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APPLICATIONS GUIDE PROPAGATION AND INTERFERENCE ANALYSIS COMPUTER PROGRAMS (0.1 to 20 GHz)

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OFFICE OF TELECOMMUNICATIONS
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16. Abstract
This report covers ten computer programs useful in estimating the service coverage of radio systems operating in the frequency band from 0.1 to 20 GHz. These programs may be used to obtain a wide variety of computer-generated microfilm plots such as transmission loss versus path length and the desired-to-undesired signal ratio at a receiving location versus the distance separating the desired and undesired transmitting facilities. Emphasis is placed on the types of outputs available and the input parameter requirements. The propagation model used with these programs is applicable to air/ground, air/air, ground/satellite, and air/satellite paths. It can also be used for ground-to-ground paths that are line-of-sight or smooth earth. Detailed information on the propagation models and software involved is not provided. The normal use made of these programs involves a Department of Commerce (DOC) response to a Federal Aviation Administration (FAA) ARD-60 request for computer output and reimbursement to the DOC by the FAA for the associated costs.

17. Key Words
Air/air, air/ground, computer program, DME, earth/satellite, EMC, frequency sharing, ILS, interference, navigation aids, propagation model, TACAN, transmission loss, VOR.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	Cm	m	Km	in	ft	s mi	n mi
Cm	1	0.1	1×10^{-5}	0.3937	0.0328	6.21×10^{-6}	5.39×10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
Km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
S mi	160,900	1609	1.609	63360	5280	1	0.8688
n mi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	Cm^2	M^2	Km^2	in^2	ft^2	$S\ mi^2$	$n\ mi^2$
Cm^2	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{-11}	5.11×10^{-11}
m^2	10,000	1	1×10^{-6}	1550	10.76	3.86×10^{-7}	5.11×10^{-7}
Km^2	1×10^{10}	1×10^{6}	1	1.55×10^{9}	1.08×10^{7}	0.3861	0.2914
in^2	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft^2	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
$S\ mi^2$	2.59×10^{10}	2.59×10^{6}	2.590	4.01×10^{9}	2.79×10^{7}	1	0.7548
$n\ mi^2$	3.43×10^{10}	3.43×10^{6}	3.432	5.31×10^{9}	3.70×10^{7}	1.325	1

VOLUME

From \ To	Cm^3	Liter	m^3	in^3	ft^3	yd^3	fl oz	fl pt	fl qt	gal
Cm^2	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^2	1×10^{6}	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64×10^{-5}	1	0,0006	2.14×10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl oz	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.0625	0.0312	0.0078
fl pt	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl qt	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	Kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
Kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$^{o}F = 5/9\ (^{o}C - 32)$

$^{o}C = 9/5\ (^{o}F) + 32$

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

Statement of Mission

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio frequency spectrum.

This object is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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APPLICATIONS GUIDE
FOR
PROPAGATION AND INTERFERENCE ANALYSIS
COMPUTER PROGRAMS (0.1 to 20 GHz)

M. E. Johnson and G. D. Gierhart[1]

Assignments for aeronautical radio in the radio frequency spectrum must be made so as to provide reliable services for an increasing air traffic density [30][2]. Potential interference between facilities operating on the same or on adjacent channels must be considered in expanding present services to meet future demands. Service quality depends on many factors, including the desired-to-undesired signal ratio at the receiver. This ratio varies with receiver location and time even when other parameters, such as antenna gain and radiated powers, are fixed.

The computer programs covered in this report were developed by the Department of Commerce (DOC) with the sponsorship of the Federal Aviation Administration (FAA). Although these programs were intended for use in predicting the service coverage associated with ground- or satellite-based VHF/UHF/SHF air navigation aids, they can be used for other services in this frequency range.

The propagation model used with these programs is applicable to air/ground, air/air, ground/satellite, and air/satellite paths over smooth or irregular terrain. It can also be used for ground/ground paths that are line-of-sight, smooth earth, or have a common horizon. These computer programs are useful in estimating

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[1] The authors are with the Institute for Telecommunication Sciences, Office of Telecommunications, U. S. Department of Commerce, Boulder, Colorado 80303.

[2] References are listed alphabetically by author at the end of the report so that reference numbers do not appear sequentially in the text.

the service coverage of radio systems operating in the frequency band from about 0.1 to 20 GHz. They may be used to obtain a wide variety of computer-generated microfilm plots such as transmission loss [43, 44] versus path length, and the desired-to-undesired signal ratio at a receiving location versus the distance separating the desired and undesired transmitting facilities.

This type of information is very similar to that previously developed by DOC during the last decade [19, 20, 21, 22, 23, 24, 26, 27, 32, 38, 39, 49, 55]. The use of such information in spectrum engineering has been discussed by Hawthorne and Daugherty [28] and Frisbie et al. [18]; other information on spectrum engineering for air navigation, and communications systems is available [13, 14, 15, 16, 29, 33].

The potential user should

1) read the brief description of the propagation model provided in section 2 to see if the model could be applicable to his problem,
2) select the program(s) whose output(s) is most appropriate from the information provided in section 3,
3) determine values for the input parameters discussed in section 4, and
4) utilize the information provided in section 5 to request program runs.

Many examples of the graphical output produced by these programs are provided in section 3.1, and additional examples are included in Appendix A (see list of figures). Most abbreviations, acronyms, and symbols used in this report are identified in Appendix B.

2. PROPAGATION MODEL

The DOC has been active in radio wave propagation research and prediction for several decades, and has provided the FAA with many propagation predictions relevant to the coverage of air navigation and communications systems [20, 21, 22].

During 1960-1973, an air/ground propagation model applicable to irregular terrain was developed by the Institute for Telecommunication Sciences (ITS) for the FAA and was documented in detail [24]. This IF-73 (ITS-FAA-1973) propagation model has evolved into the IF-77 model which is applicable to air/ground, air/air, ground/satellite, and air/satellite paths. It can also be used for ground/ground paths that are line-of-sight, smooth earth, or have a common horizon. Model applications are restricted to telecommunication links operating at radio frequencies from about 0.1 to 20 GHz with antenna heights greater than 1.5 ft (0.5 m). In addition, the elevation of the radio horizon must be less than the elevation of the higher antenna. The radio horizon for the higher antenna is taken either as a common horizon with the lower antenna or as a smooth earth horizon with the same elevation as the lower antenna effective reflecting plane [24, sec. A.4.1.]. Ranges for other parameters associated with IF-77 will be given later (table 2).

At 0.1 to 20 GHz, propagation of radio energy is affected by the lower nonionized atmosphere (troposphere), specifically by variations in the refractive index of the atmosphere [1, 2, 3, 4, 5, 6, 31, 35, 40, 47, 49, 50, 51, 52]. Atmospheric absorption and attenuation or scattering due to rain become important at SHF [24, sec. A.4.5.; 35, sec. 8; 49, ch. 3; 51; 54]. The terrain, along and in the vicinity of the great-circle path between transmitter and receiver, also plays an important part. In this frequency range, time and space variations of received signal and interference ratios lend themselves readily to statistical description [39; 45; 49, sec. 10].

Conceptually, the model is very similar to the Longley-Rice [37] propagation model for propagation over irregular terrain, particuarly in that attenuation versus distance curves calculated for the (a) line-of-sight [24, sec. A.4.2], (b) diffraction [24, sec. A.4.3], and (c) scatter [24, sec. A.4.4] regions are blended together to obtain values in transition regions. In addition, the Longley-Rice relationships involving the terrain parameter Δh are used to estimate radio horizon parameters when such information is not available from facility siting data [24, sec. A.4.1]. The model includes allowance for

a) average ray bending [4, ch. 3; 6; 24, p. 44; 49, sec. 4; 56],
b) horizon effects [24, sec. A.4.1],
c) long-term fading [24, sec. A.5; 49, sec 10],
d) facility antenna patterns (figs. 45, 46),
e) surface reflection multipath [7; 8; 23, sec. 2.3; 24, sec. A.6; 27, sec. CI-D.7],
f) tropospheric multipath [2; 11, sec. 3.1; 24, sec. A.7; 31; 36, pp. 60, 119, B-2],
g) atmospheric absorption [21, sec. A.3; 24, sec. A.4.5; 49, sec. 3],
h) ionospheric scintillations [23, sec. 2.5; 27, sec. CVII; 46; 58], and
i) rain attenuation [10, 51, 52, 54].

The model is an extended version of the IF-73 model previously described in detail by Gierhart and Johnson [24, sec. A]. These extensions include provisions for

a) sea state (table 6),
b) a divergence factor [25, sec. 3.2],
c) a ray length factor for situations where the free-space loss associated with a surface reflected ray may be significantly greater than that associated with the direct ray [25, sec. 3.3],
d) an antenna pattern at each terminal (sec. 4.1),
e) circular polarization [25, sec. 3.5],
f) frequency and temperature variations of the complex dielectric constant of water [25, sec. 3.5],
g) long-term power fading as a function of radio climatic region (table 8) or time block (table 9),
h) rain attenuation [25, sec. 4.4],

i) ionospheric scintillation (fig. 47),
j) an improved method for calculating the transmission loss associated with tropospheric scatter [25, sec. 5],
k) ray elevation angle adjustment factors to allow for ray tracing [25, sec. 10.2],
l) antenna tracking options (sec. 4.1),
m) an improved estimate of the distance where horizon effects can be neglected [25, sec. 7],
n) a free-space loss formulation that is applicable to very high antennas [25, sec. 8], and
o) a formulation for facility horizon determinations that includes ray tracing [25, sec. 9.2].

Detailed documentation covering these extensions is provided in another report [25].

3. COMPUTER OUTPUTS

The propagation model described in section 2 has been incorporated into ten computer programs. These programs are written in FORTRAN for a digital computer (CDC 6600) at the Department of Commerce Laboratories, Boulder, Colorado. Since they utilize the cathode-ray tube microfilm plotting capability at the Boulder facility, substantial modification would have to be made for operation at any other facility. Average running time for the programs ranges from a few second, for each graph produced, to a minute or so. These programs are extensions of programs previously developed and described [24; 27, sec. CII]. The extensions involve a more comprehensive propagation model (sec. 2) and a larger variety of computer generated microfilm outputs.

A guide to the plotting capabilities of these programs is provided in table[3] 1. Potential users should use it to select the program(s) whose outputs are most appropriate for their problems. Figure numbers given in table 1 refer to graphs of section

[3] Tables and figures for sections 3 and 3.1 are grouped together following the section 3.1 text.

3.1. Short discussions for each capability are given in section 3.2. Simple problem applications involving the graphs of section 3.1 are provided in section 3.3. Some additional graphs and problems are given in Appendix A. Input parameters needed to operate the various programs and plotting options such as a choice of English or metric units (table 4) are discussed in section 4.

Each program causes the computer to produce (a) listings of parameters associated with particular runs and (b) microfilm plots. These outputs are provided for each parameter set used as input to the computer and are tied to each other by a run code consisting of the date and time at which calculations for a particular parameter set started.

Parameter sheets for all programs have a similar format and provide similar information. In programs associated with interference analysis, a parameter sheet is produced for both the desired and undesired facility when the input parameters associated with them are not identical [24, figs. 8, 9].

Computer produced parameter sheets do not have dual English/metric units and are either English or metric depending on the unit option selected (sec. 4.3). Sample parameter sheets similar, except for dual units, to those produced by the programs are shown in figures[3] 1 through 5. These parameters were used in developing the curves provided in section 3.1 to illustrate the plotting capabilities of the programs. Systems considered are Air Traffic Control communications (ATC, fig. 1), Instrument Landing System (ILS, fig. 2), UHF Satellite (fig. 3), Tactical Air Navigation (TACAN, fig. 4), and VHF Omni-directional Range (VOR, fig. 5). Parameters are given in about the same order as they are discussed in section 4.1. The effective area, A_I, required to convert power density, S_R, to power available at the output of an ideal (loss less) isotropic receiving antenna, P_I, is given at the bottom of the parameter sheets for power density predictions (figs. 1, 2, 4, 5); i.e.,

$$P_I[\text{dBW}] = S_R[\text{dB-W/sq m}] + A_I[\text{dB-sq m}]. \qquad (1)^4$$

3.1 GRAPHS

Figures 6 through 39 are sample graphs associated with the various capabilities summarized in table 1. These graphs are meant to illustrate general capability and care should be taken in using them for particular problems where the parameters required may differ from those used to develop the graphs. They should be used, rather, as examples to help select the graph types that are most appropriate for the particular applications. Graphs produced by the computer are very similar to these, but do not include all the labeling. In particular, the supplementary scale is not computer generated and only provides an approximate correspondence with primary units. More accurate readings can be obtained by using the primary scale, and then converting to the desired units by using an appropriate conversion factor (p.ii). This method was used to obtain dual values for readings given in the text.

Options available (sec. 4.3) for units result in the plotting of the primary grid and heading data in English (nautical or statute) miles, or metric units. Except for figures 6 through 15 where the metric option was used, all figures in this section were generated with the nautical mile option. An option to plot against central angle (fig. 41) instead of distance was used to produce figure 16.

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[4] The notation used for the units of these quantities is intended to imply that they are decibel-type quantities obtained by taking 10 log of a quantity with the units indicated after dB-; e.g., $A_I[\text{dB-sq m}] = 10 \log \{\lambda^2[\text{sq m}]/4\pi)\}$ (where λ [m] is wavelength). Equations used in this report are dimensionally consistent. Where difficulties with units could occur, brackets are used to indicate proper units.

Table 1. Plotting Capability Guide

Capability	Figure(s)*	Program	Remarks
Lobing**	6	LOBING	Transmission loss versus path distance.
Reflection coefficient**	7	LOBING	Effective specular reflection coefficient versus path distance.
Path length difference**	8	LOBING	Difference in reflected and direct ray lengths versus path distance.
Time lag**	9	LOBING	Same as above with path length difference expressed as time delay.
Lobing frequency-D**	10	LOBING	Normalized distance lobing frequency versus path distance.
Lobing frequency-H**	11	LOBING	Normalized height lobing frequency versus path distance.
Reflection point**	12	LOBING	Distance to reflection point versus path distance.
Elevation angle**	13	LOBING	Direct ray elevation angle versus path distance.
Elevation angle difference**	14	LOBING	Angle by which the direct ray exceeds the reflected ray versus path distance.
Spectral plot**	15	LOBING	Amplitude versus frequency response curves for various path distances.
Power available	16	ATOA	Power available at receiving antenna versus path distance or central angle for time availabilities 5, 50, and 95 percent.
Power density	17-19	ATOA	Similar to above, but with power density ordinate.
Transmission loss	20	ATOA	Similar to above, but with transmission loss ordinate.
Power available curves	21	ATLAS	Power available curves versus distance are provided for several aircraft altitudes with a selected time availability, and a fixed lower antenna height.
Power density curves	22	ATLAS	Similar to above, but with power density as ordinate.
Transmission loss curves	23	ATLAS	Similar to above, but with transmission loss as ordinate.
Power available volume	24	HIPOD	Fixed power available contours in the altitude versus distance plane for time availabilities of 5, 50, and 95 percent.
Power density volume	25	HIPOD	Similar to above, but with fixed power density contours.
Transmission loss volume	26	HIPOD	Similar to above, but with fixed transmission loss contours.
EIRP contours	27-29	APODS	Contours for several EIRP levels needed to meet a particular power density requirement are shown in the altitude versus distance plane for a single time availability.
Power available contours	30	APODS	Similar to above, but with power available contours for a single EIRP.
Power density contours	31	APODS	Similar to above, but with power density contours.
Transmission loss contours	32	APODS	Similar to above, but with transmission loss contours.
Signal ratio-S	33	ATADU	Desired-to-undesired, D/U, signal ratio versus station separation for a fixed desired facility-to-receiver distance, and time availabilities of 5, 50, and 95 percent.

Table 1. Plotting Capability Guide (cont.)

Capability	Figure(s)*	Program	Remarks
Signal ratio-DD	34	DUDD	Similar to above, but abscissa is desired facility-to-receiver distance and the station separation is fixed.
Orientation	35	TWIRL	Undesired station antenna orientation with respect to the desired to undesired station line versus required facility separation curves are plotted for several desired station antenna orientations. These curves show the maximum separation required to obtain a specified D/U signal ratio value at several aircraft locations (i.e., protection points).
Service volume	36-37	SRVLUM	Fixed D/U contours are shown in the altitude versus distance plane for a fixed station separation and time availabilities of 5, 50, and 95 percent.
Signal ratio contours	38-39	DURATA	Contours for several D/U values are shown in the altitude versus distance plane for a fixed station separation and time availability.

* Additional discussion, by capability, is provided in the text.

** Applicable only to the line-of-sight region for spherical earth geometry. Variability with time and horizon effects are neglected and the counterpoise option is not available. The phase change associated with surface reflection in the lobing region is taken as 0 or 180° to avoid missing lobe nulls.

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/07/18.   17.33.01 RUN

POWER DENSITY FOR ATC
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 45000. FT (13716.M) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 50.0 FT (15.2M) ABOVE FSS
FREQUENCY: 125. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: ISOTROPIC
POLARIZATION: HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 0. FT (0.M)
EQUIVALENT ISOTROPICALLY RADIATED POWER: 14.0 DBW
FACILITY ANTENNA TYPE: ISOTROPIC
POLARIZATION: HORIZONTAL
HORIZON OBSTACLE DISTANCE: 8.69 N MI (16.09KM) FROM FACILITY*
ELEVATION ANGLE: -0/ 6/30 DEG/MIN/SEC ABOVE HORIZONTAL*
HEIGHT: 0. FT (0.M) ABOVE MSL
REFRACTIVITY:
EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: CONTRIBUTES TO VARIABILITY
SURFACE TYPE: AVERAGE GROUND
TERRAIN ELEVATION AT SITE: 0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER: 0. FT (0.M)
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

POWER DENSITY (DB-W/SQ M) VALUES MAY BE CONVERTED TO POWER AVAILABLE AT THE TERMINALS OF A PROPERLY POLARIZED ISOTROPIC ANTENNA (DBW) BY ADDING -3.4 DB-SQ M.

* COMPUTED VALUE

Notes: 1) Aircraft antenna information is not actually used in power density calculations.

2) Parameter values (or options) not indicated are taken as the assumed values (or options) provided on the general parameter specification sheet (table 2).

3) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure 1. Parameter sheet, ATC (Air Traffic Control).

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PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/07/19.   11.39.28. RUN

POWER DENSITY FOR ILS
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE:   6250. FT (1905.M) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT:      5.5 FT (1.68M) ABOVE FSS
FREQUENCY:  110. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE:  ISOTROPIC
     POLARIZATION: HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL:    0. FT (0.M)
EQUIVALENT ISOTROPICALLY RADIATED POWER:   24.0 DBW
FACILITY ANTENNA TYPE:  8-LOOP ARRAY (COSINE VERTICAL PATTERN)
     POLARIZATION: HORIZONTAL
HORIZON OBSTACLE DISTANCE:   2.88 N MI (5.33KM) FROM FACILITY*
     ELEVATION ANGLE:  -0/ 2/09 DEG/MIN/SEC ABOVE HORIZONTAL*
     HEIGHT:    0. FT ABOVE MSL
REFRACTIVITY:
     EFFECTIVE EARTH RADIUS: 4586. N MI   (8493.KM)*
     MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING:  CONTRIBUTES TO VARIABILITY
SURFACE TYPE:  AVERAGE GROUND
TERRAIN ELEVATION AT SITE:    0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER:   0. FT (0.M)
TIME AVAILABILITY:  FOR INSTANTANEOUS LEVELS EXCEEDED

POWER DENSITY (DB-W/SQ M) VALUES MAY BE CONVERTED TO POWER
     AVAILABLE AT THE TERMINALS OF A PROPERLY POLARIZED
     ISOTROPIC ANTENNA (DBW) BY ADDING   -2.3 DB-SQ M.

