/N_t}{10}$	______	______
7.18	Total median noise, $n_T(0.5)$	______	pW0	$n_T(0.5) = n_{it} + n_t(0.5,\ E,\ D)$	______	______
7.19	Signal-to-total median noise ratio, $S/N_T(0.5)$	______	dB	$S/N_T = 90 - .0 \log n_T$	______	______

Worksheet 4.5-7b Thermal Noise Calculations

8.1 Decrease RMS per channel deviation and recalculate total median noise — Divide by $\sqrt{2}$ in order to decrease it.

8.2 Is total median noise less for second choice of channel deviation? — yes/no

8.3 If yes, go to step 8.1

8.4 If no, an approximate minimum has been determined. Select the deviation which results in the least value of total noise and proceed.

8.5 Compare total median noise, $n_T(0.5)$, — $n_T(0.5)$ __________ pW0

with DCA noise allowance, $n_y(0.5)$. — $n_y(0.5)$ __________ pW0

8.6 If $n_T(0.5)$ is greater than $n_y(0.5)$, make adjustments to hop and/or equipment requirements and recalculate total median noise

8.7 • If $n_T(0.5)$ is less than or equal to $n_y(0.5)$, proceed to next step.

Worksheet 4.5-8 Noise Adjustments

9.1 Calculate and plot diversity-improved dynamic quieting curve in worksheets 4.5-2a and 4.5-2c		
9.2 Enter total feeder-echo noise and equipment intermodulation noise in their appropriate columns in the worksheet		
9.3 Using $P_r(0.5, 0.5)$ in step 7.13 and emphasis- and diversity-improved signal-to-noise ratio in step 7.16, increase both by an equal decibel amount to the nearest whole 5-dB increment of P_r		$P_r(0.5, 0.5)$ = ____dBm = Long-term median power (PLTM). The next higher integral 5-dB increment (PNHI) = ____dBm $S/N_t(0.5, 0.5)$ = ____dB. Increase $S/N_t(0.5, 0.5)$ by (PNHI - PLTM), S/N_t = ____dB
9.4 Convert the new signal-to-noise ratio to thermal noise and enter on worksheet 4.5-2a opposite the value PNHI from step 9.3	________pW0	$n_t = \text{antilog} \dfrac{90 - S/N_t}{10}$
9.5 Convert each succeeding 5-dB increment of noise by multiplying (decreasing P_r) or dividing (increasing P_r) the previous n_t value by 3.16.		
9.6 Using the diversity-improved median signal-to-path intermodulation noise ratio in step 7.7, increase by 0.7 times the dB increment determined in step 9.3		Increase $S/N_p(0.5, E, D)$ = ____dB by 0.7 (PNHI - PLTM), 0.7(____dB) or S/N_p = ____dB
9.7 Convert the new signal-to-noise ratio to path intermodulation noise and enter in worksheet 4.5-2a	________pW0	$n_p = \text{antilog} \dfrac{90 - S/N_p}{10}$
9.8 Convert each succeeding 5-dB increment of path intermodulation noise N_p by multiplying (decreasing P_r) or dividing (increasing P_r) the previous value of n_p by 2.24		
9.9 Add the noise components in each row to determine total noise	________pW0	$n_T = n_f + n_e + n_p + n_t$
9.10 Convert the total noise to signal-to-noise ratio	________dB	$S/N_T = 90 - 10 \log n_T$
9.11 Plot S/N_T versus P_r on worksheet 4.5-2c		
9.12 Determine diversity-improved threshold from figure 4.5-28 and complete dynamic quieting curve		

Worksheet 4.5-9 Final Noise Estimates

10.1	Median voice channel noise	_______ pW0	Section 4.5.38
10.2	DCS allowance for median noise	_______ pW0	"
10.3	Is 10.1 smaller than 10.2?	yes/no	"
	If yes, continue If no, adjust system parameters if possible.		
10.4	Number of hours during which hourly median noise exceeds 10^5pW0	_______ hours	Section 4.5.39
10.5	DCS allowance fornumber of hours during which hourly median noise may exceed 10^5pW0	4 hours	"
10.6	Is 10.4 smaller than 10.5?	yes/no	"
	If yes, continue If no, adjust system parameters if possible.		
10.7	Number of cumulative minutes during which noise exceeds 10^6 pW0	_______ minutes	Section 4.5.39
10.8	DCS allowance for number of minutes during which noise exceeds 10^6pW0	22 minutes	"
10.9	Is 10.7 smaller than 10.8?	yes/no	"
	If yes, complete system summary chart. If no, adjust system parameters if possible.		

NOTE: If no further adjustment of system parameters is possible, continue but note the failure to meet DCS allowance.

Worksheet 4.5-10 Compliance With DCS Allowances

NO.	PATH	HOP TIME AVAILABILITY (PERCENTILE)	NUMBER OF CHANNELS	C/N FRONT END (dB)	HIGHEST BASEBAND FREQUENCY (MHz)	PER CHANNEL RMS DEVIATION (kHz)	IF BANDWIDTH (kHz)	DIVERSITY IMPROVEMENT (dB)	EMPHASIS- AND DIVERSITY-IMPROVED TOP CHANNEL NOISE POWER, UNWEIGHTED, (picowatts)					TOTAL CHANNEL S/N, FLAT, (dB)			PERCENT OF TIME HOP NOISE EXCEEDS 10^6 pWO (flat)	NOISE ALLOCATION
									THERMAL	EQUIPMENT INTERMODULATION	FEEDER ECHO	PATH INTERMODULATION	TOTAL					
		0.5																
		0.9999																
		0.5																
		0.9999																
		0.5																
		0.9999																
		0.5																
		0.9999																
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		0.5																
		0.9999																
		0.5																
		0.9999																

NOTE: If DCS noise allowance is less than predicted performance, state reasons why it could not be achieved.

Yearly Median DCS System Noise Allocation__________pWO, based on L = __________km
Yearly Median Predicted System Noise Performance__________pWO
Estimated System Outage Time__________% of year, __________min

Worksheet 4.5-11 Noise Data Tabulations

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7. INDEX OF KEY TERMS

CLIMATOLOGICAL FACTORS contd.

Custodians:
  Army - SC
  Navy -EC
  Air Force -17
  DCA - DC

Review Activities:
  Army - EL, CE, ME
  Navy - AS, YD, MC, CG, SH
  Air Force - 1,11,13,89,90,99

User Activities:
  Army
  Navy-os
  Air Force

Preparing Activity:
  Air Force - 17

Other Interest
  JCS-J6
  NSA-NS

(Assignee-DC)

Project SLHC 4170

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3a. NAME OF SUBMITTING ORGANIZATION

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5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional

b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional

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8. DATE OF SUBMISSION *(YYMMDD)*

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82 MAR

PREVIOUS EDITION IS OBSOLETE