* COMPUTED VALUE
```

Notes: 1) Aircraft antenna information is not actually used in power density calculations.

2) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).

3) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure 2. Parameter sheet, ILS (Instrument Landing System)

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/09/01. 17.43.34. RUN

POWER AVAILABLE FOR UHF SATELLITE SEA STATE 0
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 19351. N MI (35838.KM) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 30000.0 FT (9144.M) ABOVE FSS
FREQUENCY: 1550. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: JTAC
BEAMWIDTH, HALF-POWER: 10.00 DEGREES
POLARIZATION: CIRCULAR
TILT IS -90.0 DEGREES ABOVE HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 0. FT (0.M)
EIRP PLUS RECEIVING ANTENNA MAIN BEAM GAIN: 41.0 DBW
FACILITY ANTENNA TYPE: JTAC
BEAMWIDTH, HALF-POWER: 20.00 DEGREES
POLARIZATION: CIRCULAR
ANTENNA IS TRACKING
HORIZON OBSTACLE DISTANCE: 208.85 N MI (385.79KM) FROM FACILITY*
ELEVATION ANGLE: -2/49/36 DEG/MIN/SEC ABOVE HORIZONTAL*
HEIGHT: 0. FT (0.M) ABOVE MSL
IONOSPHERIC SCINTILLATION INDEX GROUP: 0
REFRACTIVITY:
EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: CONTRIBUTES TO VARIABILITY
SURFACE TYPE: SEA WATER
STATE: 0
CALM (GLASSY)
0.00 FT (0.00M) RMS WAVE HEIGHT
TEMPERATURE: 10. DEG CELSIUS
3.6 PERCENT SALINITY
TERRAIN ELEVATION AT SITE: 0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER: 0. FT (0.M)
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

* COMPUTED VALUE

Notes: 1) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).

2) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure 3. Parameter sheet, UHF Satellite.

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/07/19. 11.39.31. RUN

POWER DENSITY FOR TACAN

SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 40000. FT (12192.M) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 30.0 FT (9.14M) ABOVE FSS
FREQUENCY: 1150. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: ISOTROPIC
    POLARIZATION: VERTICAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 0. FT (0.M)
EQUIVALENT ISOTROPICALLY RADIATED POWER: 39.0 DBW
FACILITY ANTENNA TYPE: TACAN (RTA-2)
    POLARIZATION: VERTICAL
HORIZON OBSTACLE DISTANCE 6.73 N MI (12.46KM) FROM FACILITY*
    ELEVATION ANGLE: -0/ 5/ 2 DEG/MIN/SEC ABOVE HORIZONTAL*
    HEIGHT: 0. FT (0.M) ABOVE MSL
REFRACTIVITY:
    EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
    MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: CONTRIBUTES TO VARIABILITY
SURFACE TYPE: AVERAGE GROUND
TERRAIN ELEVATION AT SITE: 0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER: 0. FT
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

POWER DENSITY (DB-W/SQ M) VALUES MAY BE CONVERTED TO POWER AVAILABLE AT THE TERMINALS OF A PROPERLY POLARIZED ISOTROPIC ANTENNA (DBW) BY ADDING -22.7 DB-SQ M.

* COMPUTED VALUE

Notes:
1) Aircraft antenna information is not actually used in power density calculations.
2) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).
3) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure 4. Parameter sheet, TACAN (Tactical Air Navigation).

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/07/19. 11.39.36. RUN

POWER DENSITY FOR VOR
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 30000. (9144.M) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 16.0 FT (4.88M) ABOVE FSS
FREQUENCY: 113. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: ISOTROPIC
POLARIZATION: HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 0. FT (0.M)
EQUIVALENT ISOTROPICALLY RADIATED POWER: 22.2 DBW
FACILITY ANTENNA TYPE: 4-LOOP ARRAY (COSINE VERTICAL PATTERN)
POLARIZATION: HORIZONTAL
COUNTERPOISE DIAMETER: 52. FT (15.8M)
HEIGHT: 12. FT (3.66M) ABOVE SITE SURFACE
SURFACE: METALLIC
HORIZON OBSTACLE DISTANCE: 4.91 N MI (9.09KM) FROM FACILITY*
ELEVATION ANGLE: -0/ 3/41 DEG/MIN/SEC ABOVE HORIZONTAL*
HEIGHT: 0. FT ABOVE MSL
REFRACTIVITY:
EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: DETERMINES MEDIAN
SURFACE TYPE: AVERAGE GROUND
TERRAIN ELEVATION AT SITE: 0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER: 0. FT (0.M)
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

POWER DENSITY (DB-W/SQ M) VALUES MAY BE CONVERTED TO POWER AVAILABLE AT THE TERMINALS OF A PROPERLY POLARIZED ISOTROPIC ANTENNA (DBW) BY ADDING -2.5 DB-SQ M.

* COMPUTED VALUE

Notes: 1) Aircraft antenna information is not actually used in power density calculations.

2) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).

3) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure 5. Parameter sheet, VOR (VHF Omni-Directional Range.)

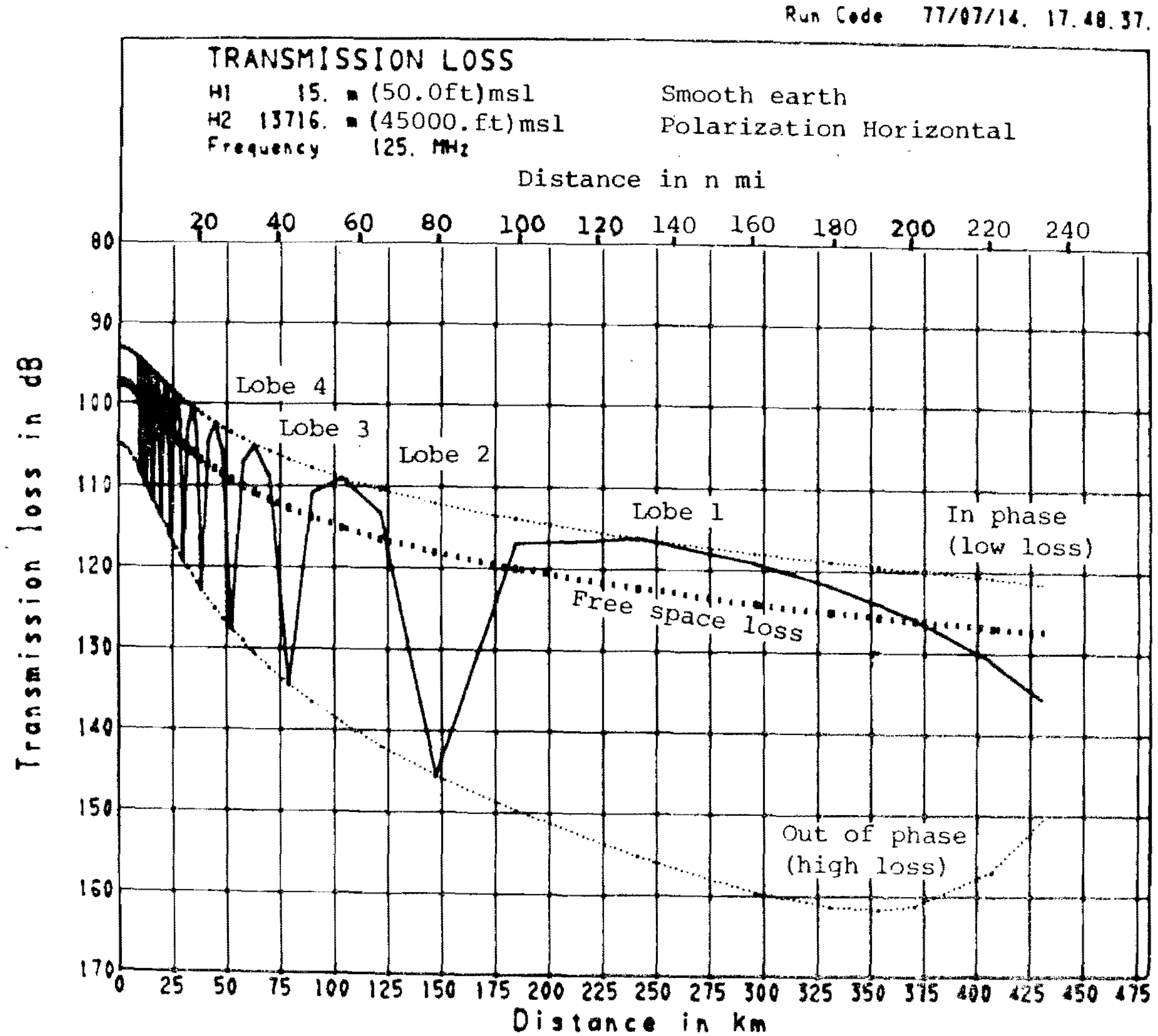


Figure 6. *Lobing, ATC. Transmission loss for the first ten lobes inside the radio horizon, limiting values associated with in and out of phase conditions and free-space loss vs. path distance are shown. These curves were computed for the parameters of figure 1.*

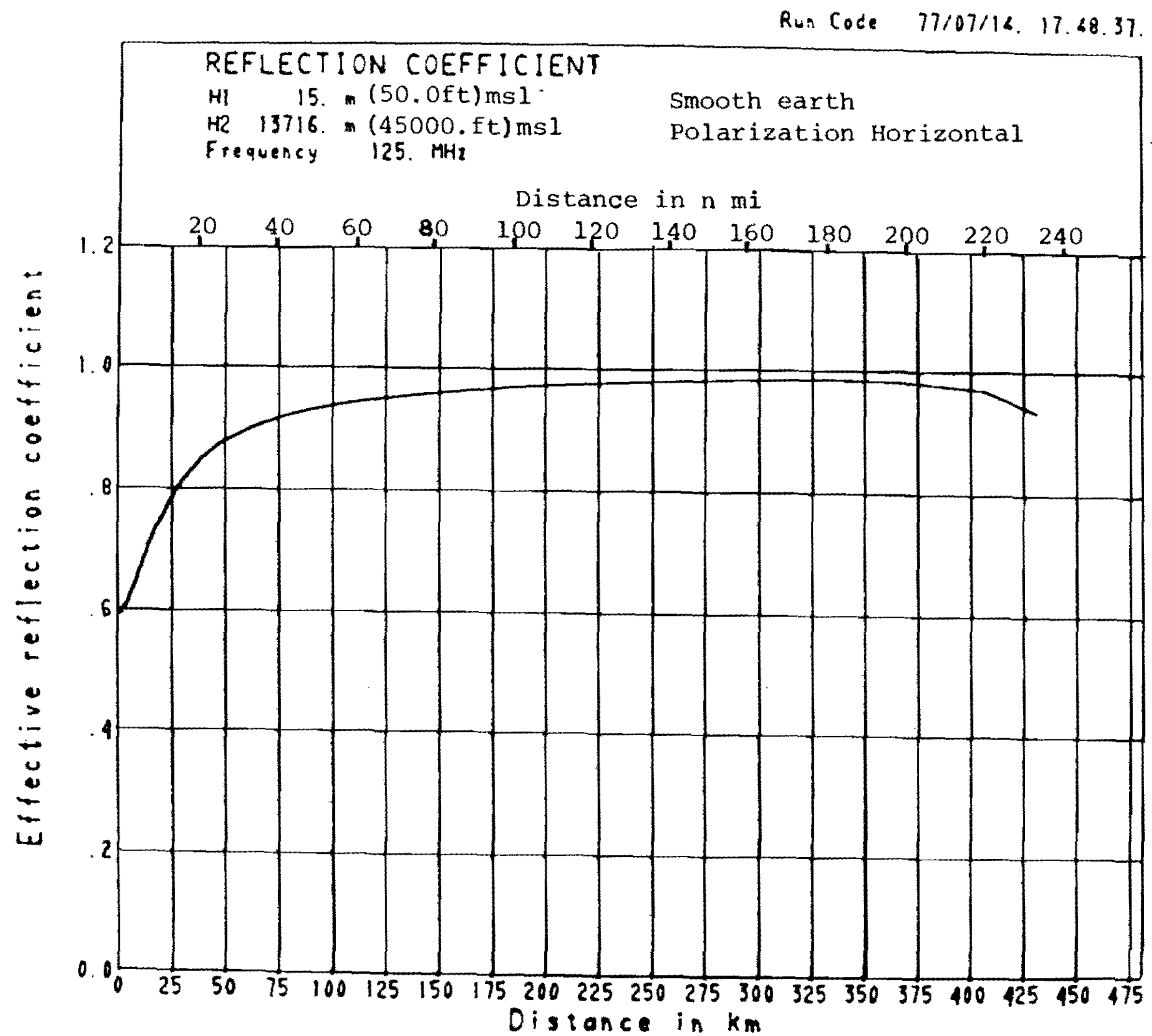


Figure 7. Reflection coefficient, ATC. Effective reflection coefficient vs. path distance is shown for the parameters of figure 1.

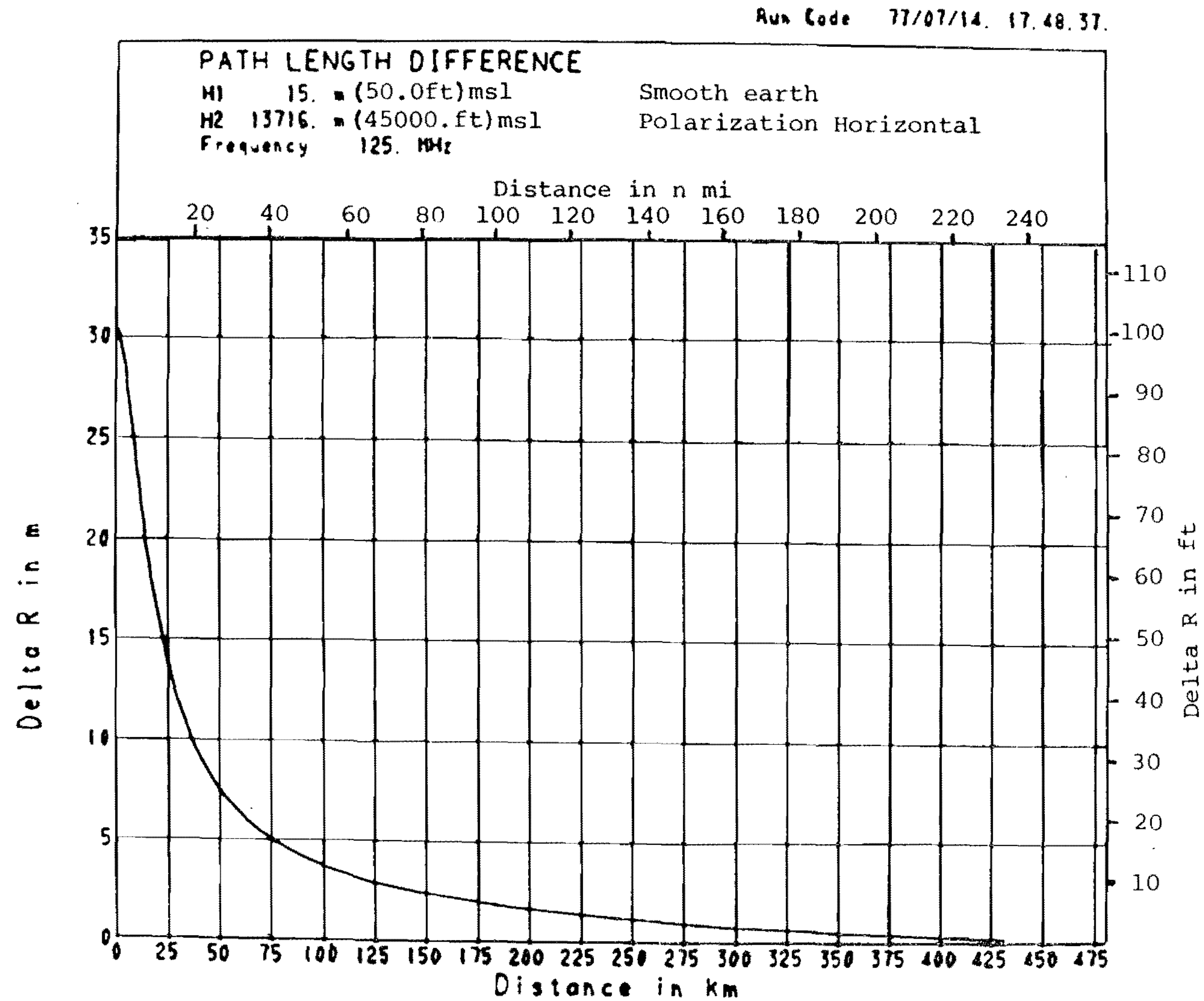


Figure 8. Path length difference, ATC. Path length difference or the extent by which the length of the reflected ray exceeds that of the direct ray vs. path distance is shown for the parameters of figure 1.

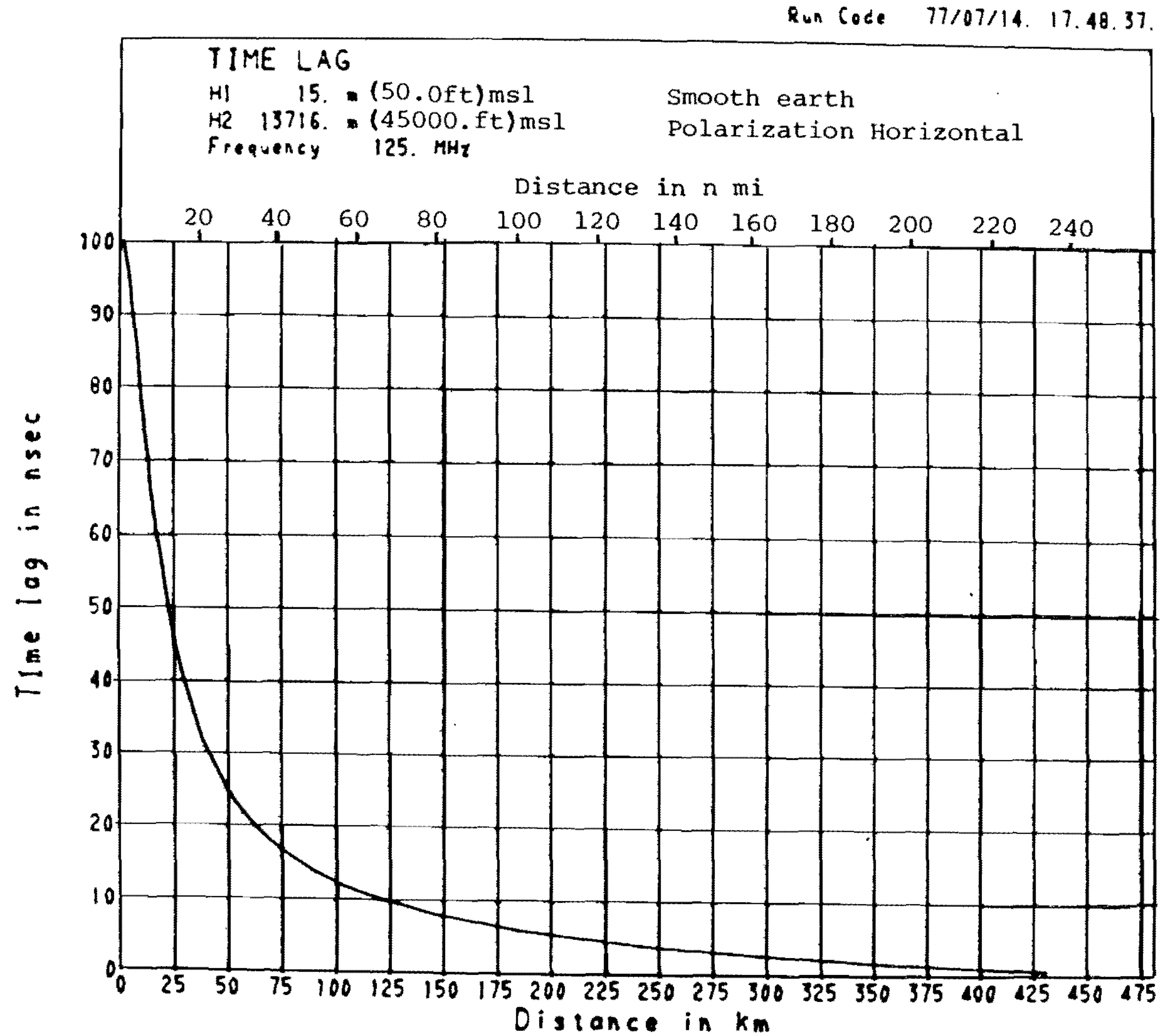


Figure 9. Time lag, ATC. Time lag of transmission via the surface reflection path relative to the direct path vs. path distance is shown for the parameters of figure 1.

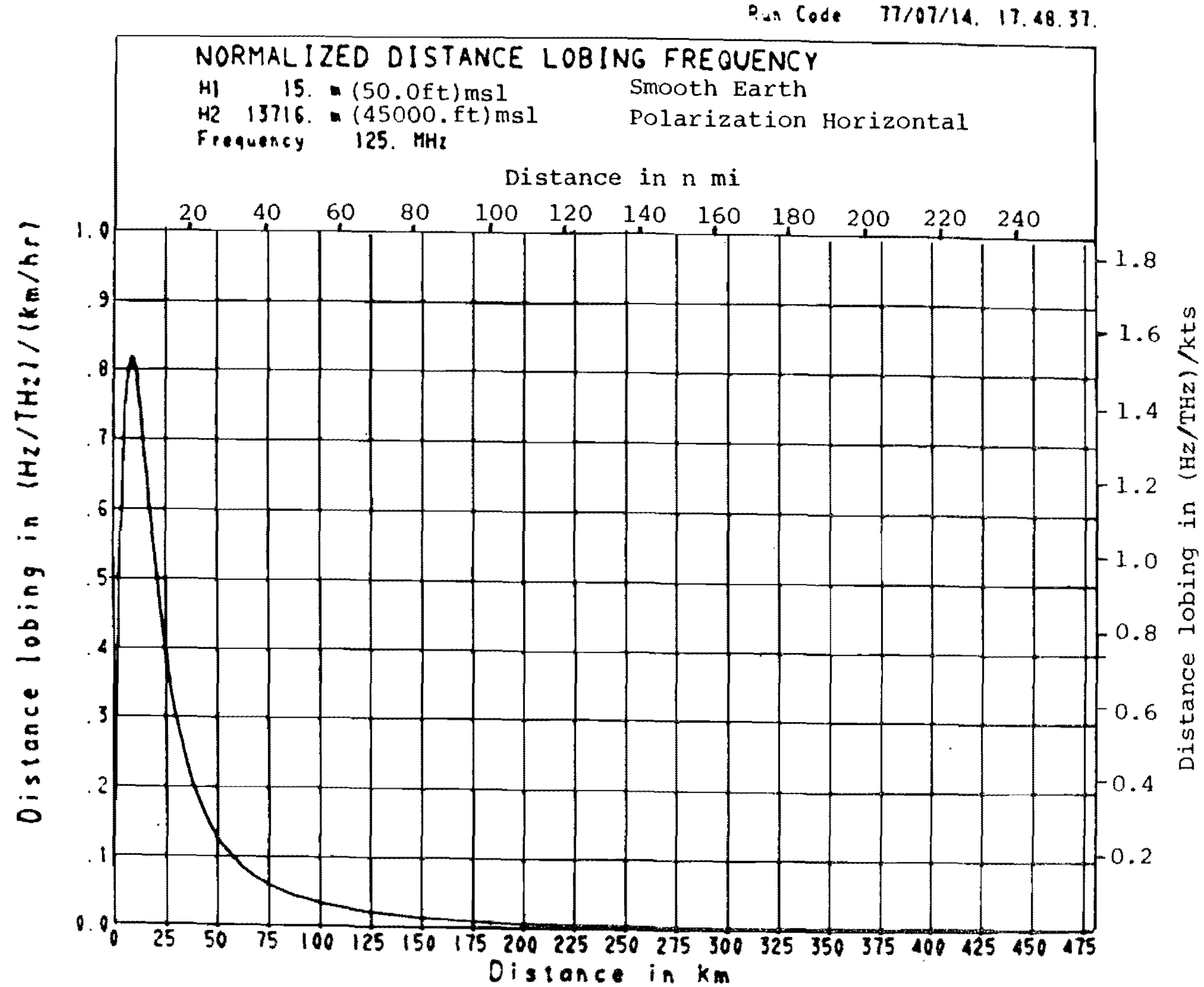


Figure 10. Lobing frequency-D, ATC. Normalized distance lobing frequency, NDLF, vs. path distance is shown for the parameters of figure 1.

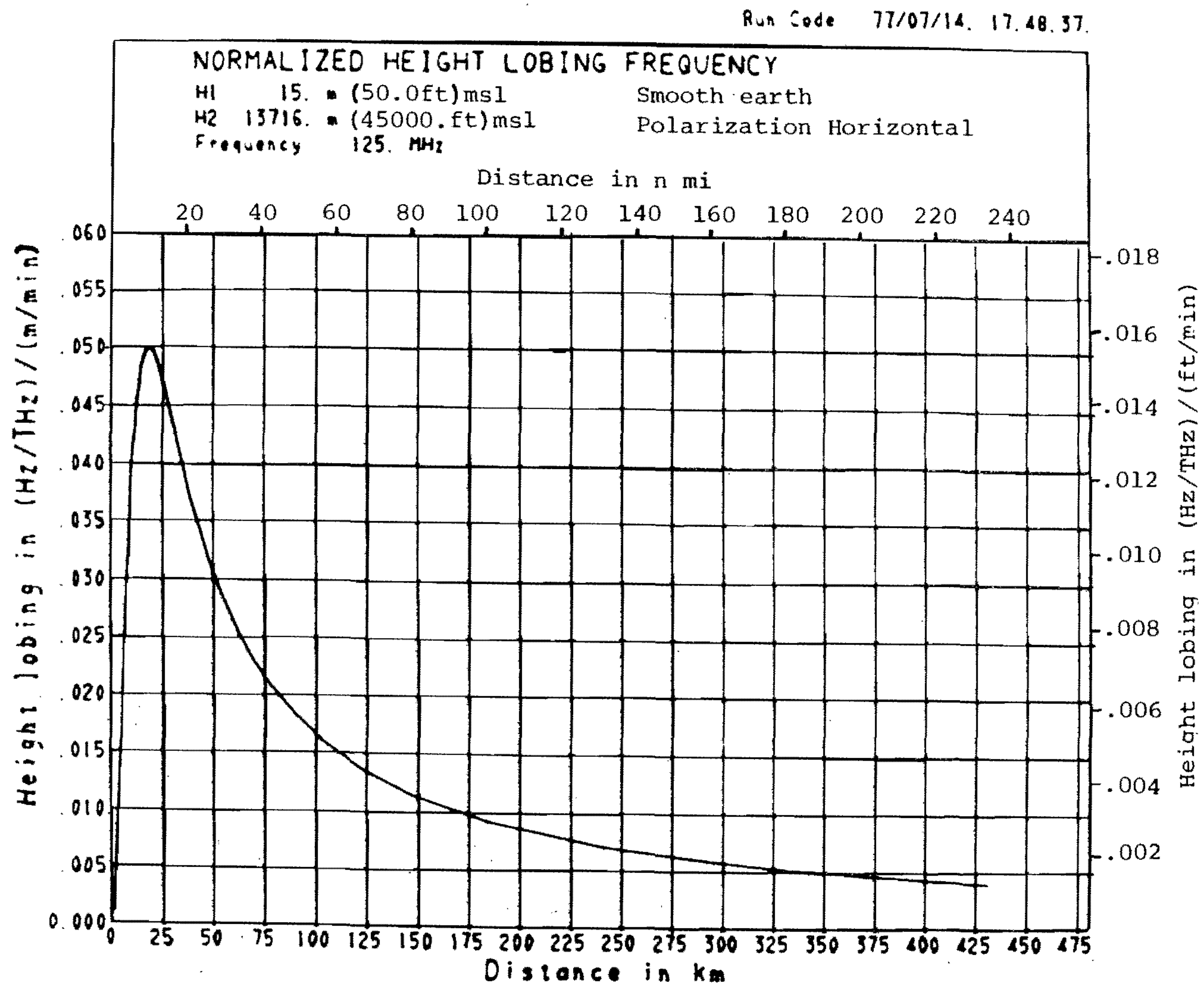


Figure 11. Lobing frequency-H, ATC. Normalized height lobing frequency, NHLF, vs. path distance is shown for the parameters of figure 1.

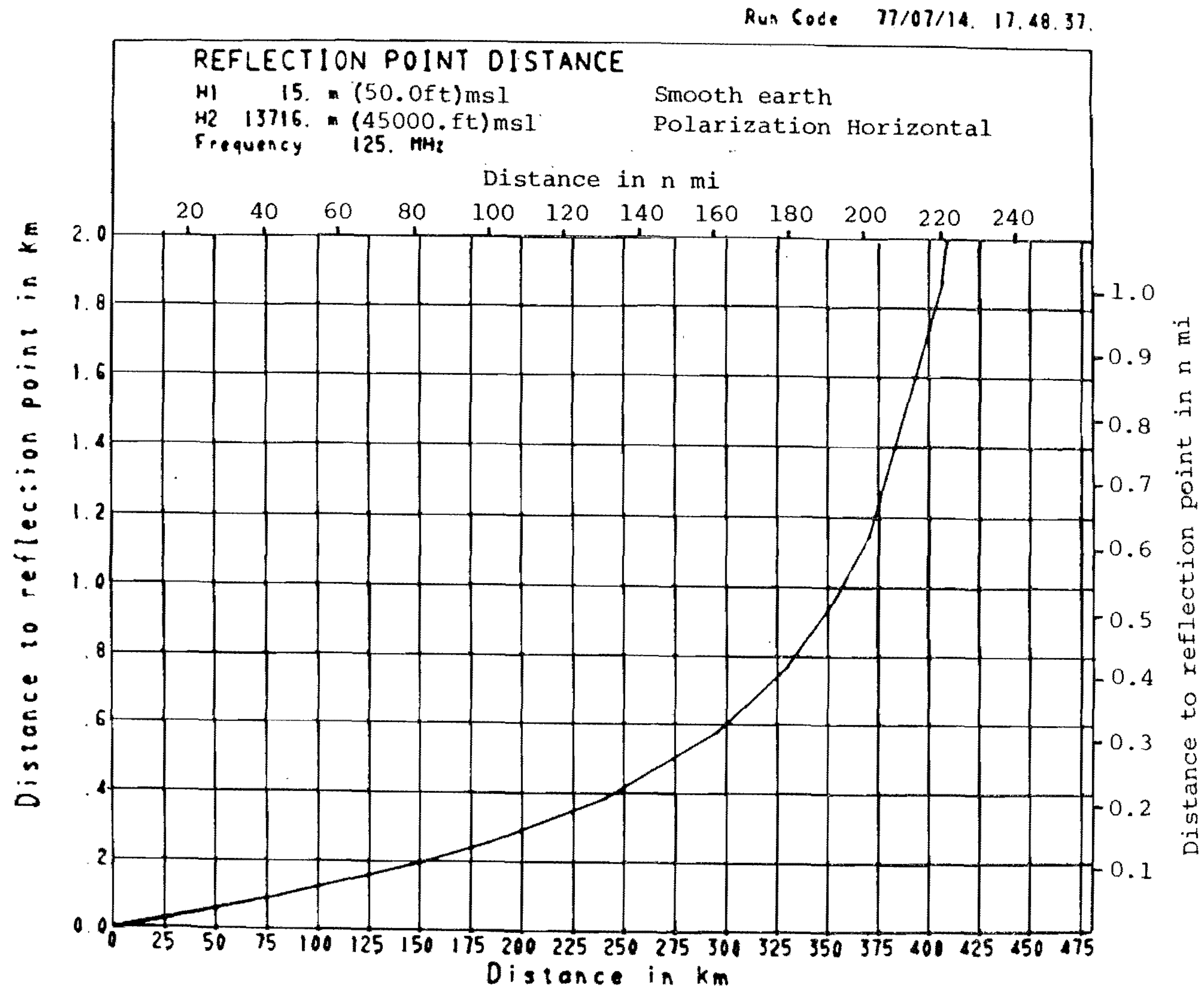


Figure 12. Reflection point, ATC. Distance from facility to reflection point vs. path distance is shown for the parameters of figure 1.

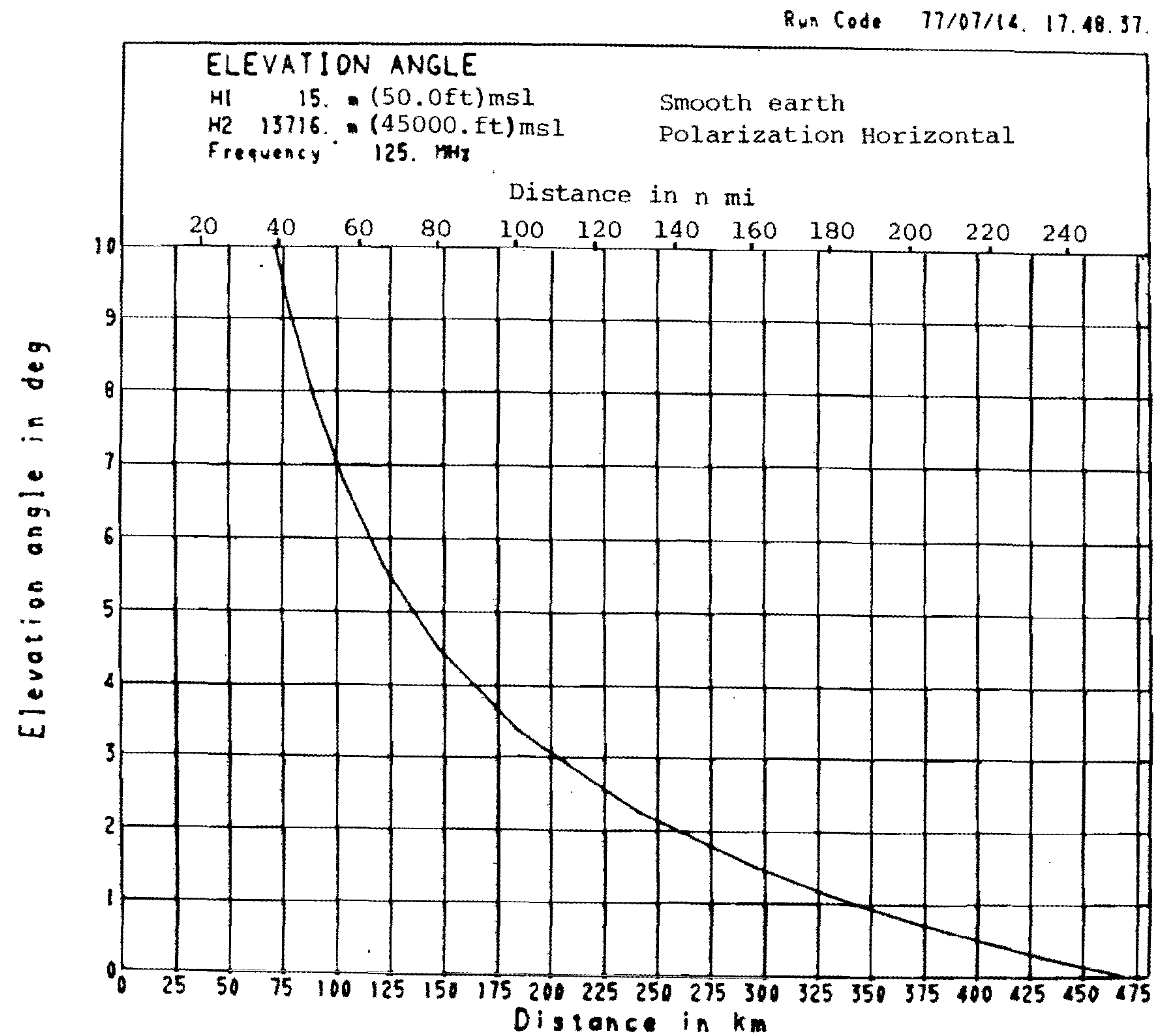


Figure 13. Elevation angle, ATC. Elevation angle of the direct ray at the facility above the horizontal vs. path distance is shown for the parameters of figure 1.

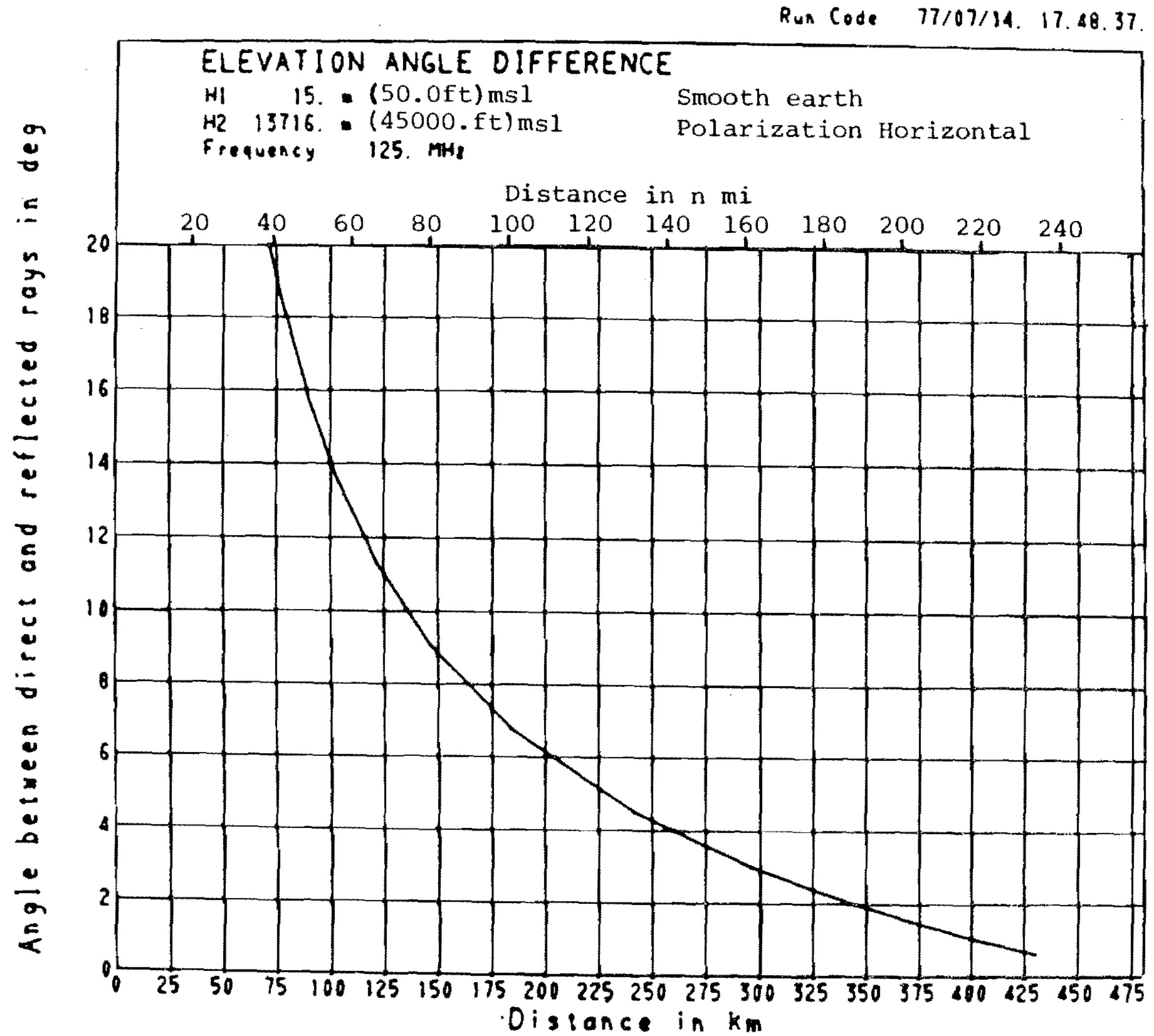


Figure 14. Elevation angle difference, ATC. The amount by which the elevation angle of the direct ray at the facility exceeds that of the reflected ray vs. path distance is shown for the parameters of figure 1.

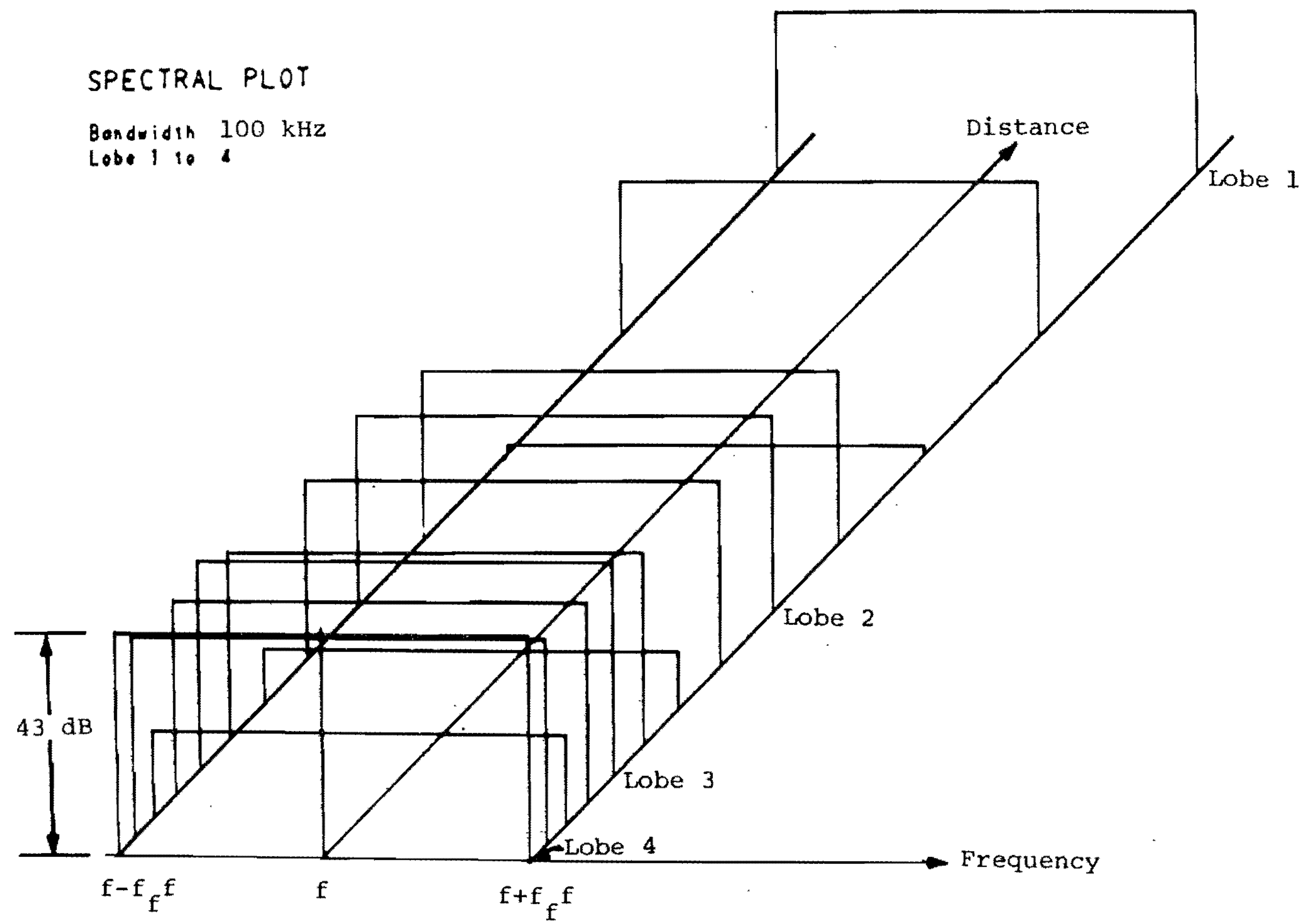


Figure 15. Spectral plot, ATC. Fading across flat spectra with 100 kHz bandwidth for the lobing structure in figure 6 and parameters of figure 1.

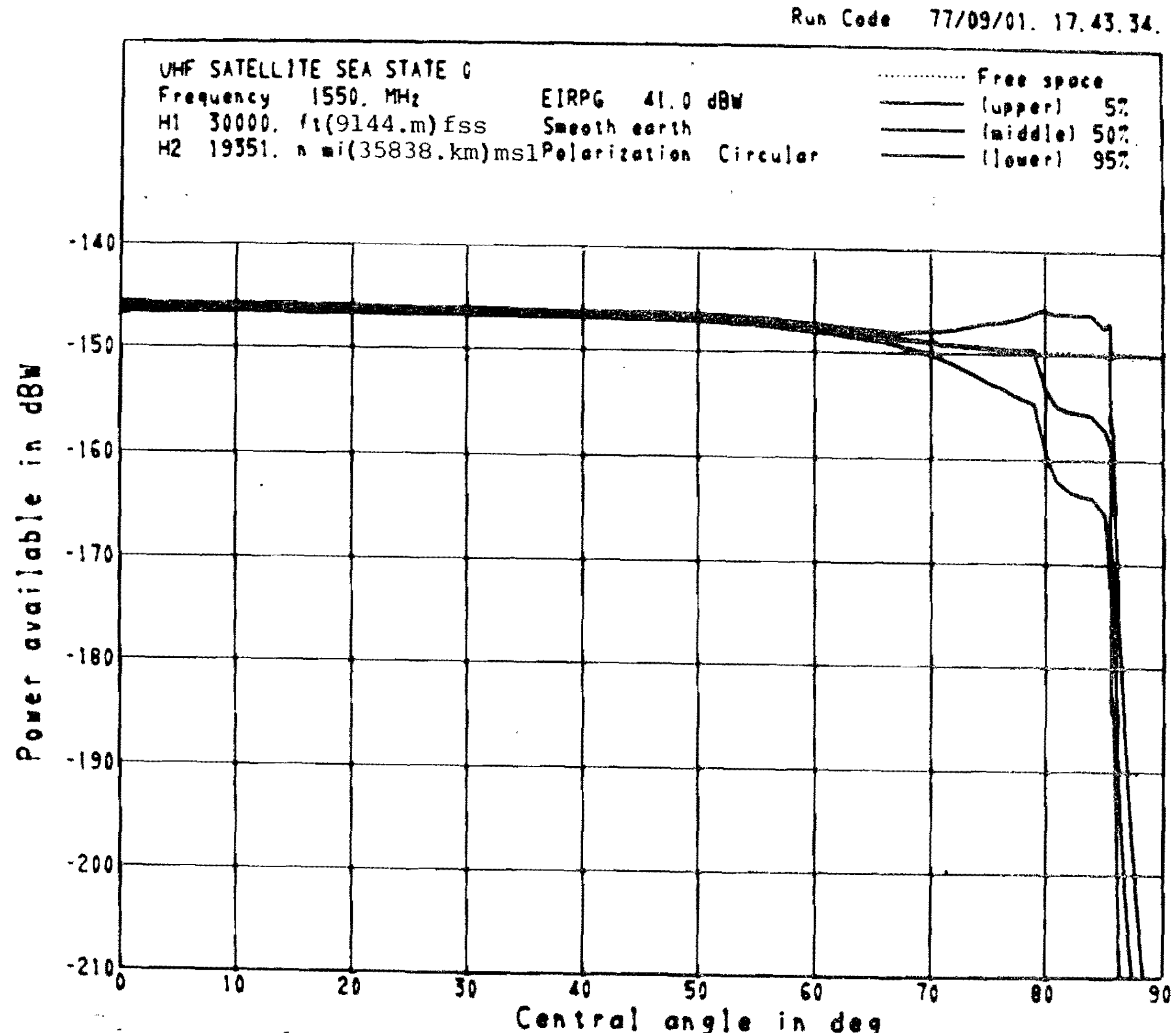


Figure 16. *Power available, UHF satellite for sea state 0. Power available values computed with parameters from figure 3 for time availability of 5, 50, and 95 percent. Central angle (fig. 41) is related to distance by (7) and (8).*

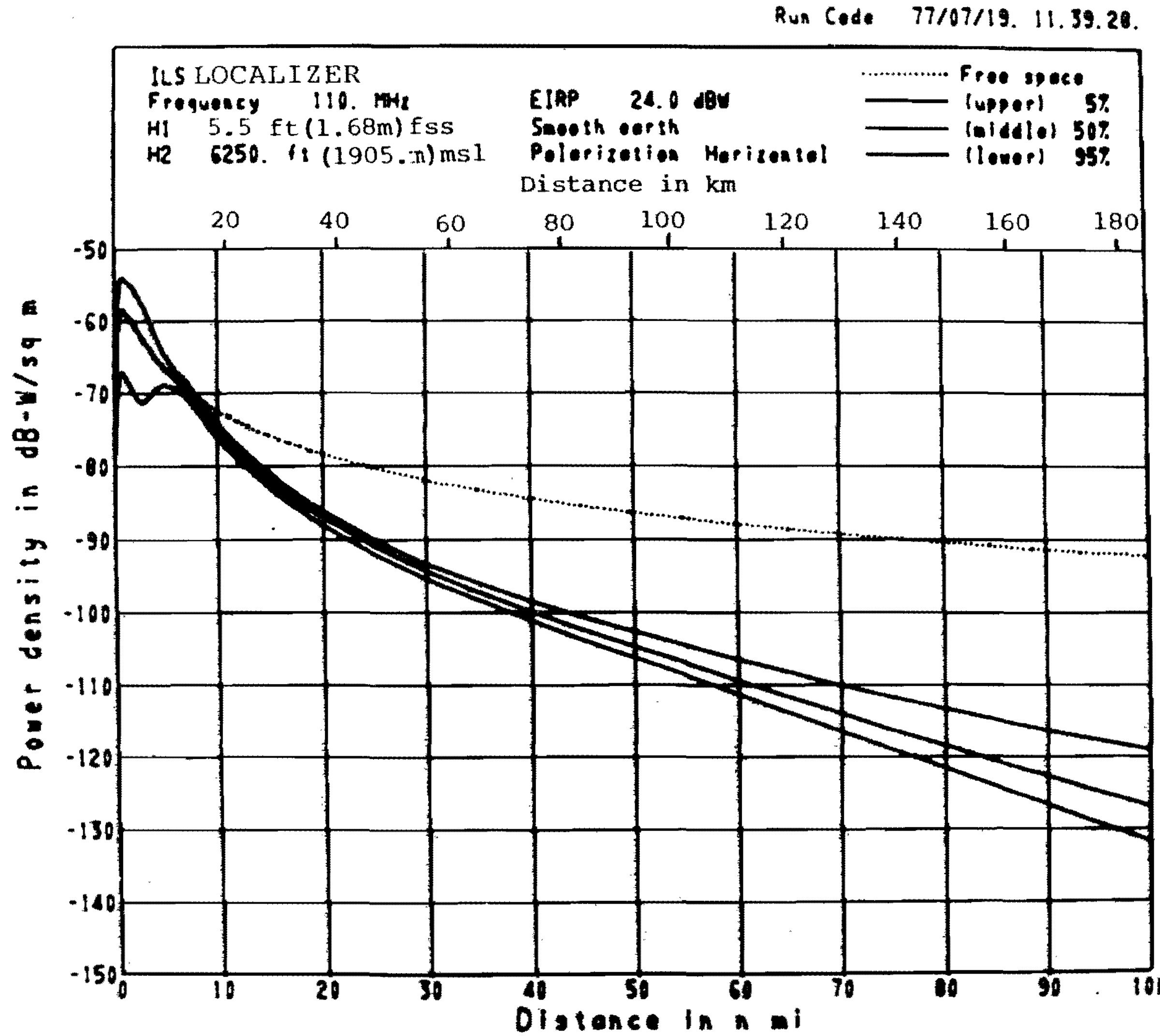


Figure 17. *Power density, ILS. Parameters used in the calculations are summarized in figure 2. This graph predicts power density on the ILS localizer front course. In other directions, the predictions should be adjusted according to the localizer's horizontal antenna pattern.*

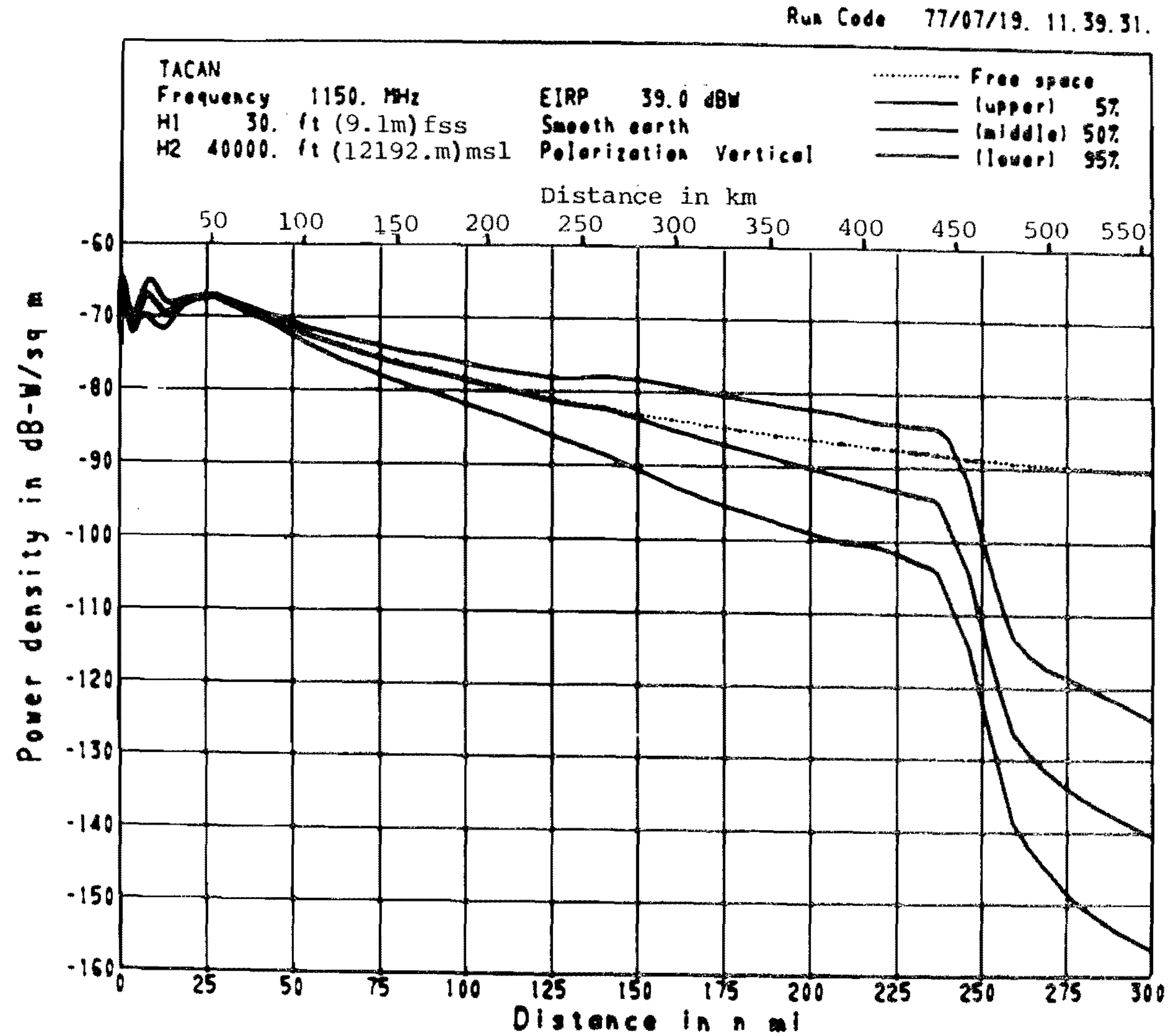


Figure 18. Power density, TACAN. Parameters used in the calculations are summarized in figure 4.

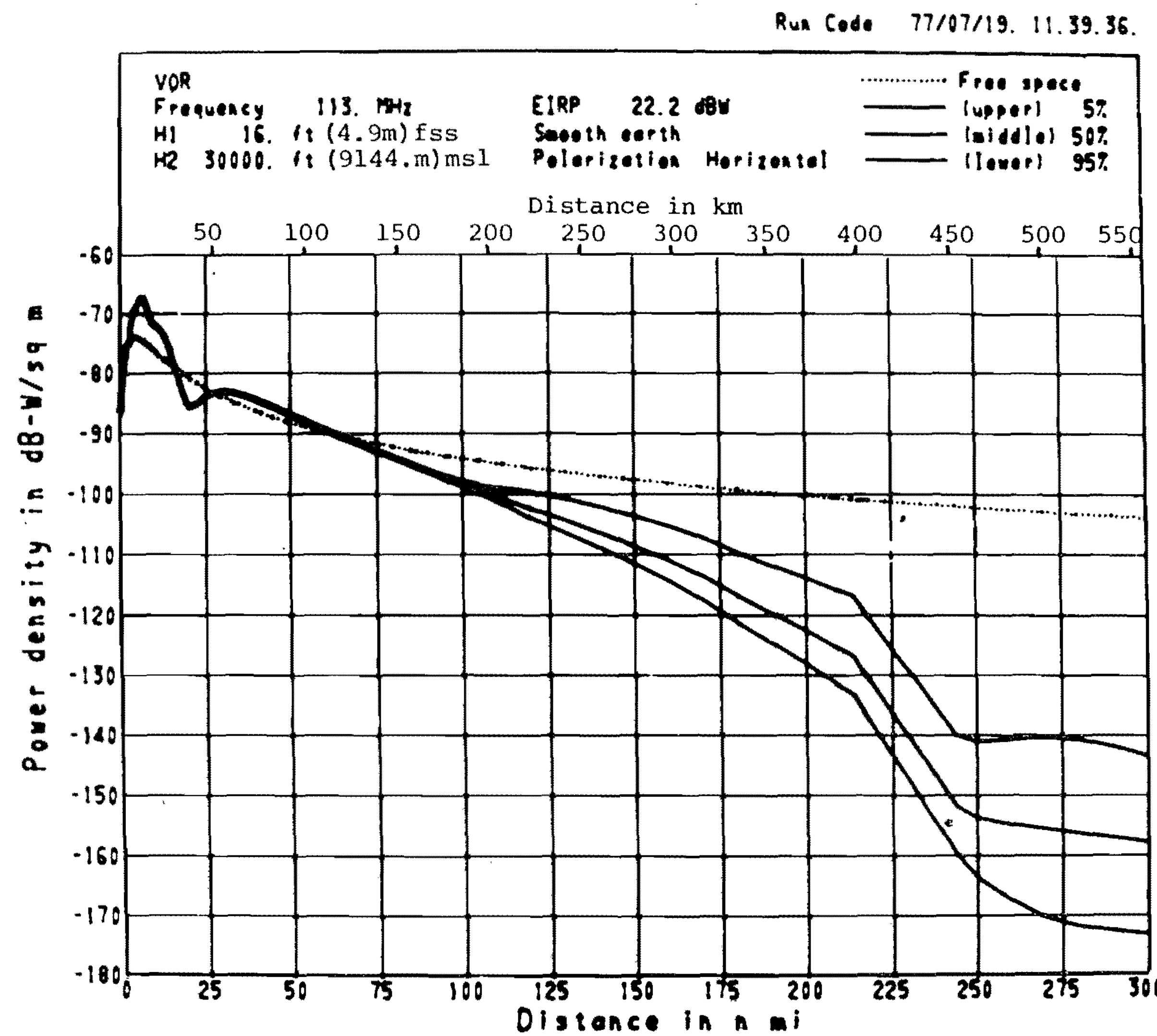


Figure 19. Power density, VOR. Parameters used in the calculations are summarized in figure 5.

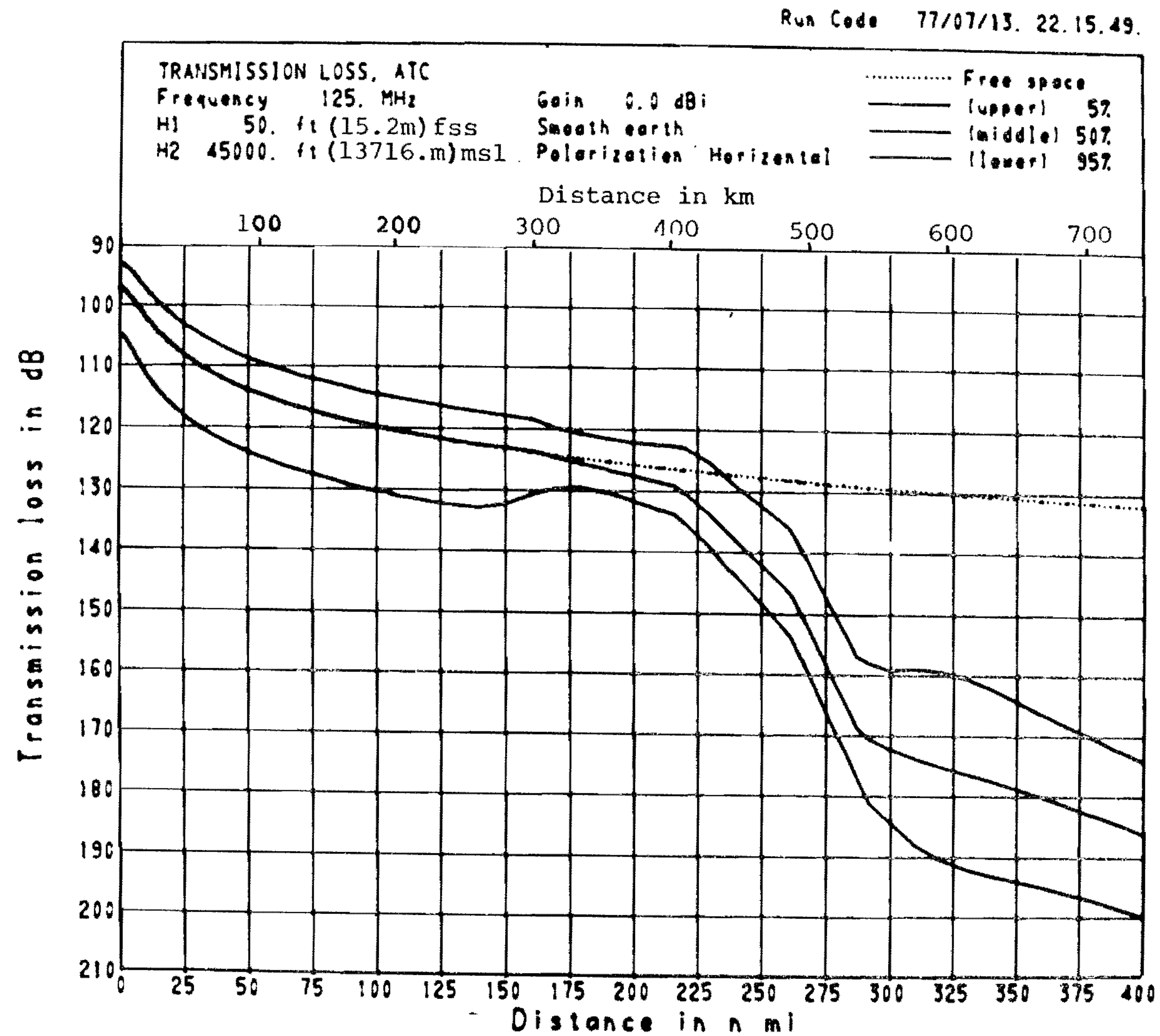


Figure 20. Transmission loss, ATC. Transmission loss values computed with parameters in figure 1 for time availability of 5, 50, and 95 percent.

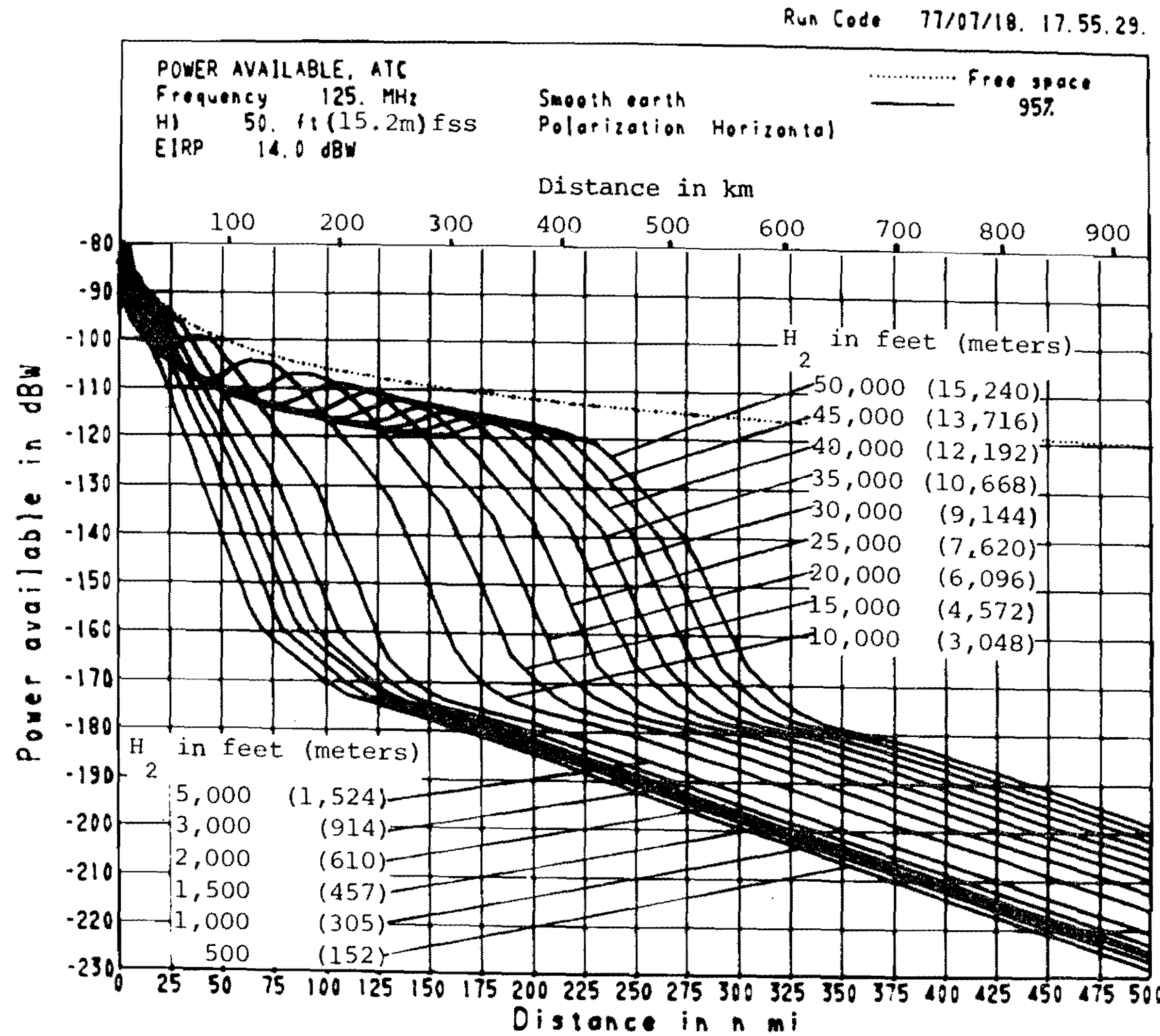


Figure 21. Power available curves, ATC. Power available curves were computed with parameters from figure 1.

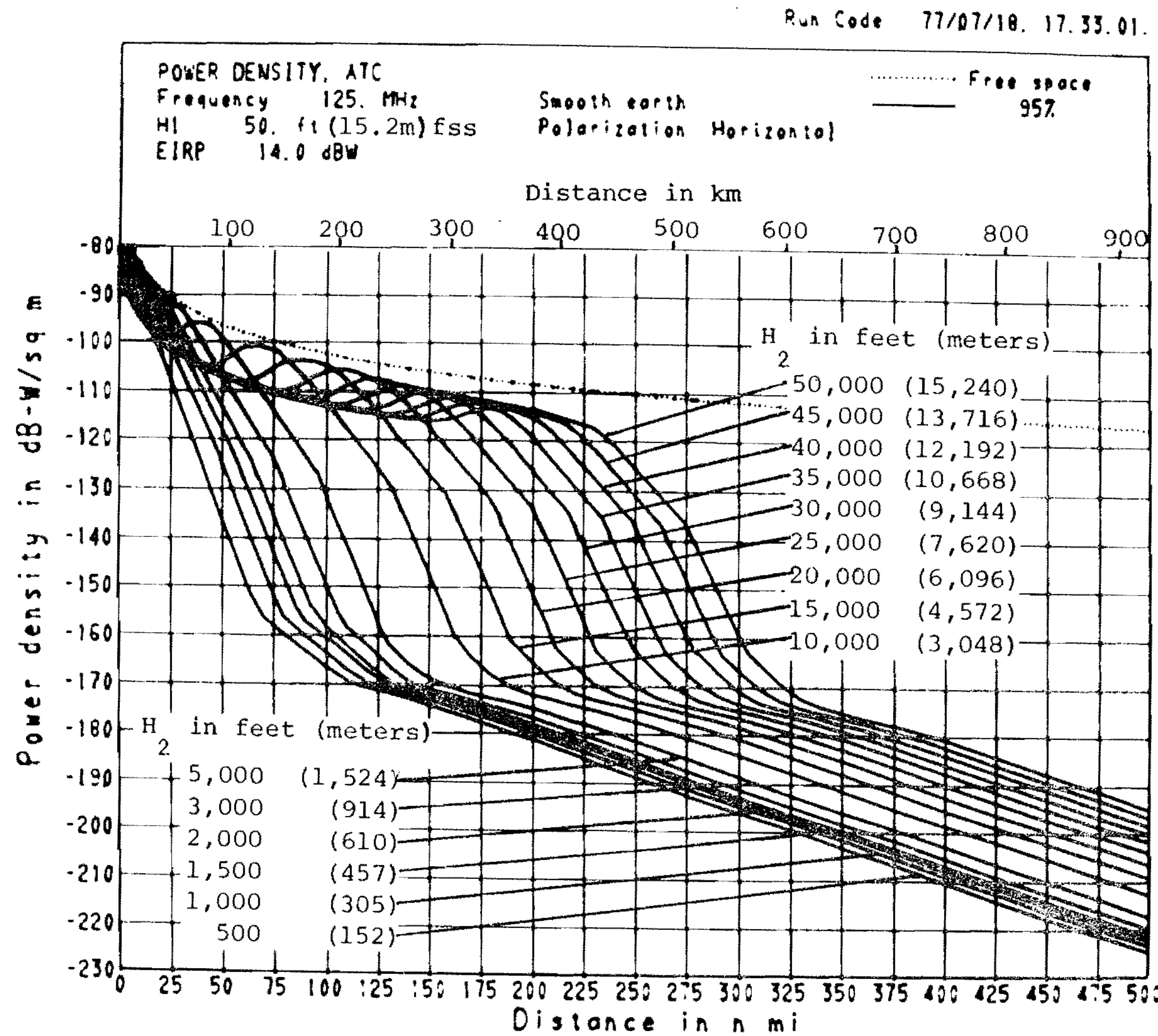


Figure 22. Power density curves, ATC. Power density curves were computed with parameters from figure 1.

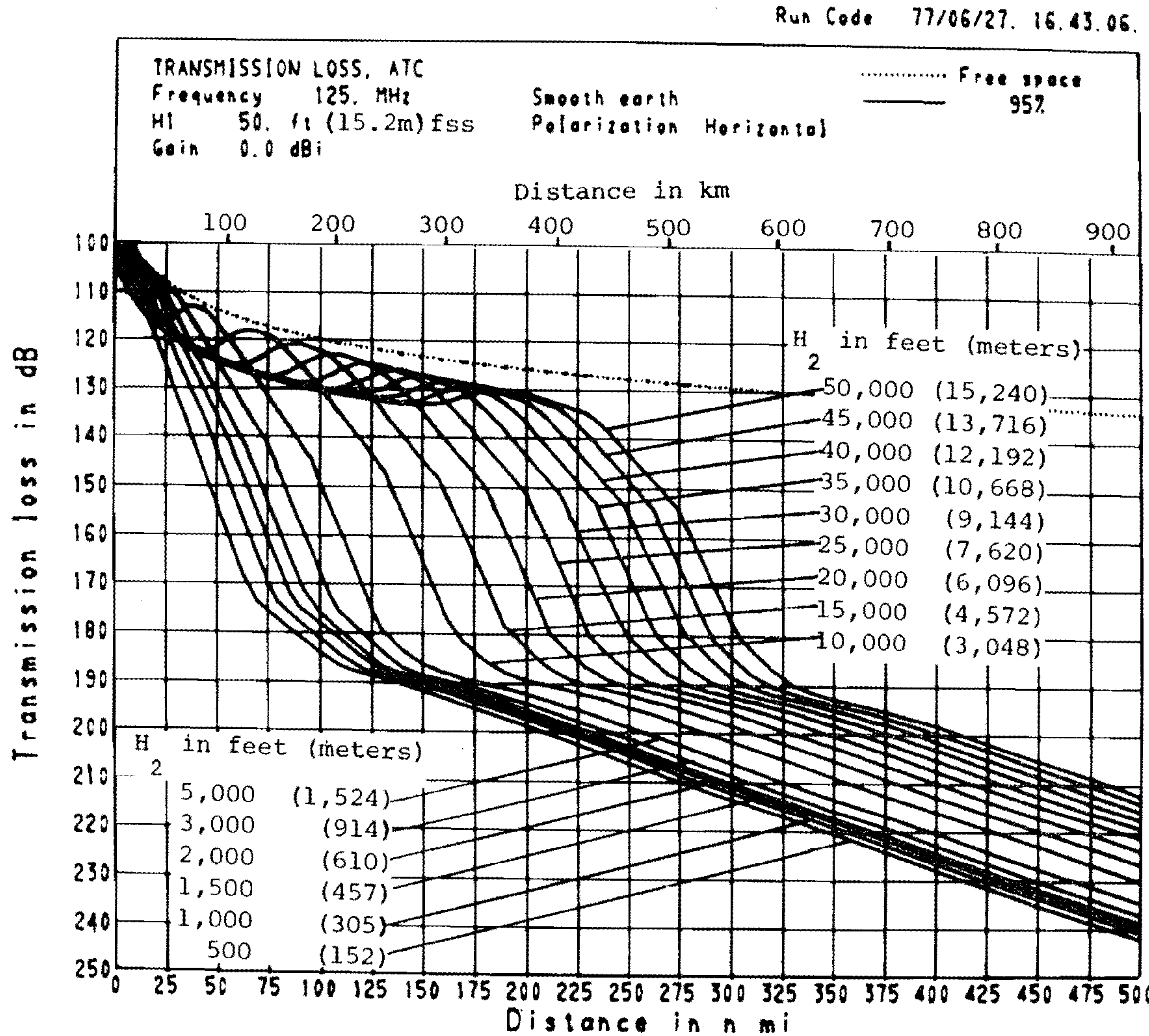


Figure 23. Transmission loss curves, ATC. Transmission loss curves were computed with parameters from figure 1.

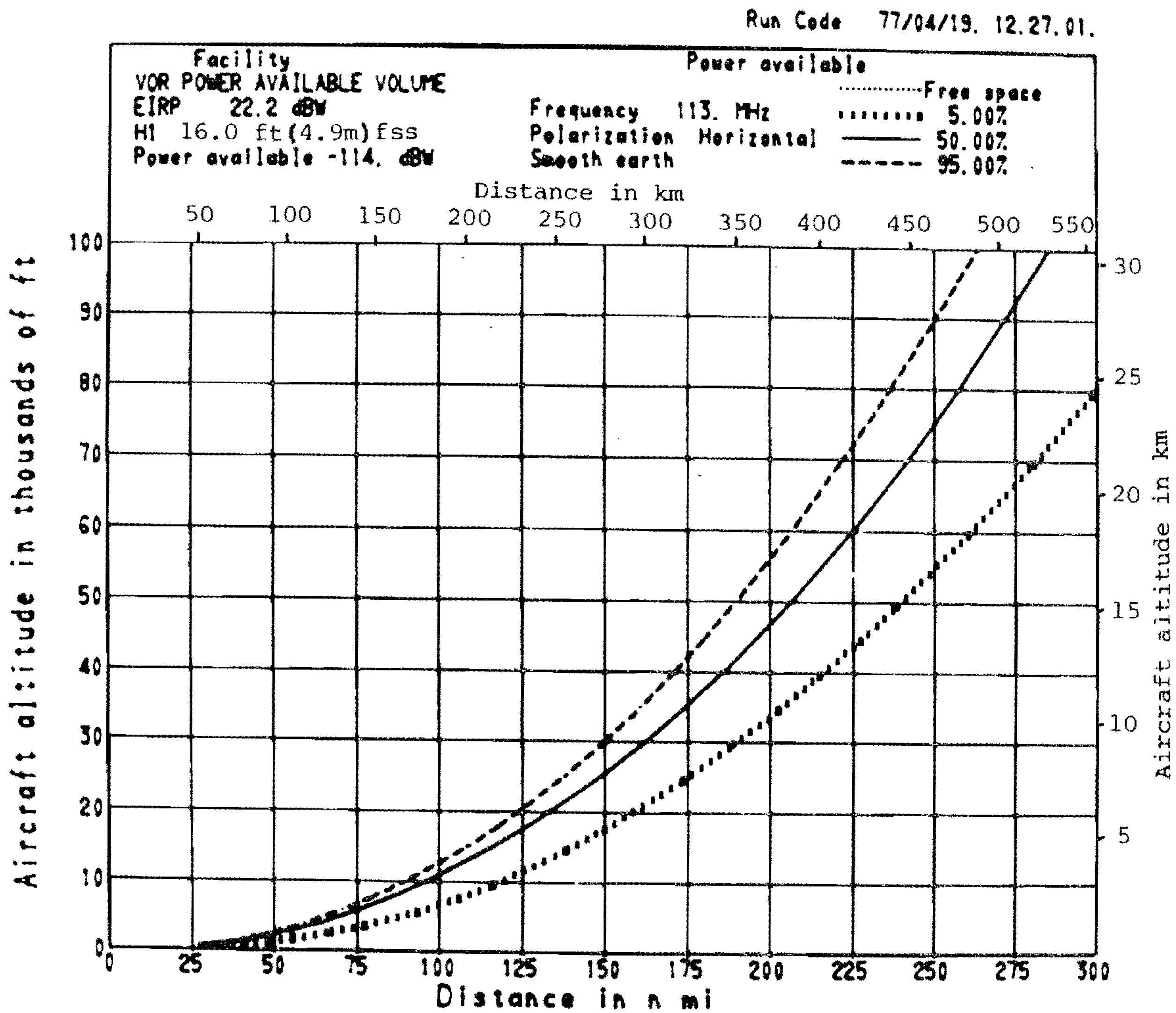


Figure 24. Power available volume, VOR. Power available volume for a single power available for 5, 50, and 95 percent time availability using the parameters in figure 5.

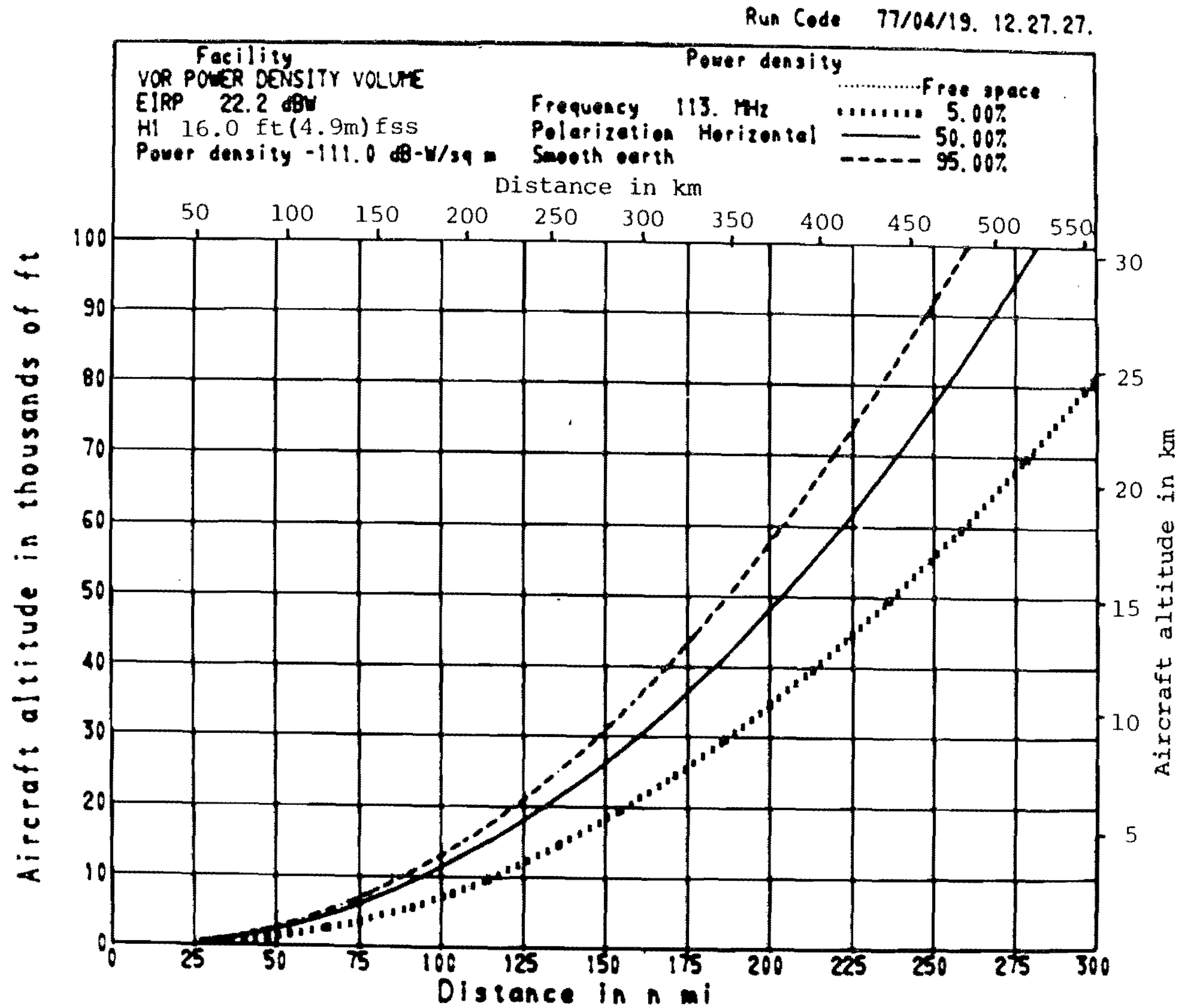


Figure 25. Power density volume, VOR. Power density volume for a single power density value for 5, 50, and 95 percent time availability using the parameters in figure 5.

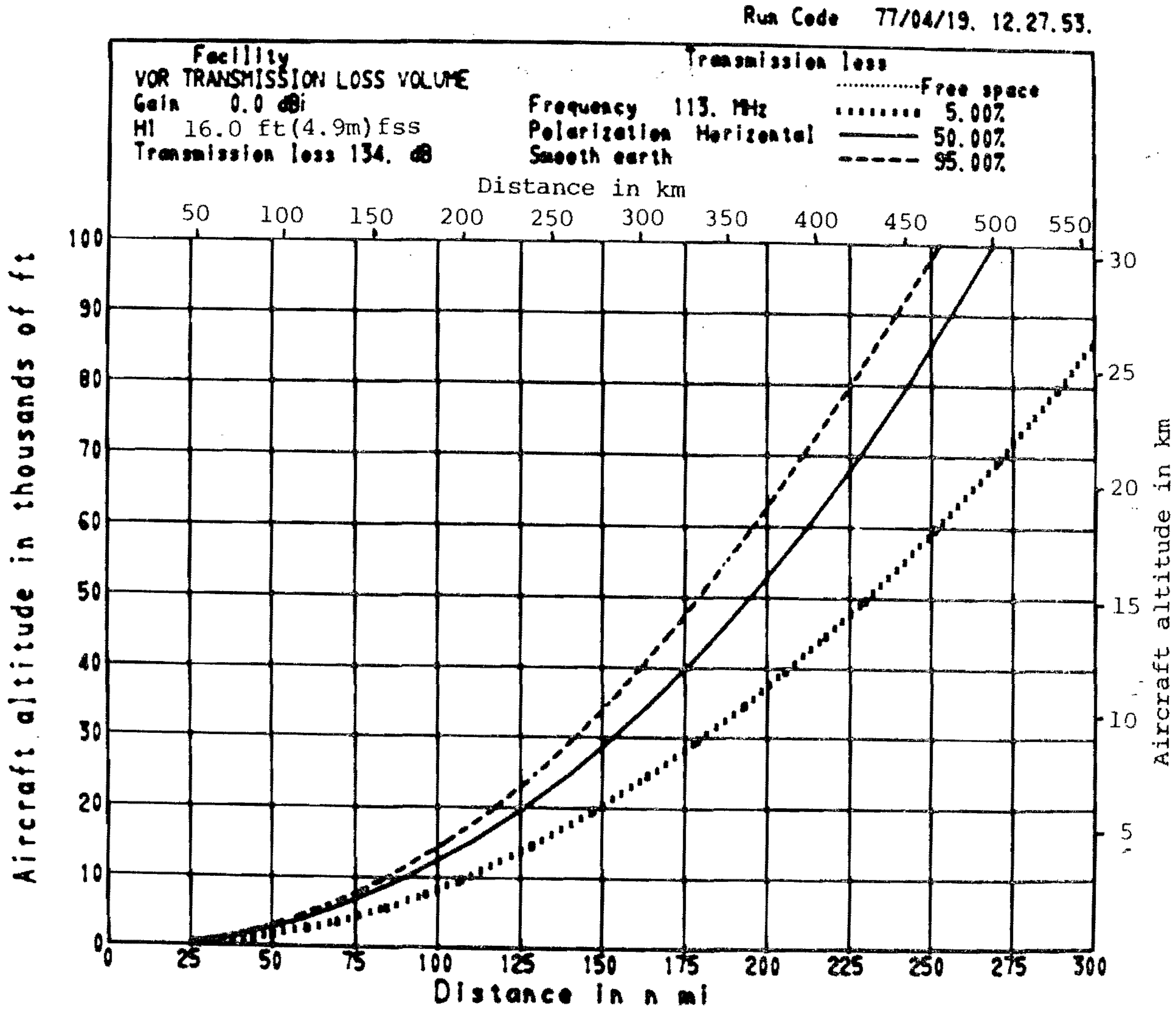


Figure 26. Transmission loss volume, VOR. Transmission loss volume for a single transmission loss value for 5, 50, and 95 percent time availability using the parameters in figure 5.

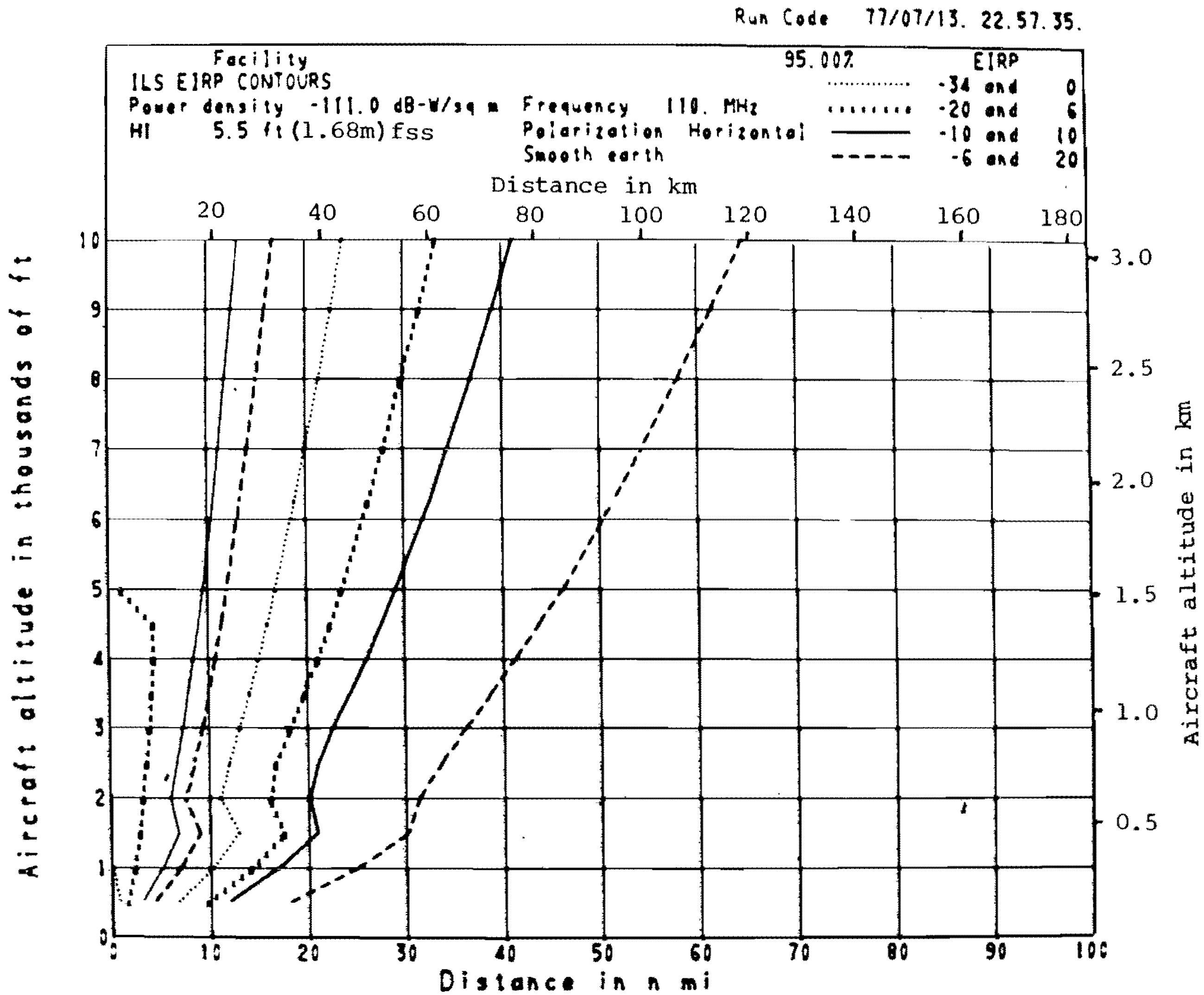


Figure 27. EIRP contours, ILS. EIRP contours are shown in the altitude vs. distance plane for a 95% time availability and the parameters of figure 2.

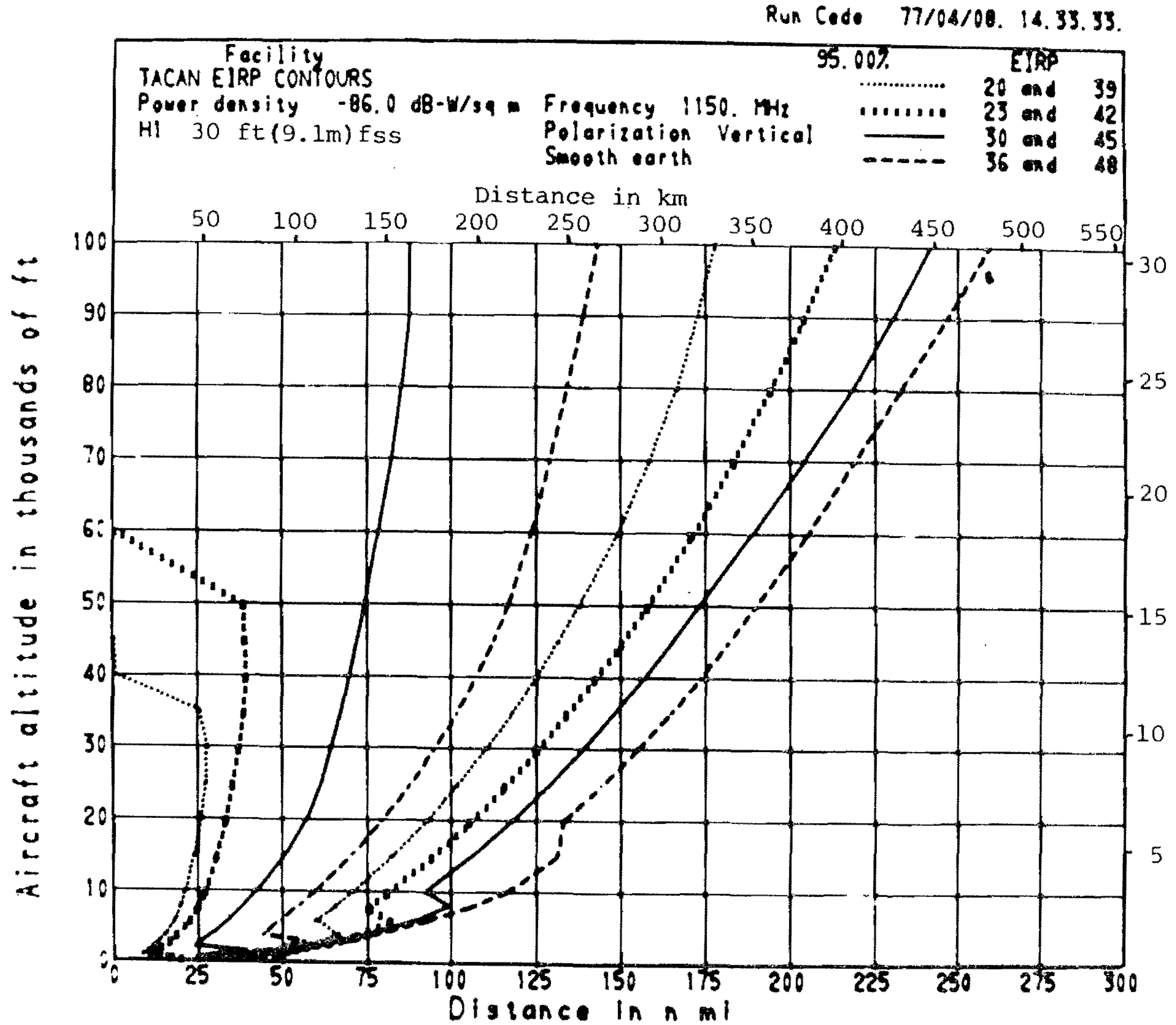


Figure 28. EIRP contours, TACAN. EIRP contours are shown in the altitude vs. distance plane for a 95% time availability and the parameters of figure 4.

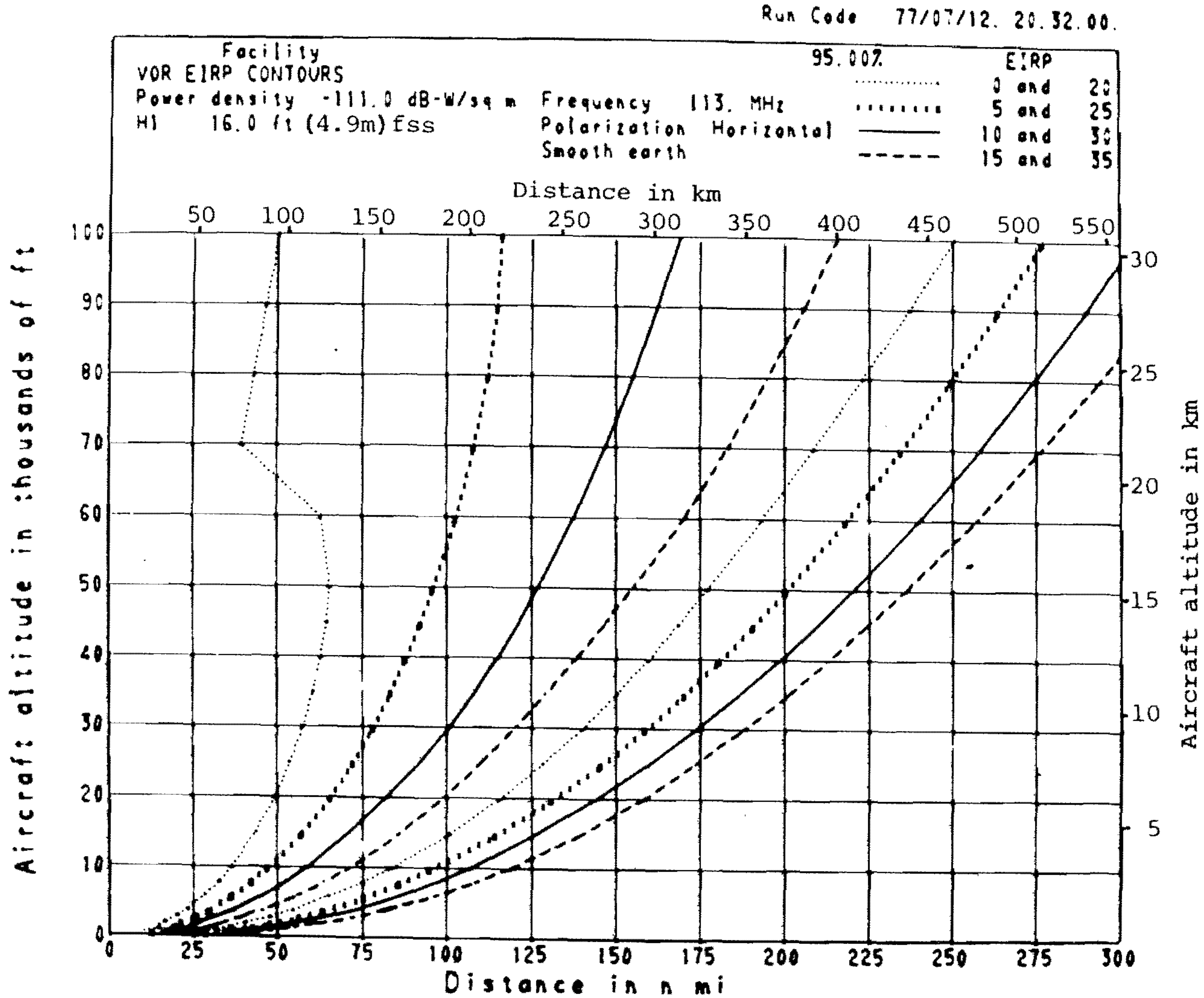


Figure 29. EIRP contours, VOR. EIRP contours are shown in the altitude vs. distance plane for a 95% time availability and the parameters of figure 5.

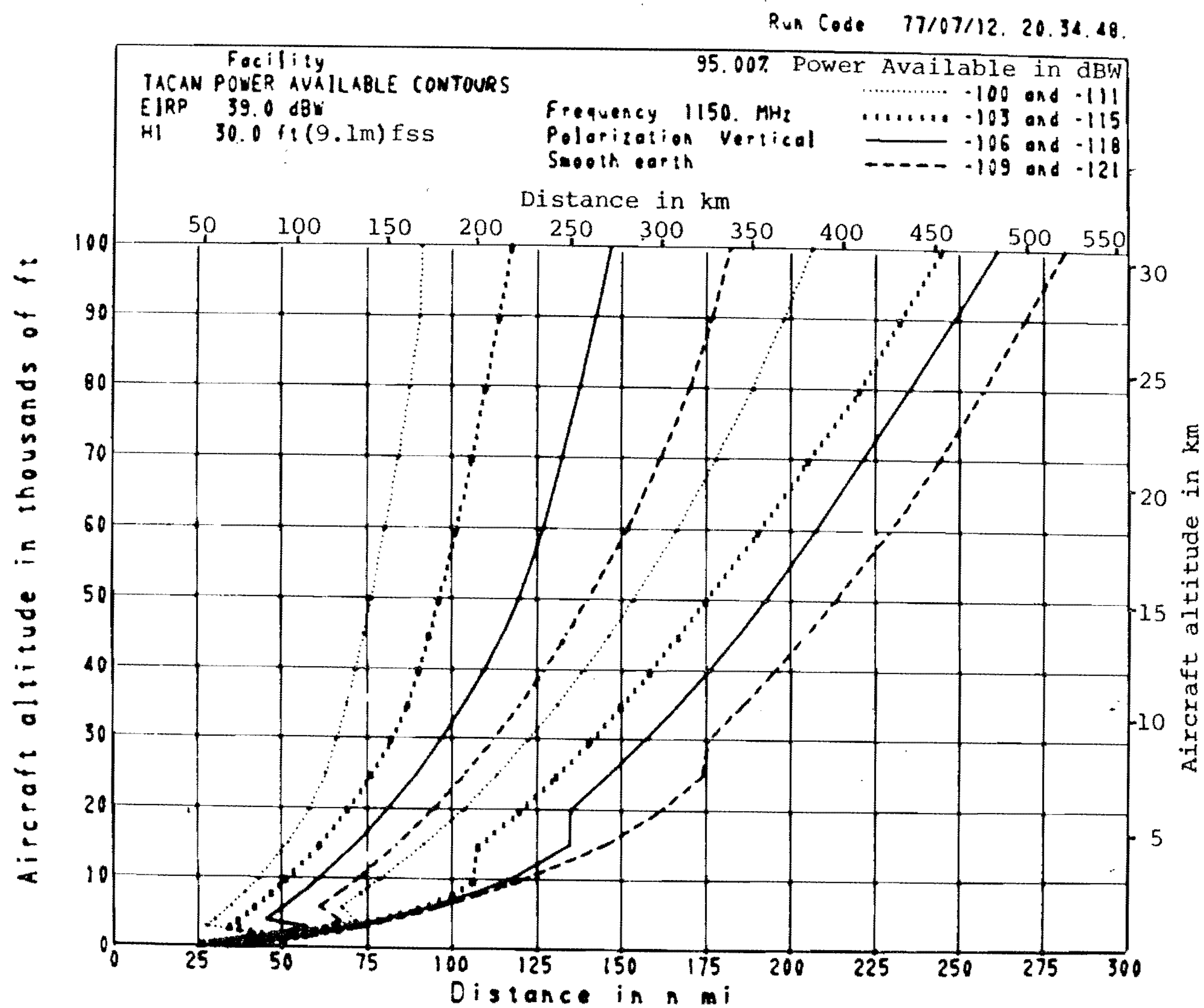


Figure 30. *Power available contours, TACAN. Power available contours are shown in the altitude vs. distance plane for a 95% time availability and the parameters of figure 4.*

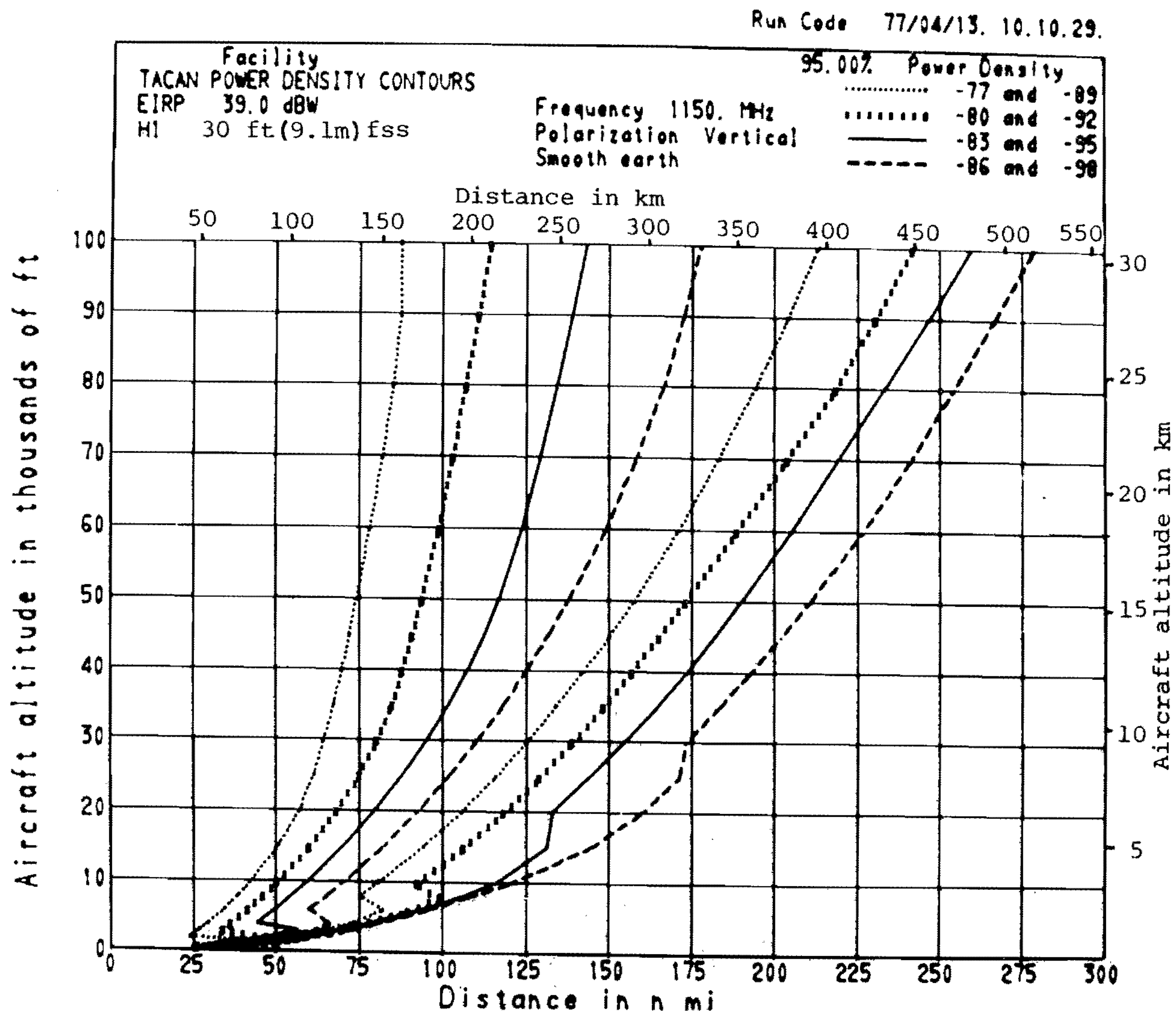


Figure 31. Power density contours, TACAN. Power density contours are shown in the altitude vs. distance plane for a 95% time availability and the parameters of figure 4.

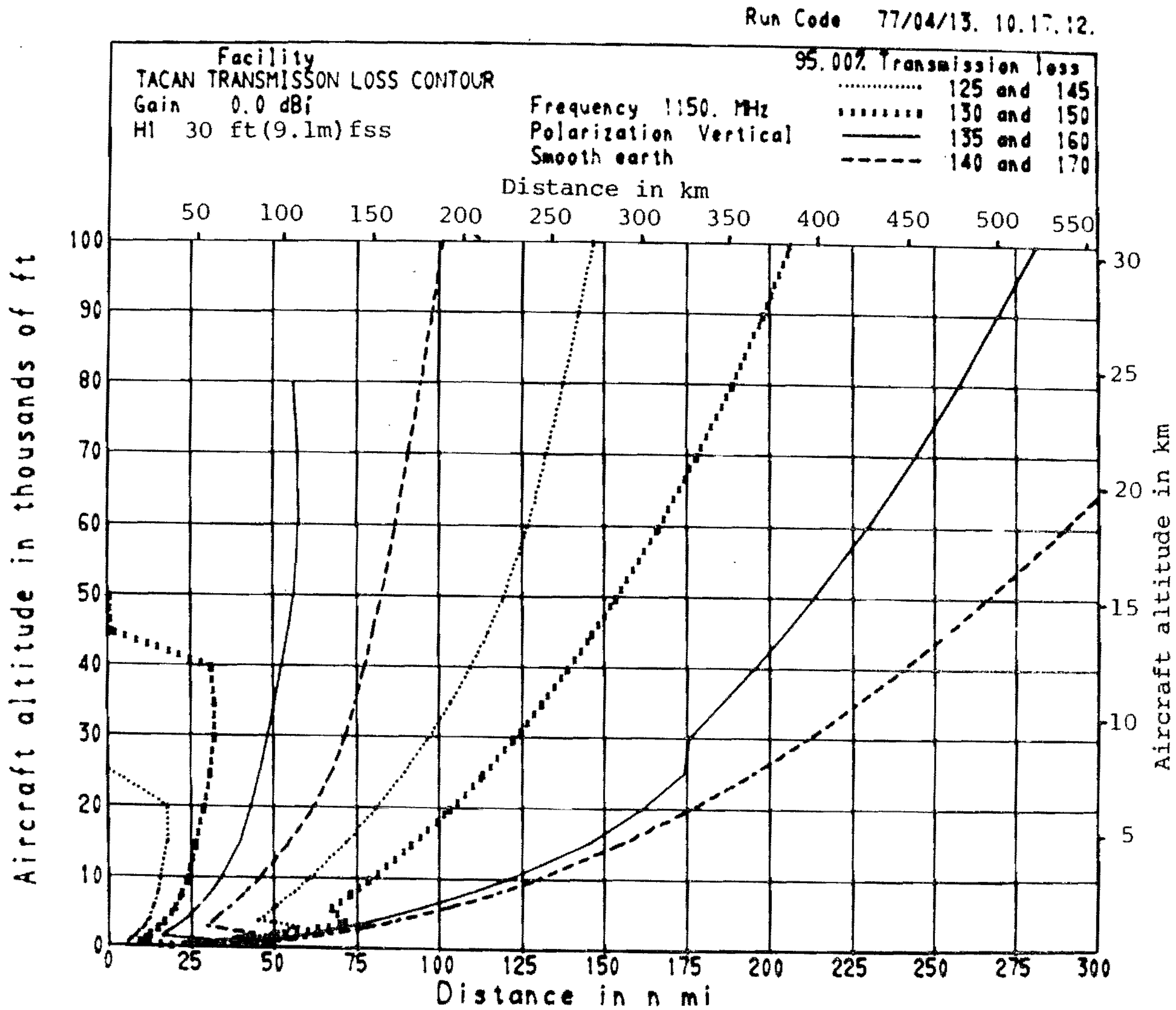


Figure 32. Transmission loss contours, TACAN. Transmission contours are shown in the altitude vs. distance plane for a 95% time availability, and the parameters of figure 4.

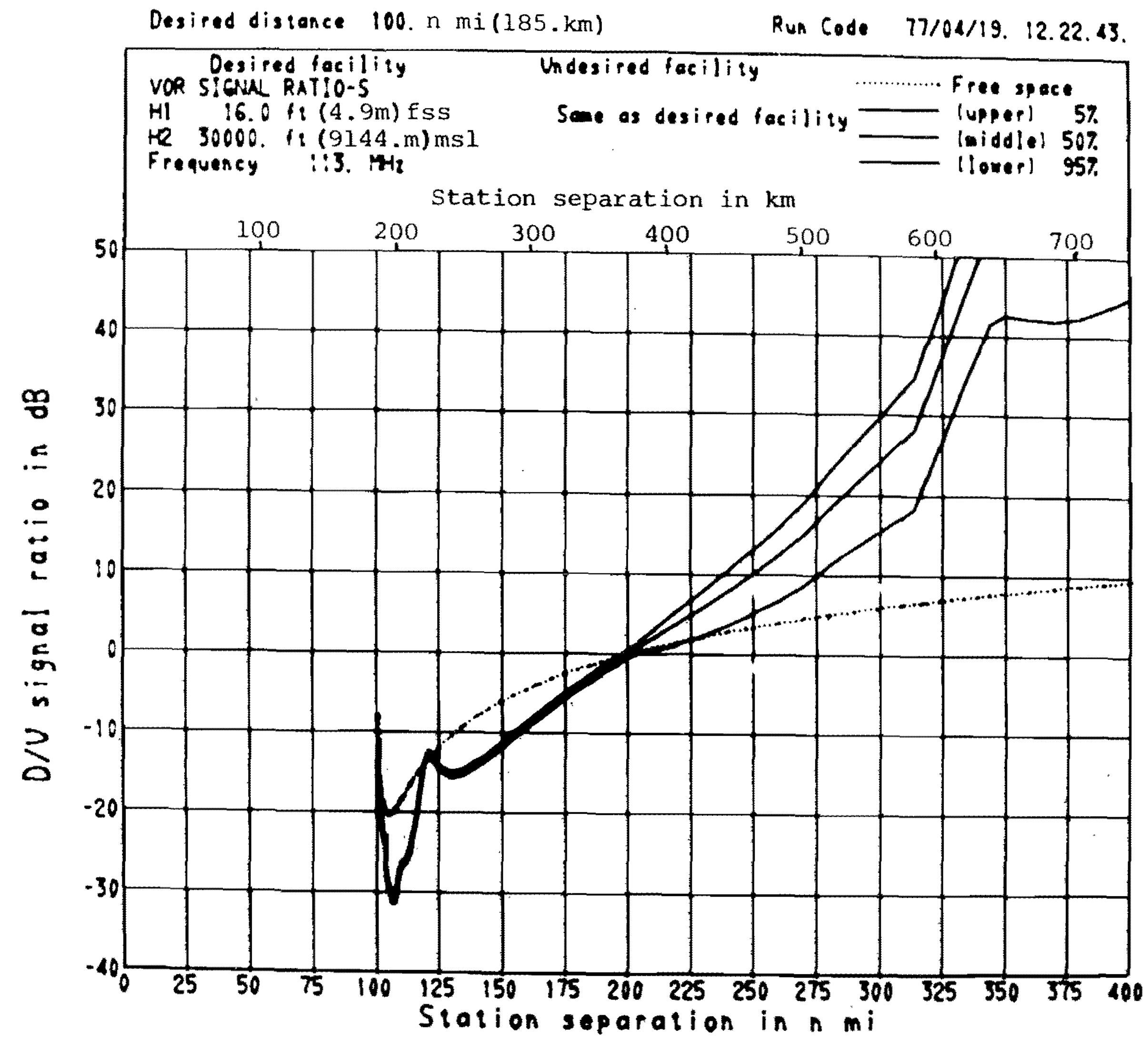


Figure 33. Signal ratio-S, VOR. Desired-to-undesired, D/U, signal ratio versus station separation curves are shown for a fixed desired facility-to-receiver distance and time availabilities of 5, 50, and 95 percent. Both the desired and undesired stations have the parameters of figure 5.

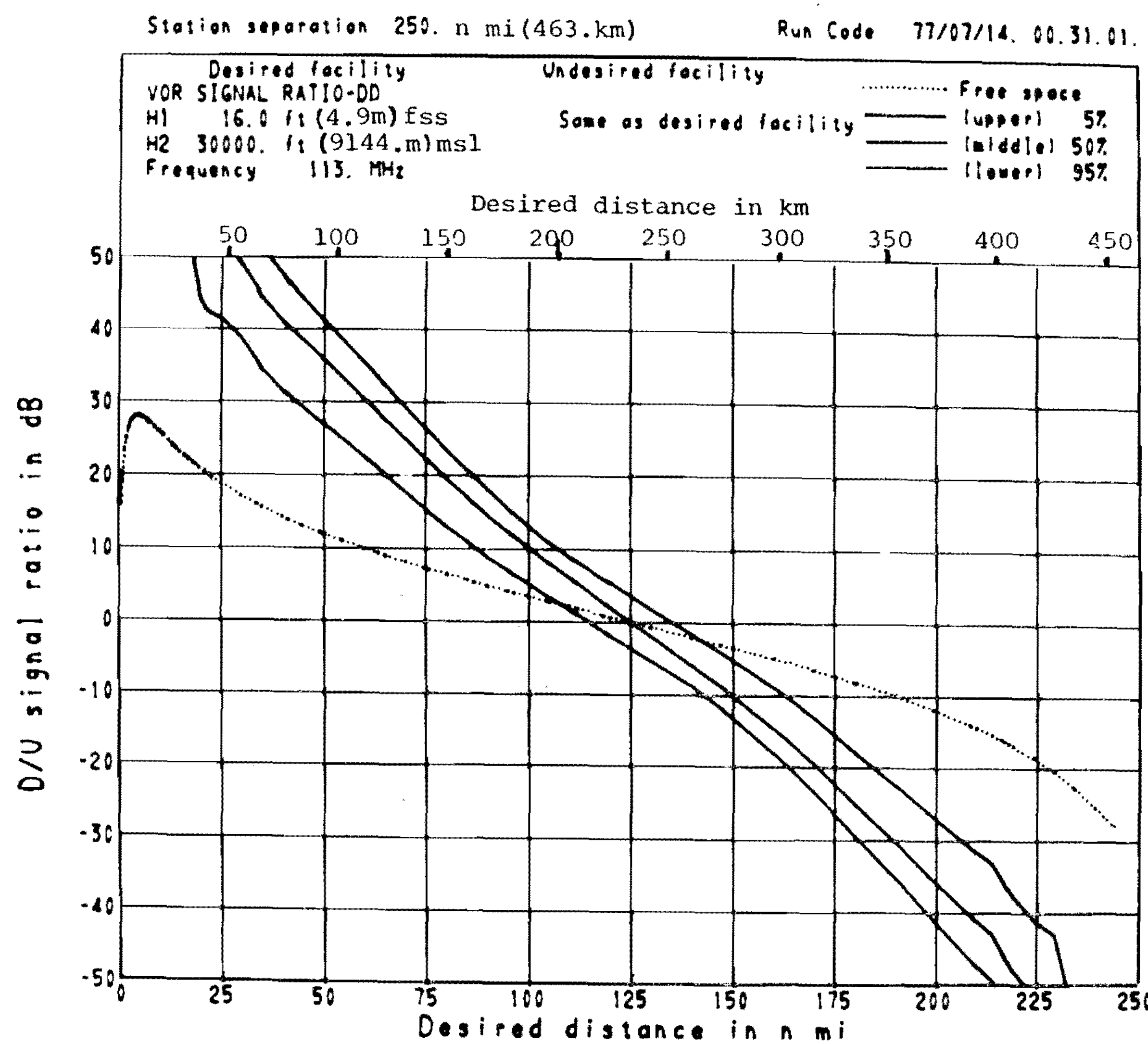


Figure 34. Signal ratio-DD, VOR. Desired-to-undesired, D/U, signal ratio versus desired facility-to-receiver distance curves are shown for a fixed station separation and time availabilities of 5, 50, and 95 percent. Both desired and undesired facilities have the parameters of figure 5.

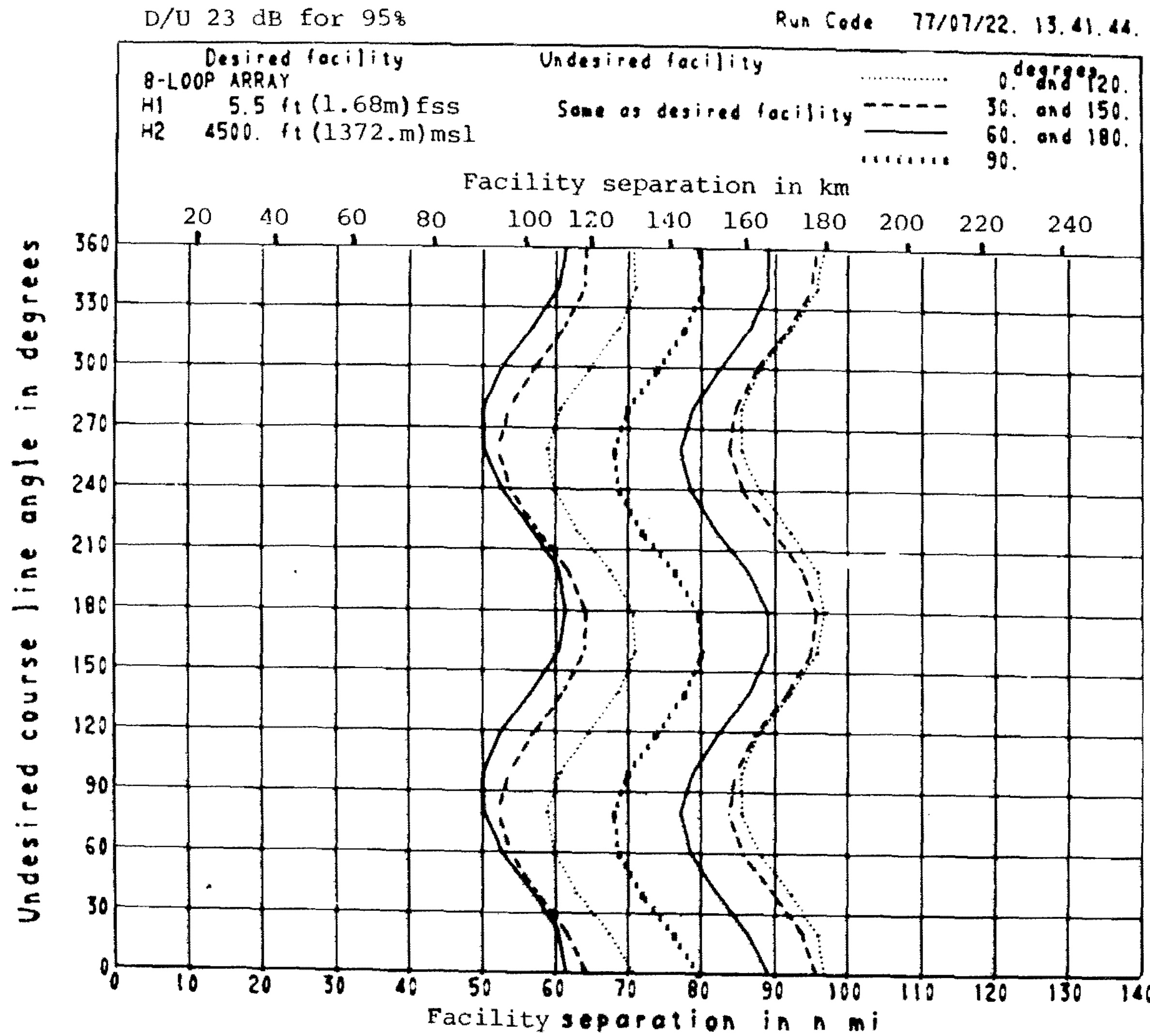


Figure 35. Orientation, ILS. Facility separation needed to obtain a D/U of 23 dB for a time availability of 95 percent is provided as a function of undesired (ordinate) and desired (line code) course line angles (fig. 43). Parameters for both the desired and undesired facilities are as given except that the aircraft altitude is 4500 ft (1372 m) msl. See page 61 for discussion of critical protection points.

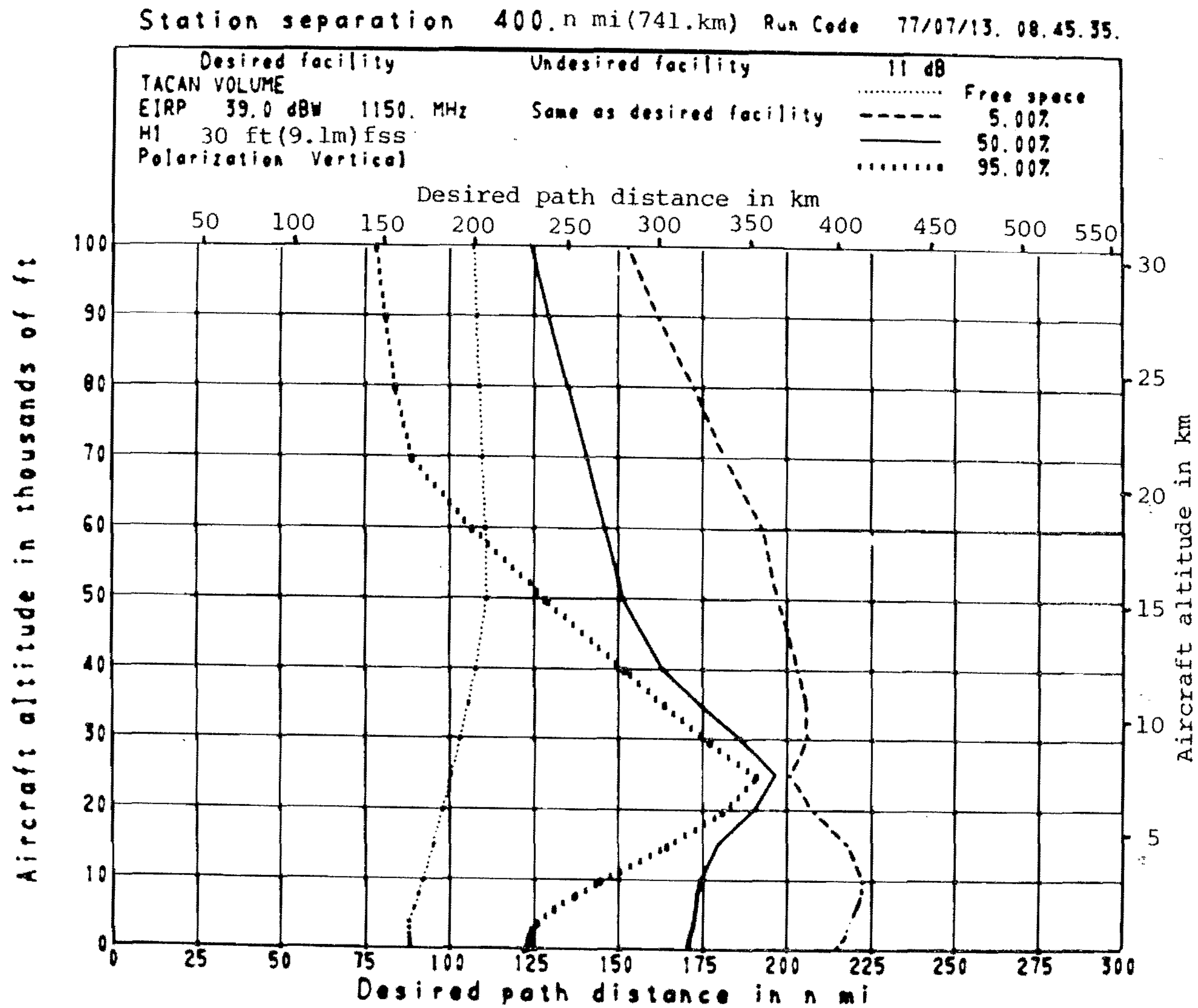


Figure 36. Service volume, TACAN. Parameters provided in figure 5 are applicable to both desired and undesired facilities.

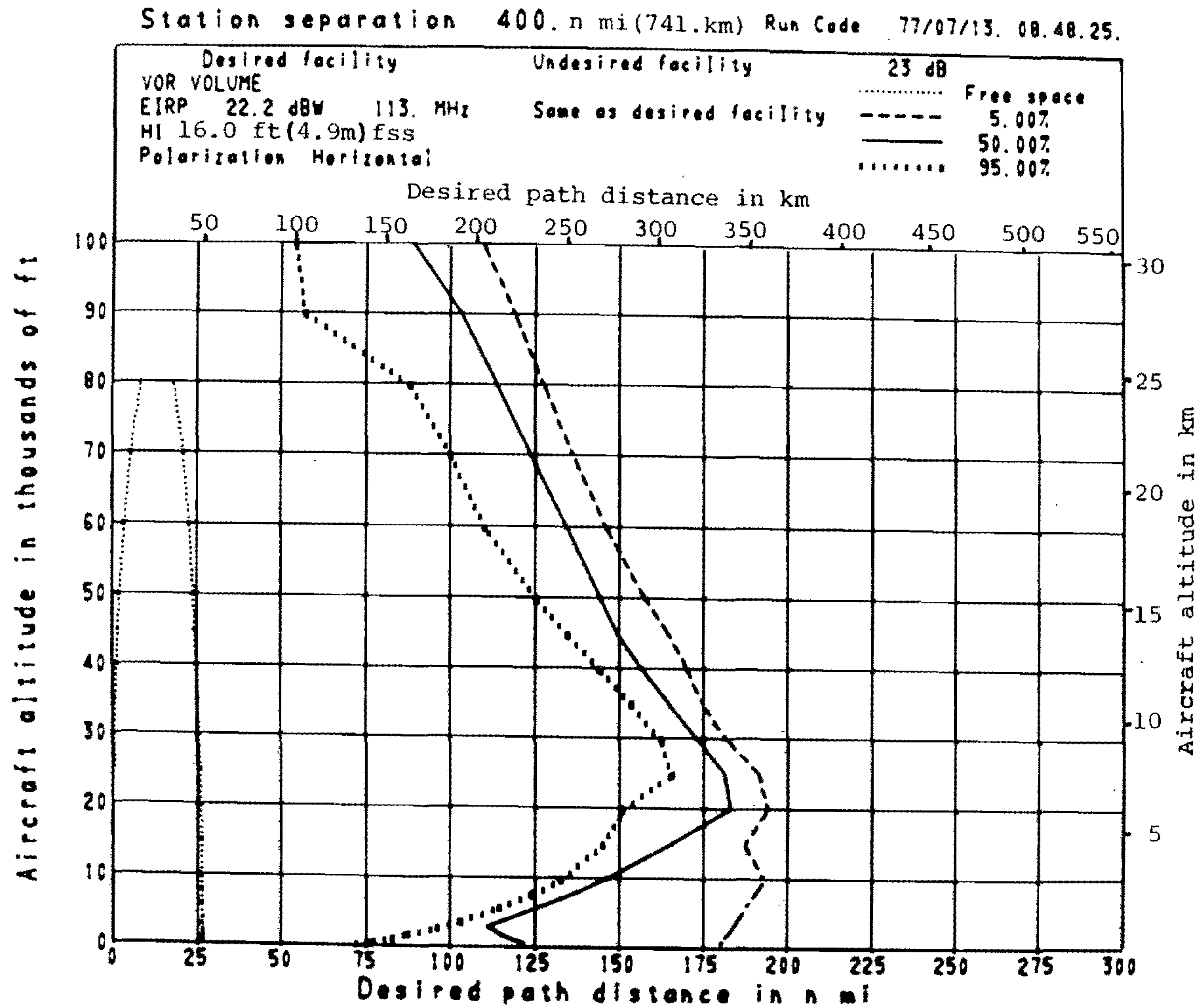


Figure 37. Service volume, VOR. Parameters provided in figure 5 are applicable to both desired and undesired facilities.

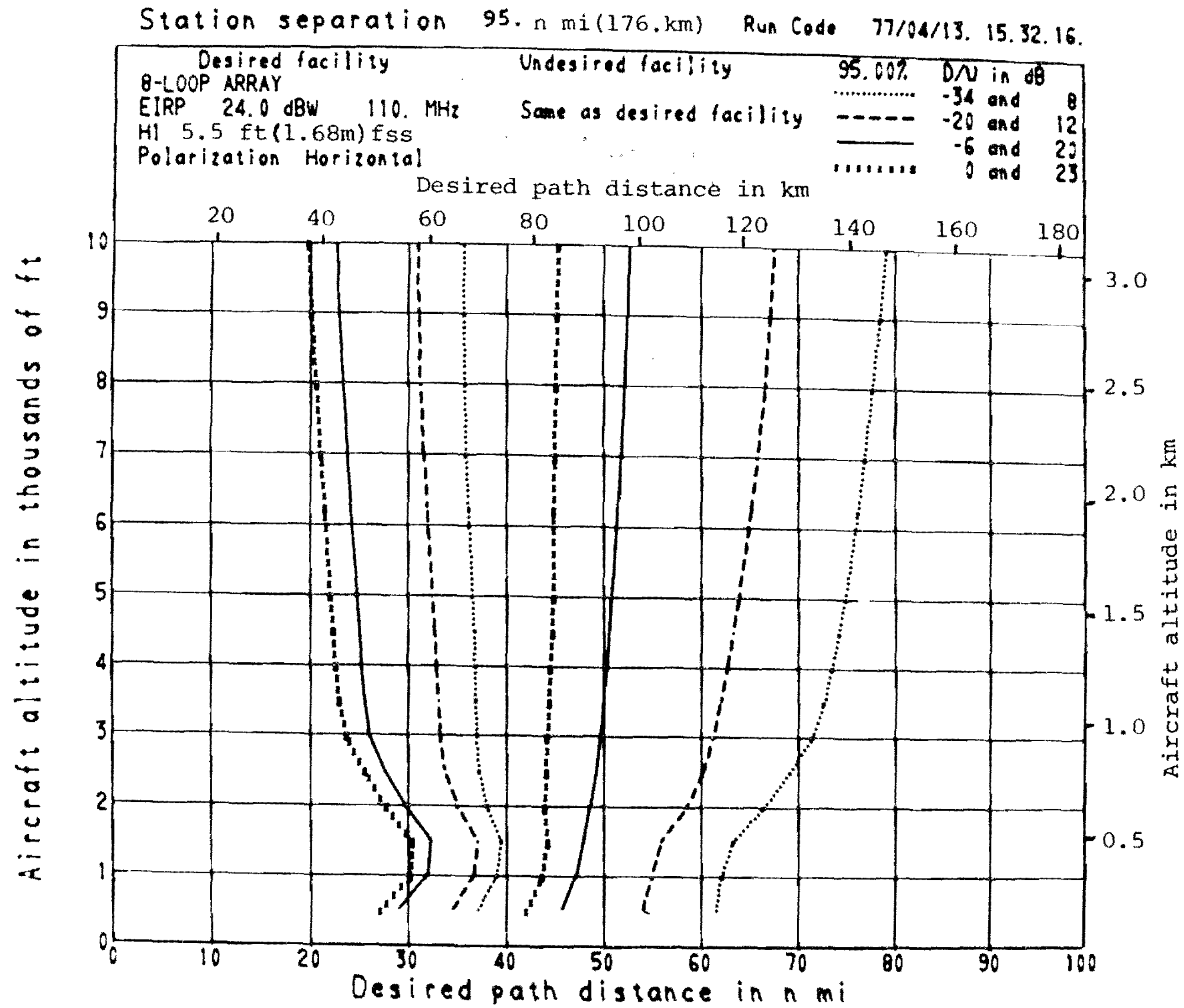


Figure 38. Signal ratio contours, ILS. Parameters used in the calculations are summarized in figure 2.

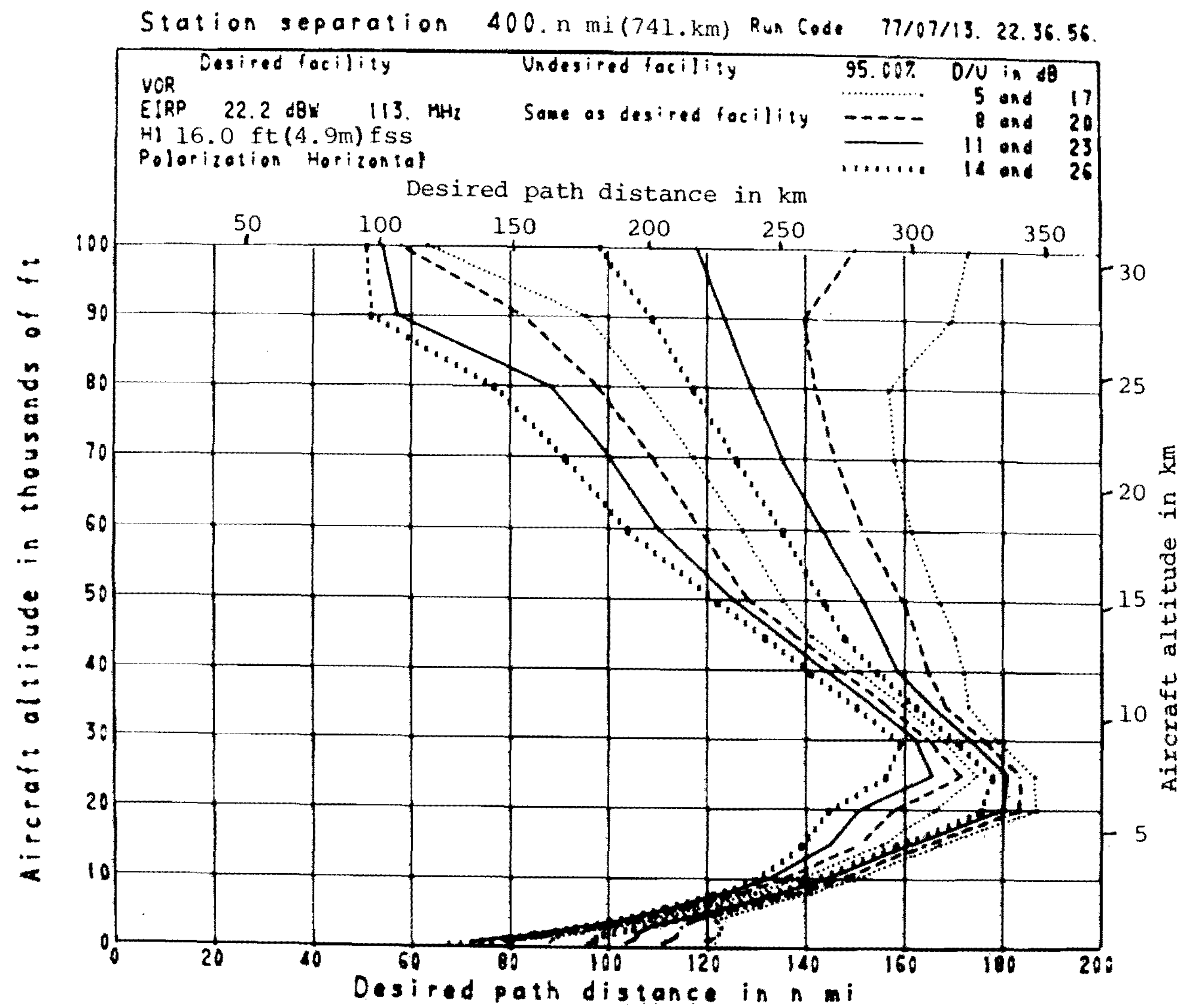


Figure 39. Signal ratio contours, VOR. Parameters used in the calculations are summarized in figure 5.

3.2 CAPABILITIES

A brief discussion of each capability summarized in table 1 is given in this section. Each discussion title contains the capability name and indicates (in parentheses) the figure and a sample problem that are associated with the capability. Application examples in the form of sample problems, with solutions, are provided in section 3.3.

LOBING (fig. 6, p. 15; prob. 1, p. 64) Transmission loss is plotted against path distance for (a) lobing (solid curve) caused by the phase difference in direct and reflected rays for the first 10 lobes inside the radio horizon, (b) limiting values associated with in phase (low loss, upper curve with small dots) and out of phase (high loss, lower curve with small dots) conditions, and (c) free space (curve with large dots) [27, sec. CII-C.1]. As indicated in a table 1 footnote, this graph and others generated via program LOBING are applicable only to the line-of-sight region for spherical earth geometry, and time variability and horizon effects are neglected. Figure 40 illustrates this geometry, shows the two rays involved (r_o and $r_{12} = r_1 + r_2$), and defines variables that will be used in the discussion of plots produced with LOBING.

Antenna gains are included in transmission loss since it is the difference (dB) between power radiated (dBW), and the power available (dBW) at the output of an ideal receiving antenna (no internal losses), but in the sample run presented here, transmission loss is the same as basic transmission loss because isotropic antennas were assumed. Spacing between the limiting curves decreases as the reflection coefficient decreases. A test is built into the program to prevent unrealistic null depths [8, p. 393]. It limits the maximum transmission loss to its free space value plus 40 dB.

REFLECTION COEFFICIENT (fig. 7, p. 16; prob. 2, p. 64) The effective reflection coefficient is plotted against path distance

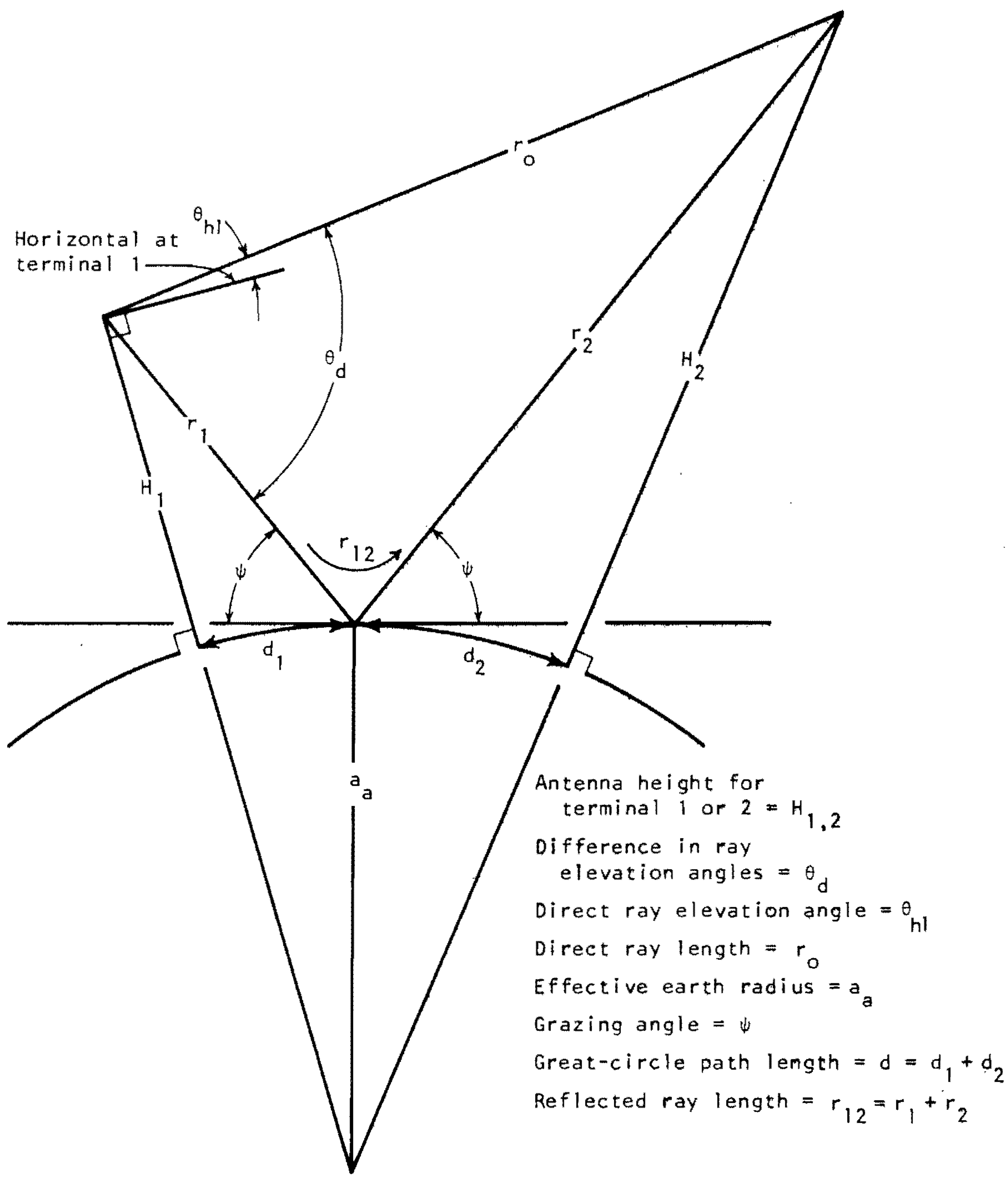


Figure 40. Geometry for reflection from spherical earth.

(d of fig. 40). Relative antenna gains, surface parameters (dielectric constant, conductivity and roughness), frequency, and grazing angle (ψ of fig. 40) are included in the calculation of effective reflection coefficient [27, secs. CI-D, CII-C.2]. The drop in reflection coefficient at short distances is associated with the ray length reduction factor [27, sec. CI-D.5]. The drop in reflection coefficient at the far distances is caused by the divergence factor [27, sec. CI-D.1].

PATH LENGTH DIFFERENCE (fig. 8, p. 17; prob. 3, p. 65) The extent (Δr) by which the length of the reflected ray (r_{12} of fig. 40) exceeds that of the direct ray (r_o of fig. 40) is plotted against path distance [27, sec. CII-C.3]; i.e.,

$$\Delta r = r_{12} - r_o. \tag{2}$$

This equation is not actually used to calculate Δr since it involves the difference of two, large, nearly equal terms. The formulation used [24, fig. 16] avoids this precision problem.

TIME LAG (fig. 9, p. 18; prob. 3, p. 65) The time lag of transmission via the surface reflection path relative to the direct path is plotted against path distance [27, sec. CII-C.4]. This is the (free space) time (τ) required for a radio wave to travel the path length difference (Δr) of figure 8; i.e.,

$$\tau[\text{nsec}] = 3.34\ [\text{nsec/m}]\ \Delta r[\text{m}]. \tag{3}$$

LOBING FREQUENCY-D (fig. 10, p. 19; prob. 4, p. 66) Lobing frequency with distance (f_d) for an aircraft traveling directly toward (or away from) the facility may be determined from values of normalized distance lobing frequency (NDLF) read from this graph, radio frequency (f), and the magnitude of its velocity (V_d); i.e.,

$$f_d[\text{Hz}] = \text{NDLF}[(\text{Hz/THz})/\text{kts}]\,f[\text{THz}]V_d[\text{kts}], \tag{4a}$$

$$f_d[\text{Hz}] = \text{NDLF}[(\text{Hz/THz})/\text{s mi/hr})]\,f[\text{THz}]V_d[\text{s mi/hr}], \tag{4b}$$

or

$$f_d[\text{Hz}] = \text{NDLF}[(\text{Hz/THz})/(\text{km/hr})]\,f[\text{THz}]V_d[\text{km/hr}]. \tag{4c}$$

Note that f is in terahertz (THz) where one terahertz is 10^{12} Hz or 10^6 MHz, but that f_d is in hertz.

Received signal level will vary with aircraft location as it moves through the lobing structure (fig. 6) associated with the phase difference between direct and surface reflected rays. The frequency at which this variation occurs is called the lobing frequency, lobe modulation frequency, or Doppler beat modulation [11, sec. 4; 27, secs. CI-C.4, CII-C.5]. Reed and Russell [47, ch. 10] developed formulas using both lobe modulation and Doppler beat modulation concepts to show that "...no fundamental difference exists between the lobe modulation and the Doppler-beat modulation concepts. They differ only in the treatment of the independent variable".

The lobing frequency (f_ℓ) encountered by an aircraft can be estimated from f_d and f_h (see eqn. 6); i.e.,

$$f_\ell \le f_d + f_h. \tag{5}$$

Here $<$ is needed since it is possible for an aircraft to follow a flight pattern such that the lobing with distance is compensated for by lobing with height so that $f_\ell = 0$ even though $f_d + f_h > 0$; e.g., an aircraft flying the glide slope of a conventional ILS in which the lobing structure is used to determine the desired flight path.

LOBING FREQUENCY-H (fig. 11, p. 20; prob. 4, p. 66) Lobing frequency [27, secs. CI-C.4, CII-C.6] with height (f_h) for an aircraft in vertical ascent (or descent) may be determined from values of normalized lobing frequency (NHLF), radio frequency (f), and the magnitude of the ascent rate (V_h); i.e.,

$$f_h[\text{Hz}] = \text{NHLF}[(\text{Hz/THz})/(\text{ft/min})]f[\text{THz}]V_h[\text{ft/min}], \tag{6a}$$

or

$$f_h[\text{Hz}] = \text{NHLF}[(\text{Hz/THz})/(\text{m/min})]f[\text{THz}]V_h[\text{m/min}]. \tag{6b}$$

Values of f_h can be used in (5) to estimate lobing frequency.

REFLECTION POINT (fig. 12, p. 21; prob. 2, p. 64) Distance (d_1 of fig. 40) from the facility to reflection point is plotted against path distance [27, secs. CI-C.2.3, CII-C.7].

ELEVATION ANGLE (fig. 13, p. 22; prob. 2, p. 64) The elevation angle (θ_{h1} of fig. 40) of the direct ray at the facility in degrees above horizontal is plotted against path distance [27, secs. CI-C.2.3, CII-C.8].

ELEVATION ANGLE DIFFERENCE (fig. 14, p. 23; prob. 2, p. 64) The amount (θ_d of fig. 40) by which the elevation angle of the direct ray at the facility exceeds that of the reflected ray (elevation angle difference) is plotted against path distance [27, secs. CI-C.2.3, CII-C.9].

SPECTRAL PLOT (fig. 15, p. 24; prob. 5, p. 66) Figure 15 shows one spectrum corresponding to each path distance point calculated for the lobing graph (fig. 6). Each spectrum is of bandwidth $2f_f f$, where f_f is a fraction of the carrier frequency f; i.e., bandwidth = (2)(0.0004)(125) = 0.1 MHz = 100 kHz. The scale along the diagonal axis is proportional to the distance shown for that point on the lobing graph, and the amplitude scale is linear in decibels with a maximum range of 43 dB [27, sec. CII-C.10].

POWER AVAILABLE (fig. 16, p. 25; prob. 6, p. 67) Power available (see eqn. 1) at the output of an ideal antenna (no internal losses) is plotted against central angle for a particular satellite (or higher antenna such as an aircraft) altitude. Available power expected to be exceeded for 5, 50, and 95 percent of the time (i.e., 5, 50, and 95 percent time availabilities) is plotted along with the available power that would be present under free-space propagation conditions. The term "EIRPG" used in the parameter summary at top of the graph is an abbreviation for equivalent isotropically radiated power (EIRP) plus receiving antenna main beam gain (see eqn. 12). Options exist to express the abscissa (path length) in kilometers, statute miles, nautical miles, or degrees of central angle.

Central angle is the angle subtended by the great-circle path (θ_o of fig. 41 inset); it is useful when coverage estimates for a geostationary satellite are desired since the central angle corresponds to latitude along the subsatellite meridian, and longitude along the equator from the subsatellite point. Loci of constant central angle are circles on earth projections normally used to show earth coverage [23, 46]. Figure 41 illustrates such loci for a geostationary satellite located at 100° W. Great-circle path distance (d of fig. 41 inset) is related to central angle by

$$d[\text{n mi}] = 60.0[\text{n mi/deg}]\theta_o[\text{deg}], \tag{7a}$$

$$d[\text{s mi}] = 69.1[\text{s mi/deg}]\theta_o[\text{deg}], \tag{7b}$$

$$d[\text{km}] = 111.2[\text{km/deg}]\theta_o[\text{deg}], \tag{7c}$$

$$\theta_o[\text{deg}] = 0.0167[\text{deg/n mi}]d[\text{n mi}], \tag{8a}$$

$$\theta_o[\text{deg}] = 0.0145[\text{deg/s mi}]d[\text{s mi}], \tag{8b}$$

or

$$\theta_o[\text{deg}] = 0.00899[\text{deg/km}]d[\text{km}]. \tag{8c}$$

POWER DENSITY (figs. 17-19, pp. 26-28; prob. 7, p. 67) Sample "POWER DENSITY" graphs are provided for ILS (fig. 17), TACAN (fig. 18), and VOR (fig. 19). Power density (see eqn. 1) at the receiving antenna location (aircraft in this case) is plotted against path distance for a particular aircraft (or higher antenna) altitude. The curves show the power density expected to be exceeded for 5, 50, and 95 percent of the time along with the power density that would be present under free-space propagation conditions. Options exist to express the abscissa in kilometers, statute miles, nautical miles, or degrees of central angle. Central angle is useful when coverage estimates for a geostationary satellite are desired (see POWER AVAILABLE, fig. 16, discussion).

TRANSMISSION LOSS (fig. 20, p. 29; prob. 1, p. 64) Transmission loss (see LOBING, fig. 6, discussion) is plotted against path distance for a particular aircraft altitude. The curves show transmission loss values that are unexceeded for at least 5, 50, and 95 percent of the time along with the transmission loss that would be present under free-space propagation conditions. The

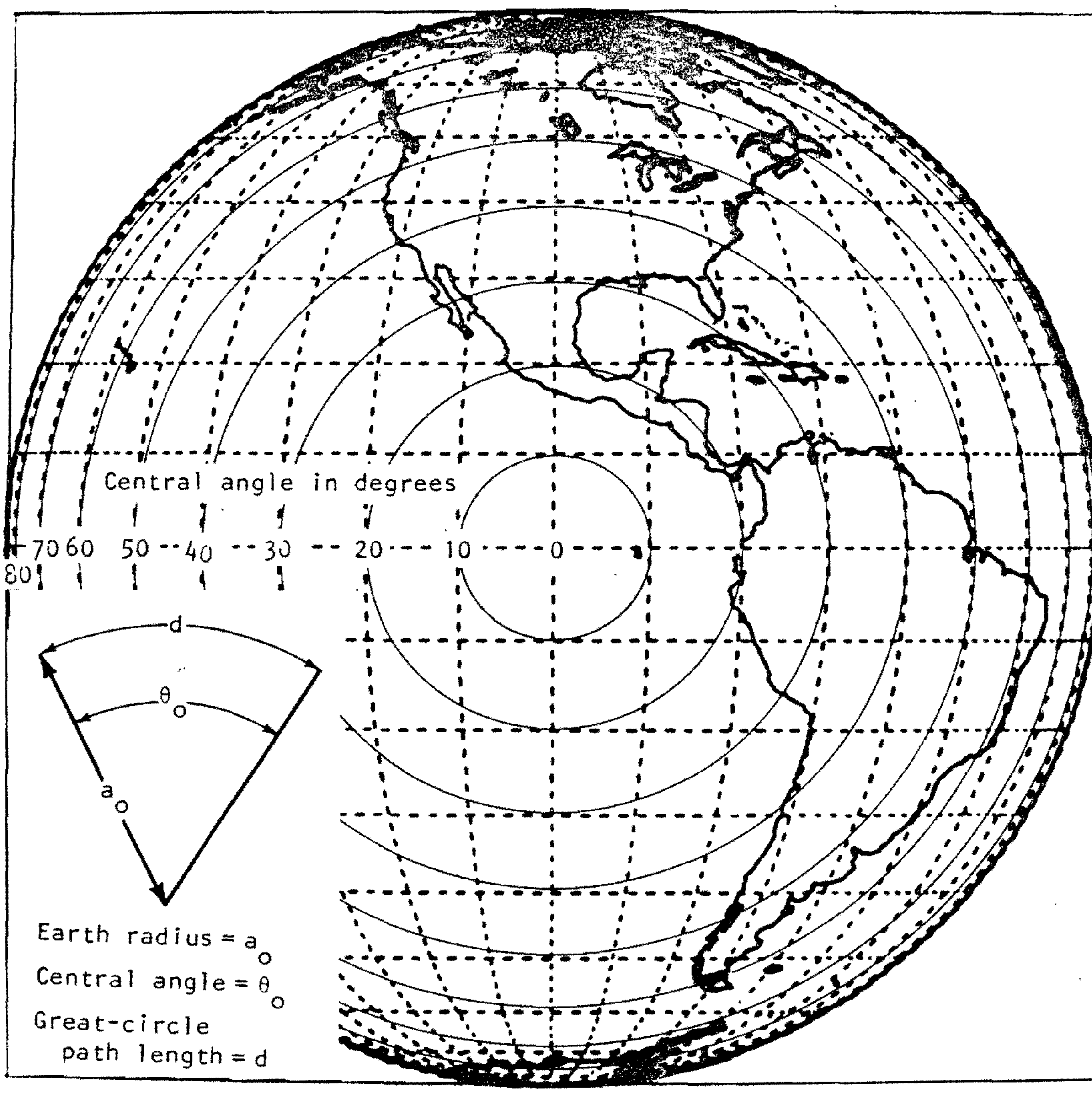


Figure 41. Geographic location of constant central angle contours The subsatellite point is at 100°W [23, figs. 8, 9].

term "GAIN" used in the parameter summary at the top of the graph is an abbreviation for the sum of the transmitting and receiving antennas' main beam gains. Since GAIN = 0 in this case, transmission loss is really basic transmission loss. Options exist to express the abscissa in kilometers, statute miles, nautical miles, or degrees of central angle. Central angle is useful when coverage estimates for a geostationary satellite are desired (see POWER AVAILABLE, fig. 16, discussion).

Values obtained from figure 20 may differ somewhat from those obtained from figure 6 since the calculations for figure 20 included lobing as part of the time variability along with horizon effects, while those for figure 6 did not.

The increase in variability for distances somewhat less than 150 n mi (278 km) occurs because of the specular surface reflection multipath contribution to variability that occurs somewhat inside the horizon. Lower short-term variability near the horizon has been observed in propagation data [1].

POWER AVAILABLE CURVES (fig. 21, p. 30; prob. 8, p. 67) Curves of power available (see eqn. 1) at the output of the receiving antenna are plotted against distance for several aircraft altitudes, a single facility antenna height, and a time availability of 95 percent. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and to use other time availabilities.

POWER DENSITY CURVES (fig. 22, p. 31; prob. 9, p. 68) Curves of power density (see eqn. 1) at the receiving antenna location (aircraft in this case) are plotted against distance for several aircraft altitudes, a single facility antenna height, and a time availability of 95 percent. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and to use other time availabilities.

TRANSMISSION LOSS CURVES (fig. 23, p. 32; prob. 1, p. 64) Curves of transmission loss (see LOBING, fig. 6, discussion) are plotted against distance for several aircraft altitudes, a single facility antenna height, and a time availability of 95 percent. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and to use other time availabilities.

POWER AVAILABLE VOLUME (fig. 24, p. 33; prob. 10, p. 68) Contours for a single available power (see eqn. 1) are plotted in the altitude versus distance plane for time availabilities of 5, 50, and 95 percent. When symmetry about the ordinate axis can be assumed (e.g., omnidirectional antenna), the volume formed by rotating a contour about the ordinate axis defines the air space in which the time availability will almost always equal or exceed that associated with the contour used to form it. This volume might include some air space with inadequate time availability, since it may not describe conditions directly above the desired facility perfectly. Noise and interference levels are not considered in this display. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and to express the ordinate in feet or meters.

POWER DENSITY VOLUME (fig. 25, p. 34; prob. 11, p. 68) Contours for a single power density value are plotted in the altitude versus distance plane for time availabilities of 5, 50, and 95 percent. When symmetry about the ordinate axis can be assumed (e.g., omnidirectional antenna), the volume formed by rotating a contour about the ordinate axis defines the air space in which the time availability will almost always equal or exceed that associated with the contour used to form it. This volume might include some air space with inadequate time availability, since it may not describe conditions directly above the desired facility perfectly. Noise and interference levels are not considered in this display. Options exist to express the abscissa in kilometers, statute miles or nautical miles, and to express the ordinate in feet or meters.

TRANSMISSION LOSS VOLUME (fig. 26, p. 35; prob. 12, p. 69) Contours for a single transmission loss (see LOBING, fig. 6, discussion) value are plotted in the altitude versus distance plane for time availabilities of 5, 50, and 95 percent. When symmetry about the ordinate axis can be assumed (e.g., omnidirectional antenna), the volume formed by rotating a contour about the ordinate axis defines the air space in which the time availability will almost always equal or exceed that associated with the contour used to form it. This volume might include some air space with inadequate time availability, since it may not describe conditions directly above the desired facility perfectly. Noise and interference levels are not considered in this display. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and the ordinate in feet or meters.

EIRP CONTOURS (figs. 27-29, pp. 36-38; prob. 13, p. 69) Sample "EIRP CONTOURS" graphs are provided for ILS (fig. 27), TACAN (fig. 28), and VOR (fig. 29). Several (up to eight) contours of EIRP (see eqn. 11) levels needed to meet a single power density requirement are plotted in the altitude versus distance plane. The contours pass through points where the power density requirement can be met by using the EIRP associated with the contour. A single time availability is applicable to all contours. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and the ordinate in feet or meters.

POWER AVAILABLE CONTOURS (fig. 30, p. 39; prob. 14, p. 69) Several (up to eight) contours of available power (dBW, see eqn. 1) are plotted in the altitude versus distance plane. Identical values (one each) of time availability and EIRP (see eqn. 11) are used for all contours. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and the ordinate in feet or meters.

POWER DENSITY CONTOURS (fig. 31, p. 40; prob. 15, p. 70) Several (up to eight) contours of power density (dB-W/sq m, see eqn. 1) are plotted in the altitude versus distance plane. Identical values (one each) of time availability and EIRP (see eqn. 11) are used for all contours. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and to express the ordinate in feet or meters.

TRANSMISSION LOSS CONTOURS (fig. 32, p. 41; prob. 16, p. 70) Several (up to eight) contours of transmission loss (see fig. 6 discussion) are plotted in the altitude versus distance plane for a single time availability value. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and the ordinate in feet or meters.

SIGNAL RATIO-S (fig. 33, p. 42; prob. 17, p. 70) Desired-to-undesired (D/U [dB]) signal ratio available at the output of the receiving antenna (aircraft in this case) is plotted against station separation. The curves show D/U ratios for time availabilities of 5, 50, and 95 percent along with the D/U values that would be obtained under free-space propagation conditions. Figure 42 shows the interference configuration. Aircraft-to-desired facility great-circle distance (d_D) and aircraft-to-undesired great-circle facility distance (d_U) are used to determine station separation (S) from

$$S = d_D + d_U \tag{9}$$

where d_D and d_U do not have to be part of the great-circle connecting the facilities. Aircraft location relative to the desired facility (altitude and d_D) is fixed for each graph. An option exists to express the abscissa in kilometers, statute miles, or nautical miles.

SIGNAL RATIO-DD (fig. 34, p. 43; prob. 18, p. 70) The D/U [dB] signal ratio available at the output of the receiving antenna (aircraft in this case) is plotted against the desired facility to aircraft distance (DD or d_D of fig. 42). The curves show D/U ratios for time availabilities of 5, 50, and 95 percent along with D/U values that would be obtained under free-space propagation conditions. Aircraft altitude and station separation (see SIGNAL RATIO-S, fig. 33, discussion) are fixed for each graph.

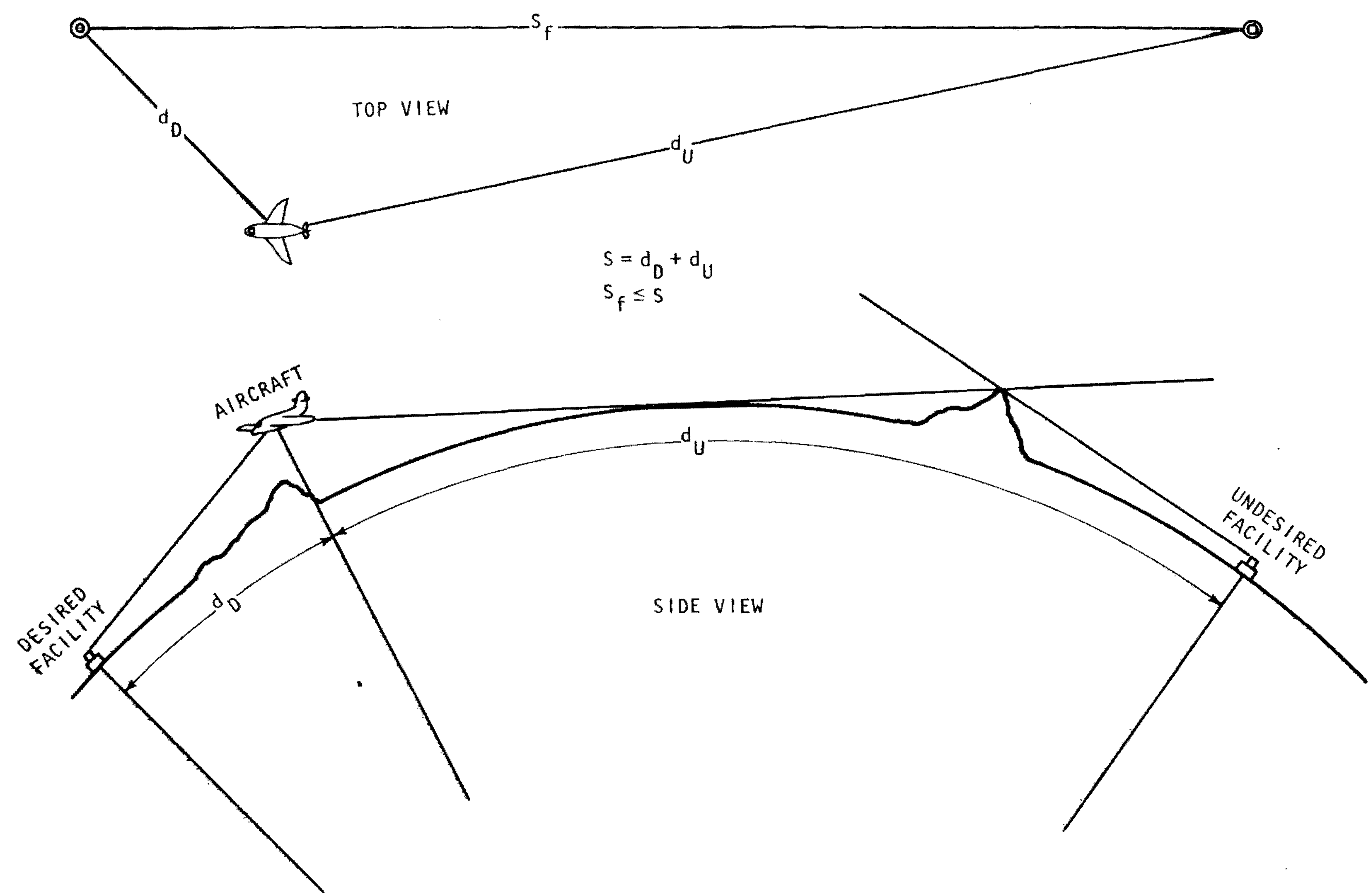


Figure 42. Sketch illustrating interference configuration.

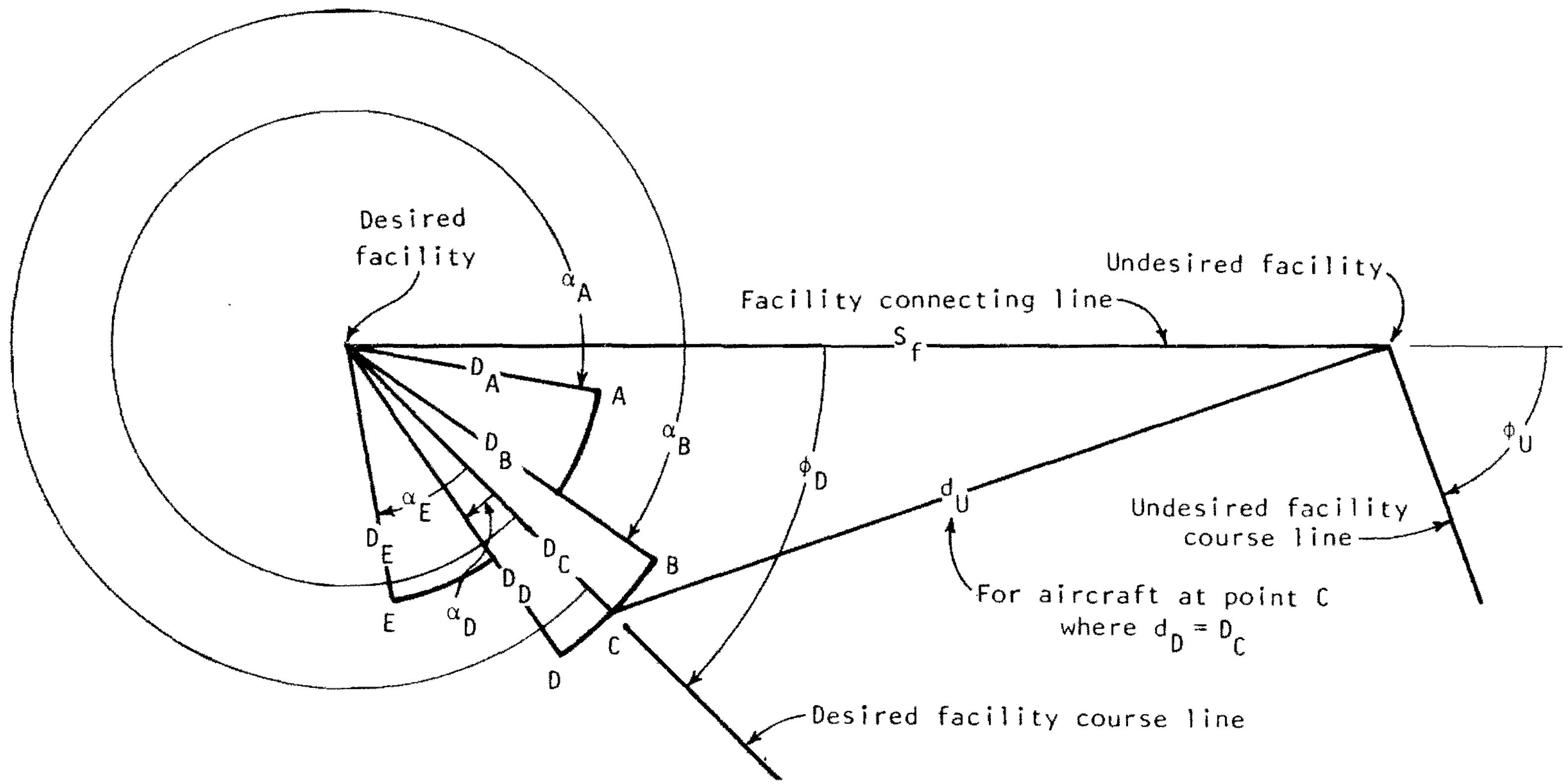
An option exists to express the abscissa in kilometers, statute miles, or nautical miles.

ORIENTATION (fig. 35, p. 44; prob. 19, p. 71) Curves showing the relative azimuthal orientation of the undesired facility course line (ϕ_U) with respect to the great circle-path connecting the desired and undesired facilities are plotted versus the facility separation required to achieve a specified D/U ratio or better at each of five specified protection points. Each curve represents a different relative azimuthal orientation of the desired facility course line (ϕ_D) with respect to the path connecting facilities. Orientation geometry for the protection points is illustrated in figure 43. These protection points are located relative to the desired facility by a distance from the desired ($D_{A,B,C,D,E}$) facility and relative azimuth angle from the desired facility course line ($\alpha_{A,B,C,D,E}$). In the calculations for figure 35, (a) the protection points were at

Distance	Angle
D_A = 10 n mi (18.5 km)	α_A = 325°
D_B = 18 n mi (33.3 km)	α_B = 350°
D_C = 18 n mi (33.3 km)	α_C = 0°
D_D = 18 n mi (33.3 km)	α_D = 10°
D_E = 10 n mi (18.5 km)	α_E = 35°

(b) ϕ_D was varied in 30° increments from 0 to 180° (see line code in upper right of fig. 35), (c) ϕ_U was varied in 10° increments from 0 to 360°, and (d) azimuth (horizontal) patterns for the 8-loop localizer were used for both facilities.

Protection point C on figure 43 is used to illustrate the difference between facility separation (S_f) calculated via program TWIRL and station separation (S) used elsewhere (see SIGNAL RATIO-S, fig. 33, discussion). In particular, $S_f \leq S$ since S need not be measured along the great-circle path connecting the facilities. Note that (a) the d_U to point C changes as ϕ_D changes, even if S_f remains fixed, and (b) the angle from the



All angles are positive clockwise.

Angles to course lines, $\phi_{D,U}$, are measured from facility connecting line.

Angles to protection points, $\alpha_{A,B,C,D,E}$, are measured from the desired station course line.

Point C is along the course line so that $\alpha_C = 0$, but this is not a required condition.

Facility separation, S_f, is in general less than station separation, S, when S is calculated from $S = d_D + d_U$ where $d_{D,U}$ are facility to aircraft distances. This is illustrated for protection point C.

Figure 43. Orientation geometry for protection points.

undesired facility to point C changes with both ϕ_D and ϕ_U even if S_f remains fixed, so that the applicable gain for the undesired facility varies in accordance with its horizontal pattern.

The geometrical consequences of these complications are handled as part of the calculations performed by program TWIRL. These calculations would be very tedious to perform by hand even if appropriate signal ratio graphs (fig. 33) were available. A graph similar to figure 35 is constructed for each protection point and the maximum S_f for each combination of ϕ_D and ϕ_U is selected for the final graph. These intermediate graphs have a format identical to figure 35 and are available as computer output even though no samples are provided here.

Options exist to express the abscissa in kilometers, statute miles, or nautical miles.

SERVICE VOLUME (figs. 36-37, p. 45-46; prob. 20, p. 71) Sample "SERVICE VOLUME" graphs are provided for TACAN (fig. 36) and VOR (fig. 37). Fixed D/U contours are plotted in the altitude versus distance plane for free space conditions and for time availabilities of 5, 50, and 95 percent. A fixed station separation (see SIGNAL RATIO-S, fig. 33, discussion) is used for each graph. When symmetry about the ordinate axis can be assumed (e.g., omnidirectional antenna), the volume formed by rotating a contour about the ordinate axis defines the air space in which the time availability will almost always equal or exceed that associated with the contour used to form it. This volume might include some air space with inadequate time availability, since it may not describe conditions directly above the desired facility perfectly. Service limitations associated with noise level are not considered in this display. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and the ordinate in feet or meters.

SIGNAL RATIO CONTOURS (figs. 38-39, pp. 47-48; prob. 21, p. 71) Sample "SIGNAL RATIO CONTOURS" graphs are provided for ILS (fig. 38) and VOR (fig. 39). Several (up to eight) D/U signal ratio contours are plotted in the altitude versus distance plane (cf., figs. 36, 37). Single values of time availability and station separation are used for each graph. Options exist to express the abscissa in kilometers, statute miles, or nautical miles, and the ordinate in feet or meters.

3.3 APPLICATIONS

Graphs like those provided in section 3.1 and discussed in section 3.2 can be used to solve a wide variety of problems where system reliability is dependent upon radio-wave propagation. The application of each plotting capability is illustrated by a problem and solution in the remainder of this section. These problems are ordered by the capability applied in accordance with the table 1 listing.

LOBING GRAPH (fig. 1, p. 10; fig. 6, p. 15; fig. 20, p. 29; fig. 23, p. 32).

Problem 1: Estimate the extent of smooth earth coverage for a system with the parameters of figure 1 and an allowable transmission loss of 135 dB.

Solution: Figure 6 indicates potential coverage gaps from 75 to 87 n mi (139 to 161 km) and no coverage beyond 232 n mi (430 km). Figure 20 indicates coverage to 259, 233, and 220 n mi (480, 432, and 407 km) for time availabilities of 5, 50, and 95 percent. Figure 20 has the effects of surface reflection multipath included statistically in the signal level variability so that nulls, while not shown, are accounted for in the time availability estimate. Figure 20 also provides a better estimate of transmission loss near the horizon. Figure 23 could have been used instead of figure 20 to obtain coverage for a 95 percent time availability.

REFLECTION COEFFICIENT (fig. 6, p. 15; fig. 7, p. 16; fig. 12, p. 21; fig. 13, p. 22; fig. 14, p. 23).

Problem 2: Determine the reflection coefficient, reflection point location, elevation angle, and elevation angle difference associated with the null inside the horizon for the conditions of problem 1. These parameters are useful in evaluating potential methods of reducing the null depth by effective reflection coefficient reduction. For example, terrain near the reflecting point could be altered to reduce surface reflectivity or an antenna pattern could be used that has low gain toward the reflecting surface.

Solution: The required parameters are obtained from graphs produced by program LOBING; i.e.,

distance to null (fig. 6) is 79 n mi (147 km),

effective reflection coefficient (fig. 7) for 79 n mi (147 km) is 0.96,

distance to reflection point (fig. 12) for 79 n mi (147 km) is 0.15 n mi (0.28 km),

elevation angle (fig. 13) for 79 n mi (147 km) is 4.5°,

and

difference in direct and reflected ray elevation angle (fig. 14) for 79 n mi (147 km) is 9°.

PATH LENGTH DIFFERENCE (fig. 8, p. 17; fig. 9, p. 18)

Problem 3: For the conditions of problem 1, find the maximum time by which a pulse traveling the reflected ray route will lag the pulse traveling the direct ray route. Pulse distortion associated with smooth earth multipath can be avoided if the pulse duration is much larger than the time lag.

Solution: The maximum path length difference (fig. 8) occurs at 0 n mi (0 km) and is 30.4 m. This path difference, Δr, is converted to time lag via (3); i.e.,

$$\tau = 3.34 \text{ [nsec/m] } \Delta r \text{ [m]} = (3.34)(30.4) = 102 \text{ nsec.}$$

Note that values for τ can be obtained directly from figure 9 where the time lag is given as slightly larger than 100 nsec.

TIME LAG This capability was used in the solution to problem 3.

LOBING FREQUENCY-D (fig. 1, p. 10; fig. 10, p. 19; fig. 11, p. 20).

Problem 4: For the conditions of problem 1, determine the lobing frequency via (5) for an aircraft at 4.8 n mi (8.9 km) with a radial velocity of 250 kts (463 km/hr) and an ascent rate of 10^3 ft/min (305 m/min).

Solution: First, required parameters are obtained from output of program LOBING; i.e.,

f (fig. 1) is 125 MHz = 1.25×10^{-4} THz,

NDLF (fig. 10) is 1.52 (Hz/THz)/kts or 0.819 (Hz/THz)/(km/hr) at 4.8 n mi (8.9 km),

and

NHLF (fig. 11) is 10^{-2} (Hz/THz)/(ft/min) or 0.035 (Hz/THz)/(m/min) at 4.8 n mi (8.9 km).

Then,

f_d[Hz] = NDLF[(Hz/THz)/kts]f[THz]V_d[kts] from (4a),

$f_d = (1.52)(1.25\text{x}10^{-4})(250) = 4.75\text{x}10^{-2}\text{Hz}$,

f_h[Hz] = NHLF[(Hz/THz)/(ft/min)]f[THz]V_h[ft/min] from (6a),

$f_h = (10^{-2})(1.25\text{x}10^{-4})(10^3) = 0.125\text{x}10^{-2}$ Hz,

$f_\ell \leq f_d + f_h$ from (5),

and

$f_\ell \leq (4.75 + 0.125)10^{-2}\text{Hz} = 4.9 \times 10^{-2}$ Hz.

Therefore the maximum value of f_ℓ at 4.8 n mi (8.9 km) is 4.9×10^{-2} Hz.

LOBING FREQUENCY-H This capability was used in the solution to problem 4.

REFLECTION POINT This capability was used in the solution to problem 2.

ELEVATION ANGLE This capability was used in the solution to problem 2.

ELEVATION ANGLE DIFFERENCE This capability was used in the solution to problem 2.

SPECTRAL PLOT (fig. 6, p. 15; fig. 15, p. 24).

Problem 5: For the conditions of problem 1, would spectra associated with lobing within ± 50 kHz of 125 MHz be flat for distances from 27 n mi (50 m) to the radio horizon? Frequency selective fading (i.e., when all frequencies within a receiver bandpass do not fade together) can distort a modulated signal so that intelligibility is lowered. It does not occur when spectra are flat.

Solution: Figure 6 indicates that the top of the lobe 4 occurs at a distance somewhat less than 27 n mi (50 km). Therefore, the spectra shown in figure 15 are applicable to this problem, and these spectra are flat, so the answer is yes.

POWER AVAILABLE, UHF SATELLITE (fig. 3, p. 12; fig. 16, p. 25).
Problem 6: Determine how far north coverage from a geostationary UHF satellite extends when the parameters of figure 3 are applicable, and a time availability of 95 percent and a power available of -160 dBW are required.

Solution: Figure 16 is applicable to this problem, and it indicates that coverage out to an angular distance of 80° can be obtained for the required time availability. Therefore, coverage to 80°N is possible along the subsatellite meridian. The great-circle distance for this arc can be obtained using (7c); i.e.,

$$d[\text{km}] = 111.2\ [\text{km/deg}]\,\theta_o[\text{deg}],$$

$$(111.2)(80) = 8{,}900\ \text{km}\ (4{,}800\ \text{n mi}).$$

POWER DENSITY (fig. 5, p. 14; fig. 19, p. 28)
Problem 7: For the VOR parameters of figure 5, determine the interference range of a VOR at 30,000 ft (9,144 m) when a time availability of 5 percent and a power density of -134 dB-W/sq m or more are used to define the interference range.

Solution: Figure 19 is applicable to this problem, and it indicates an interference range of 236 n mi (437 km).

TRANSMISSION LOSS This capability was used in the solution to problem 1.

POWER AVAILABLE CURVES (fig. 1, p. 10; fig. 21, p. 30)
Problem 8: For the ATC parameters of figure 1 where the aircraft is at 45,000 ft (13,716 m), determine the service range when a

time availability of 95 percent and a power available of -130 dBW are used to define service range.

Solution: Figure 21 is applicable to this problem, and it indicates a service range of 239 n mi (443 km).

POWER DENSITY CURVES (fig. 1, p. 10; fig. 21, p. 30; fig. 22, p. 31).

Problem 9: Solve problem 8 using the power density graph of figure 22.

Solution: First, convert the power available requirements of problem 8 to power density using (1) and the conversion factor provided in figure 1; i.e.,

$$P_I(\text{dBW}] = S_R[\text{dB-W/sq m}] + A_I[\text{dB-sq m}],$$

$$S_R = P_I - A_I = P_I - (-3.4),$$

and

$$S_R = -130-(-3.4) = -126.6 \text{ dB-W/sq m}.$$

Then, using this power density, read the 95 percent time availability curve of figure 22. This gives 241 n mi (446 km), which is less than 1 percent larger than the answer obtained previously for problem 8 using figure 21.

TRANSMISSION LOSS CURVES This capability was used in the solution to problem 1.

POWER AVAILABLE VOLUME (fig. 24, p. 33)

Problem 10: For the VOR parameters of figure 5, a time availability of 95 percent, and an available power of -114 dBW, determine the minimum altitude at which the service range extends to 150 n mi (278 km).

Solution: Figure 24 is applicable to this problem, and it indicates a minimum altitude of 30,000 ft (9,144 m) for the 150 n mi (278 km) service range.

POWER DENSITY VOLUME (fig. 5, p. 14; fig. 25, p. 34)

Problem 11: For the VOR parameters of figure 5, a time availability of 95 percent, a power density of -111 dB-W/sq m, and altitudes up to 100,000 ft (30,480 m), determine aircraft altitudes for which service is not available at 150 n mi (278 km).

Solution: Figure 25 is applicable to this problem, and it indicates that service is not available at 150 n mi (278 km) for altitudes below 31,000 ft (9,449 m).

TRANSMISSION LOSS VOLUME (fig. 5, p. 14; fig. 26, p. 35)

Problem 12: For the VOR parameters of figure 5, a time availability of 50 percent, and altitudes up to 100,000 ft (30,480 m), determine the altitudes for which a basic transmission loss of 134 dB is exceeded at a distance of 175 n mi (324 km).

Solution: Figure 26 is applicable, and it indicates that the 134 dB transmission loss level is exceeded 50 percent of the time at a distance of 175 n mi (324 km) for altitudes below 40,000 ft (12,192 m).

EIRP CONTOURS (fig. 4, p. 13; fig. 28, p. 37)

Problem 13: For the TACAN parameters of figure 4, determine the minimum EIRP of transmitted pulses necessary to maintain a pulse power density greater than -86 dB-W/sq m for 95 percent of the time at an altitude of 30,000 ft (9,144 m) and a distance of 125 n mi (232 km).

Solution: Figure 28 is applicable to this problem, and it indicates that an EIRP of 42 dBW would be sufficient.

POWER AVAILABLE CONTOURS (fig. 4, p. 13; fig. 30, p. 39)

Problem 14: For the TACAN parameters of figure 4, a service range defined by a time availability of 95 percent, and a power density of -86 dB-W.sq m, determine the service range available at 30,000 ft (9,144 m) by using figure 30.

Solution: First convert the power density requirement to power available using (1) and the conversion factor provided in figure 4; i.e.,

$$P_I[\text{dBW}] = S_a[\text{dB-W/sq m}] + A_I[\text{dB-sq m}],$$

and $$P_I = -86+(-22.7) = -108.7 \text{ dBW}.$$

Then, using this power available, read the 95 percent time availability curve of figure 30. This gives 111 n mi (206 km).

POWER DENSITY CONTOURS (fig. 4, p. 13; fig. 30, p. 39; fig. 31, p. 40).

Problem 15: Solve problem 14 using figure 31.

Solution: Figure 31 indicates that the service range at 30,000 ft (9,144 m) is 111 n mi (206 km), which is the same answer obtained previously for problem 14 using figure 30.

TRANSMISSION LOSS CONTOURS (fig. 4, p. 13; fig. 32, p. 41)

Problem 16: For the TACAN parameters of figure 4 and a time availability of 95 percent, determine the minimum altitude for which a basic transmission loss of 150 dB is not exceeded at a distance of 100 n mi (185 km).

Solution: Figure 32 is applicable since it was developed with antenna gains set to zero so that basic transmission loss is obtained. It indicates that 150 dB of basic transmission loss is not exceeded for 95 percent of the time at 100 n mi (185 km) for altitudes above 18,000 ft (5,486 m).

SIGNAL RATIO-S (fig. 5, p. 14; fig. 33, p. 42; fig. 42, p. 60)

Problem 17: For the VOR parameters of figure 5, a time availability of 95 percent, and a desired facility to aircraft distance, d_D, of 100 n mi (185 km), determine the station separation (fig. 42) necessary to obtain a desired-to-undesired signal ratio, D/U, of 23 dB at an altitude of 30,000 ft (9,144 m).

Solution: Figure 33 is applicable to this problem, and it indicates that a station separation of 320 n mi (593 km) is adequate to obtain D/U (95%) = 23 dB with d_D = 100 n mi (185 km). However, this signal ratio is not available beyond 100 n mi (185 km) for altitudes less than 30,000 ft (9,144 m).

SIGNAL RATIO-DD (fig. 5, p. 14; fig. 34, p. 43)

Problem 18: For the VOR parameters of figure 5, a time availability of 95 percent, and a D/U of 23 dB or more, determine the maximum d_D available for a station separation of 250 n mi (463 km).

Solution: Figure 34 is applicable to this problem and it indicates that a maximum d_D of 59 n mi (109 km) is available.

ORIENTATION (fig. 2, p. 11; fig. 35, p. 44; fig. 43, p. 62)

Problem 19: For the ILS localizer parameters of figure 2, but with altitude of 4500 ft (1,372 m), the protection point locations associated with figure 43 (see ORIENTATION, fig. 35, discussion in sec. 3.2), a time availability of 95 percent, and a D/U of 23 dB determine the facility separation required when the undesired course line angle (ϕ_U in fig. 43) is 150° and the desired course line angle (ϕ_D of fig. 43) is 60°.

Solution: Figure 35 is applicable to this problem, and it indicates that a facility separation of 88 n mi (163 km) is sufficient.

SERVICE VOLUME (fig. 5, p. 14; fig. 37, p. 46)

Problem 20: For the VOR parameters of figure 5, a time availability of 95 percent, and a station separation of 400 n mi (741 km), determine the maximum d_D for which D/U = 23 dB is available at an altitude of 40,000 ft (12,192 m).

Solution: Figure 37 is applicable to this problem, and it indicates that a d_D of 144 n mi (267 km) is available at 40,000 ft (12,192 m).

SIGNAL RATIO CONTOURS (fig. 2, p. 11; fig. 38, p. 47)

Problem 21: For the ILS localizer parameters of figure 2, a time availability of 95 percent, and a station separation of 95 n mi (176 km), determine the maximum d_D available at 1,000 ft (305 m) for which D/U $\geq$ 23 dB.

Solution: Figure 38 is applicable to this problem, and it indicates that a d_D of 30 n mi (56 km) is available at 1,000 ft (305 m).

4. INPUT PARAMETERS

Parameters that may be specified as input to the programs are summarized in tables 2, 3, and 4. Blank spaces are provided in these tables so that copies of them can be used to specify input requirements for program runs. These tables cover input parameters for 10 programs which have 28 plotting capabilities (table 1) so that only information for a small fraction of the parameters listed need be provided for any one capability.

Table 2 covers general parameters that are usually applicable to many programs, and multiple entries or two copies of this table may be used if the desired and undesired facilities have different parameter values. Note that, although about 40 items can be specified, specification of only 3 is required. These "primary parameters" consist of antenna heights and frequency. Values for "secondary parameters" will be computed or assumed if not specified. A more detailed discussion of table 2 is provided in section 4.1.

Table 3 covers special parameters required for particular capabilities. Some of these parameters are required by more than one capability, and 13 (i.e., first 13 of table 1) of the capabilities do not require parameters from table 3. Additional discussion of table 3 is provided in section 4.2.

Table 4 covers parameters associated with graph formats. In many cases, an adequate selection of these parameters can be made by the program operator so that complete specification via table 4 is not often required. Options associated with ordinate (feet or meters) and/or abscissa (kilometers, statute miles, or nautical miles) units are available. These options are selected via table 4. A more detailed discussion of table 4 is provided in section 4.3.

4.1 GENERAL PARAMETERS (Table 2, p. 73)

General parameters that are usually applicable to many programs may be specified by using copies of table 2. Multiple entries or two copies of this table may be used if the desired and undesired facilities have different parameter values associated with them. In the absence of such information, it will be assumed that the two facilities have identical parameters. All

Table 2. Parameter Specification, General

Parameter	Range	Value
PRIMARY PARAMETERS, SPECIFICATION REQUIRED		
Aircraft (or higher) antenna height above mean sea level (msl)	≥ Facility horizon height	________ ft, m, km, n mi, s mi,
Facility (or lower) antenna height above facility site surface (fss)	> 1.5 ft (0.5 m) above fss	________ ft, m
Frequency	0.1 to 20 GHz	________ MHz
SECONDARY PARAMETERS, SPECIFICATION OPTION	Specified, Computed, or Assumed	
Aircraft antenna type options	Isotropic*, or as specified	
Beam width, half-power	0.1 to 45°	________ deg
Polarization options	None, identical with facility	
Tilt, main beam above horizontal	-90° to 90°	________ deg
Tracking options	Directional* or tracking	
Effective reflection surface elevation above msl	At fss* or specified value above msl	________ ft, m
Equivalent isotropically radiated power	0.0 dBW* or specified	________ dBW
Facility antenna type options	Isotropic* or as specified	
Beam width, half-power	0.1 to 45°	________ deg
Counterpoise diameter	0* to 500 ft (152 m)	________ ft, m
Height above fss	0* to 500 ft (152 m) Below facility antenna by at least 3 ft (1 m) but no more than 2000 ft (610 m)	________ ft, m
Surface options	Poor, average, or good ground, or fresh or sea water, concrete, or metal*	
Polarization options	Horizontal,* vertical, or circular	
Tilt, main beam above horizontal	-90° to 90°	________ deg
Tracking	Directional* or tracking	

Table 2. Parameter Specification, General (cont.)

	Range	Value
Frequency fraction (half-bandwidth)	0 to 0.2 (0.1)*	________
Gain, receiving antenna (main beam)	0* to 60 dBi	________dBi
Transmitting antenna (main beam)	0* to 60 dBi	________dBi
Transmitting antenna location	Aircraft or facility*	
Horizon obstacle distance from facility	From 0.1 to 3 times smooth earth horizon distance (calculated)*	________km, n mi, s mi
Elevation angle above horizontal at facility	<12 deg (calculated)*	________deg
Height above msl	0* to 15,000 ft-msl(4572 m-msl) and ≤ aircraft altitude	________ft, m
Ionospheric scintillation options	No scintillation* or specified	
Frequency scaling factor	Not used* or (136/frequency in MHz)^n with $1 \leq n \leq 2$	
Index group	0* to 5, 6 for variable	________
Rain attenuation options	None* or computed with dB/km or zone	
Attenuation/km	0 dB/km and up	________dB/km
Storm size	5, 10,* 20 km	
Zone	1 to 6	________
Refractivity		
Effective earth's radius	4010 to 6070 n mi (7427 to 11,242 km)	________km, s mi, n mi
or minimum monthly mean, N_o	200 to 400 N-units (301 N-units)*	________
Surface reflection lobing options	Contributes to variability* or determines median level	

Table 2. Parameter Specification, General (cont.)

	Range	Value
Surface type options	Poor, average* or good ground, fresh or sea water, concrete, metal	
Sea state	0-glassy,* 1-rippled, 2-smooth, 3-slight, 4-moderate, 5-rough, 6-very rough, 7-high, 8-very high, 9-phenomenal	
or rms wave height, σ_h	0 to 50 m (164 ft)	______ft, m
Temperature	0, 10,* or 20°C	
Terrain elevation above msl at facility	0* to 15,000 ft-msl (4572 m-msl)	______ft, m
Parameter, Δh	0* or greater	______ft, m
Type options	Smooth* or irregular	
Time availability options	For instantaneous levels exceeded* or for hourly median levels exceeded	
Climates	0*-Continental all year, 1-Equatorial, 2-Continental subtropical, 3-Maritime sub-tropical, 4-Desert, 6-Continental Temperate, 7a-Maritime Temperate Overland, 7b-Maritime Temperate Overseas	
or time blocks	1, through 8, summer, winter	______

(a) Copies of this table may be used to provide data for computer runs by utilizing the blanks provided in the value column and circling desired options. These parameters are common to most programs. However, additional information is needed for various programs and it may be supplied via tables 3 and 4. If desired and undesired facility parameters are not identical, two table 2 parameter specifications, or appropriate notes on a single copy are required.

(b) Parameters are listed in about the same order as on parameter sheets produced by the various programs (figs. 1 through 5). Parameter sheets produced by the various programs are similar, but not identical since only those parameters relevant to a particular program and run will be listed. For example, if the counterpoise diameter is input as zero, the counterpoise will not be considered and none of the parameters associated with it will be listed on the parameter sheet (c.f., fig. 1 with fig. 5).

* Values or options that will be assumed when specific designations are not made are flagged by asterisks.

Table 3. Parameter Specification, Special

Capability	Program	Parameter and Value(s)*
Power available curves	ATLAS	Aircraft altitudes, up to 25, may be specified to cover airspace required: ______ ______ ______ ______ ft-msl, or m-msl.
Power density curves		
Transmission loss curves		
Power available volume	HIPOD	
Power density volume		
Transmission loss volume		
EIRP contours	APODS	
Power available contours		
Power density contours		
Transmission loss contours		
Service volume	SRVLUM	
Signal ratio contours	DURATA	
Power available curves	ATLAS	Time availability: ______ percent. Acceptable values range from 0.01 to 99.99 percent. A value of 95 percent will be used if a value is not specified.
Power density curves		
Transmission loss curves		
EIRP contours	APODS	
Power available contours		
Power density contours		
Transmission loss contours		
Orientation	TWIRL	
Signal ratio contours	DURATA	

Table 3. Parameter Specification, Special (cont.)

Capability	Program	Parameter and Value(s)*
Power available volume	HIPOD	Power available:__________ dBW.
Power density volume	HIPOD	Power density:____________dB-W/sq m
EIRP contours	APODS	
Transmission loss volume	HIPOD	Transmission loss:__________dB.
EIRP contours	APODS	EIRP'S, up to 8:______________________________dBW.
Power available contours	APODS	Powers available, up to 8:______________________________dBW.
Power density contours	APODS	Power densities, up to 8:___________________________dB-W/sq m
Tranmission loss contours	APODS	Transmission loss, up to 8:______________________________dB
Signal ratio-DD	DUDD	
Service volume	SRVLUM	Station separation:____________km, n mi, or s mi.
Signal ratio contours	DURATA	
Signal ratio-S	ATADU	Desired facility-to-aircraft distance:____________km, n mi, or s mi.
Orientation	TWIRL	Desired-to-undesired signal ratio:____________dB.
Service volume	SRVLUM	
Orientation	TWIRL	Protection point location, up to 6:

NOTE: Azimuth is relative to desired station course line with positive values taken as clockwise, and distance is the desired facility-to-aircraft great circle distance

Azimuth		Distance	
_______		_______	
_______		_______	
_______	deg	_______	km, n mi, or s mi
_______		_______	
_______		_______	

*Parameter values required for particular capabilities that are not specified in table 2 may be specified by using the blanks provided here. Circle desired units where multiple units are given.

Table 4. Parameter Specification, Graph Formats

Capability[a]	Program	Ordinate Lower	Ordinate Upper	Ordinate Increment	Ordinate Units[b]	Abscissa Left Side	Abscissa Right Side	Abscissa Increment	Abscissa Units[b]
Lobing	LOBING				dB				km, n mi, or s mi
Reflection coefficient	LOBING								km, n mi, or s mi
Path length difference	LOBING				m				km, n mi, or s mi
Time delay	LOBING				nsec				km, n mi, or s mi
Lobing frequency -D	LOBING				(Hz/THz)/(km/hr) (Hz/THz)/kts (Hz/THz)/(s mi/hr)				km, n mi, or s mi
Lobing frequency -H	LOBING				(Hz/THz)/(m/min) (Hz/THz)/(ft/min)				km, n mi, or s mi
Reflection point	LOBING				km, n mi, or s mi				km, n mi, or s mi
Elevation angle	LOBING				deg				km, n mi, or s mi
Elevation angle difference	LOBING				deg				km, n mi, or s mi
Spectral plot	LOBING	Plot lobe ________ thru ________, counting from the Horizon[c]							
Power available	ATOA				dBW				deg, km, n mi, or s mi
Power density	ATOA				dB-W/sq m				deg, km, n mi, or s mi
Transmission loss	ATOA				dB				km, n mi, or s mi
Power available curves	ATLAS				dBW				km, n mi, or s mi
Power density curves	ATLAS				dB-W/sq m				km, n mi, or s mi
Transmission loss curves	ATLAS				dB				km, n mi, or s mi
Power available curves	HIPOD				ft or m				km, n mi, or s mi
Power density volume	HIPOD				ft or m				km, n mi, or s mi
Transmission loss volume	HIPOD				ft or m				km, n mi, or s mi
EIRP contours	APODS				ft or m				km, n mi, or s mi
Power available contours	APODS				ft or m				km, n mi, or s mi

Table 4. Parameter Specification, Graph Formats (cont.)

		Ordinate				Abscissa			
Capability[a]	Program	Lower	Upper	Increment	Units[b]	Left Side	Right Side	Increment	Units[b]
Power density contours	APODS				ft or m				km, n mi, or s mi
Transmission loss contours	APODS				ft or m				km, n mi, or s mi
Signal ratio -S	ATTADU				dB				km, n mi, or s mi
Signal ratio -DD	DUDD				dB				km, n mi, or s mi
Orientation	TWIRL				deg				deg
Service volume	SERVLUM				ft or m				km, n mi, or s mi
Signal ratio contours	DURATA				ft or m				km, n mi, or s mi

(a) In many cases appropriate graph limit can be adequately selected by the program operator so that values need not always be provided here. However, in such cases the capabilities desired should be indicated (circled), and where required (a,b) units should be specified. A plotting capability guide is provided in table 1.

(b) Circle desired units when multiple units are given. Selections for a particular capability must be consistant; i.e., all English or all metric units.

(c) Any 5 consecutive lobes within 10 lobes of the radio horizon may be specified.

capabilities that involve the use of desired to undesired (D/U) signal ratios involve two facilities. This includes the last 5 capabilities listed in table 1.

Although about 40 items can be specified with table 2, required specification involves only 3. These "primary parameters" consist of antenna heights and frequency. Values for "secondary parameters" will be computed or assumed if not specified. Parameter values (or options) that will be assumed in lieu of specification are indicated in the table along with the acceptable value range (or options available).

The nomenclature used to distinguish between the two antennas of a particular path may be misleading to the uninitiated but is used for convenience. The lower of the two antennas is called the "facility" even though it may be an aircraft. The other antenna must be equal to or higher in altitude than the "facility or lower" antenna and is designated as the "aircraft" even though it may be a ground-based antenna or a satellite.

For convenience, the parameters in table 2 are listed alphabetically within categories. A short discussion of each parameter is provided in the remainder of this section, and these discussions are ordered in accordance with the order of appearance of the parameter in table 2.

AIRCRAFT (OR HIGHER) ANTENNA HEIGHT As shown in figure 44, this altitude is measured above mean sea level (msl). The propagation model is not valid for antennas located below the surface, and radio horizons may not be treated correctly if the aircraft altitude is less than the facility antenna horizon elevation above msl. Use of such aircraft altitudes will result in an aborted run after an appropriate note has been printed on the computer-generated parameter sheet (e.g., fig. 1). Notes are printed, but the run is not aborted if the altitude is (a) less than 1.5 ft (0.5 m) where surface wave contributions that are not included in the model could become important, or (b) less than the effective reflecting surface elevation plus 500 ft (152 m) where the model may fail to give proper consideration to the aircraft radio horizon.

<u>FACILITY (OR LOWER) ANTENNA HEIGHT</u> As shown in figure 44, this height is measured above the facility site surface (fss). The propagation model is not valid for antennas below the surface, and such a facility antenna height will result in an aborted run, after an appropriate note has been printed on the computer-generated parameter sheet (e.g., fig. 1). A note is printed, but the run is <u>not</u> aborted if the height is less than 1.5 ft (0.5 m), for which surface wave contributions not included in the model could become important.

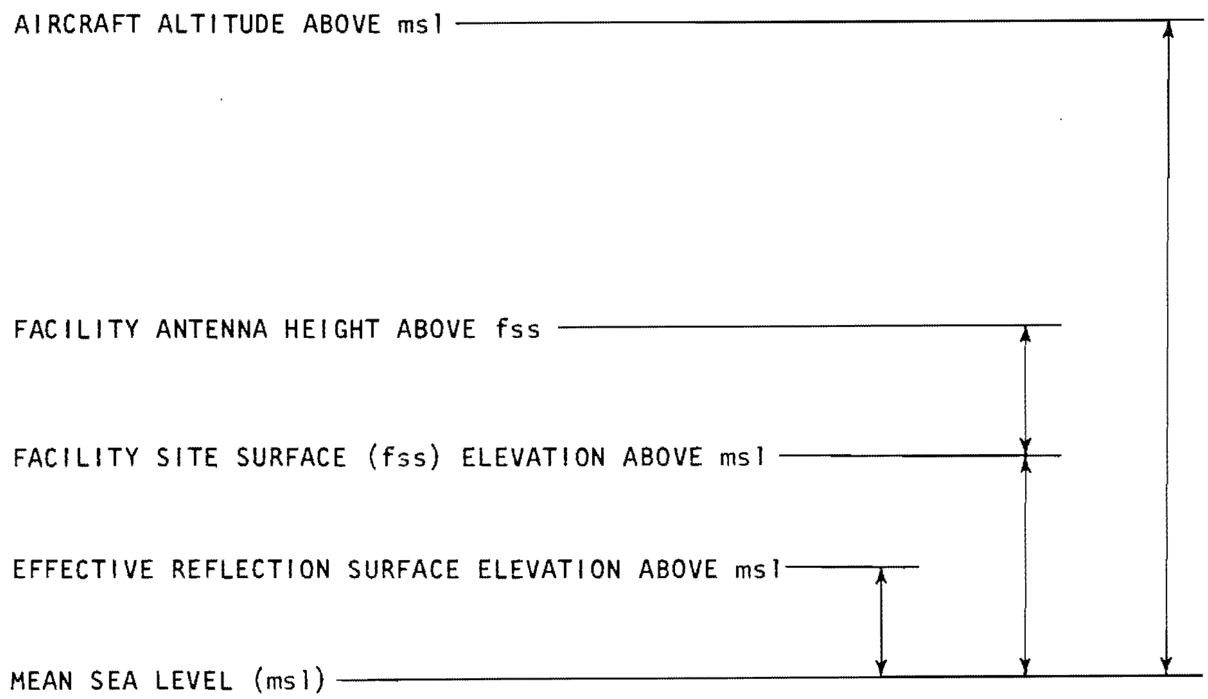


Figure 44. Antenna heights and surface elevations. Note that the aircraft altitude is elevation above msl while the facility antenna height is measured with respect to fss.

FREQUENCY Notes are printed if the frequency is (a) less than 100 MHz, when neglected ionospheric effects may become important; (b) greater than 5 GHz, when neglected scattering from hydrometeors (rain, etc.) may become important; and (c) greater than 17 GHz, when the estimates made for atmospheric absorption may be inaccurate. For frequencies less than 20 MHz or greater than 100 GHz, the run is aborted.

AIRCRAFT ANTENNA TYPE OPTIONS These options involve the antenna gain pattern of the aircraft antenna in the vertical plane. Options currently built into the program include isotropic, cosine (voltage), and JTAC (see eqn. 10) patterns (fig. 45). Program modifications can easily be made to accommondate other patterns that are specified in terms of gain versus elevation angle. Horizontal (or azimuth) patterns for the aircraft antenna are not used in any program.

Antenna pattern data are used to provide information on gain relative to the main beam only. The extent to which the main beam antenna gain exceeds that of an isotropic antenna is listed in table 2 as a separate item (i.e., under GAIN) and is included in the specification of EIRPG (see eqn. 12).

AIRCRAFT ANTENNA BEAM WIDTH This parameter is currently used only in connection with the JTAC [33, p. 51] antenna pattern where relative (voltage) gain (g) is a function of the half-power beam width (θ_{HP}), beam tilt above horizontal (θ_t), and the ray elevation angle (θ_e) for which g is desired [24, (67)]; i.e.,

$$g[V/V] = \left[1 + (2|\theta_e - \theta_t|/\theta_{HP})^{2.5}\right]^{-0.5} \tag{10}$$

where θ_e, θ_t, and θ_{HP} must all be expressed in the same units of angular measure, such as degrees or radians.

AIRCRAFT ANTENNA POLARIZATION OPTIONS Polarization of the aircraft is not optional. It is always taken as being identical with that of the facility antenna, which may be specified as circular, horizontal, or vertical. Therefore, losses associated with polarization sense mismatch are not included in the programs. However, provisions do exist to allow antenna gain patterns for horizontally and vertically polarization components to be individually specified for calculations involving circular polarization.

AIRCRAFT ANTENNA TILT The aircraft antenna main beam tilt above horizontal is currently used only with the JTAC antenna pattern formulation of (10).

AIRCRAFT ANTENNA TRACKING OPTION If this tracking option is used, the main beam of the aircraft antenna will always point at the desired facility antenna.

EFFECTIVE REFLECTION SURFACE ELEVATION As shown in figure 44, this elevation is measured above msl. If not specified, it will be taken as the terrain elevation above msl of the facility site surface (fss). This factor is used when the terrain from which reflection is expected is not at the same elevation as the facility site; e.g., a facility located on a hilltop or cliff edge. When the elevation of the facility antenna or horizon obstacle is below the effective reflection surface level, a note will be printed and the run aborted. This elevation is also used as the elevation of average terrain for terrain other than the facility site and horizon obstacle.

The following guidelines are useful in estimating effective reflecting surface elevations:

1) Do not specify a value for this elevation (then a value equal to the facility site elevation will be assumed) if (a) terrain information is too difficult to obtain, or (b) the path profile [49, sec. 6.2] is such that a reasonable estimate is difficult. For example, do not specify a value when the facility-to-horizon reflection would be expected to occur from a tilted plane and the facility horizon obstacle elevation is greater than the facility site elevation.

2) Take this elevation as the facility horizon obstacle elevation if the path profile is such that the facility-to-horizon reflection would be expected to occur from a tilted plane and the

horizon obstacle elevation is <u>less</u> than the facility site elevation; e.g., when the terrain slopes downward from the facility site to its horizon so that none or very little of the terrain between the two has an elevation less than that of the horizon obstacle.

3) This elevation should, in most cases, be taken as an estimate of average terrain elevation in the vicinity of the surface along the great-circle path that is expected to support reflection between the facility antenna and the facility horizon obstacle. In a plane tangent to the reflecting point, the angle of incidence should equal the angle of reflection; i.e., grazing angles (ψ of fig. 40) are equal at the reflecting point [8, sec. 11.A; 27, sec. CI-C.2].

The effort required to determine appropriate terrain input parameters for IF-77 when the first two guidelines are not applicable can be very difficult for inexperienced personnel without adequate tools. Experienced personnel and computer programs useful in processing terrain data are available at DOC and should be utilized for difficult problems.

<u>EQUIVALENT ISOTROPICALLY RADIATED POWER</u> Equivalent isotropically radiated power (EIRP) is the power radiated from the transmitting antenna increased by the antenna's main lobe gain; i.e.,

$$EIRP[dBW] = P_{TR}[dBW] + G_T[dBi] \tag{11}$$

where P_{TR} is the total power radiated from the transmitting antenna and G_T is the main beam gain of the transmitting antenna. The term EIRPG is sometimes used (e.g., fig. 16) to indicate EIRP increased by the receiving antenna main beam gain (G_R); i.e.,

$$EIRPG(dBW] = EIRP[dBW] + G_R[dBi]. \tag{12}$$

In the calculation of transmission loss (e.g., fig. 23) only the sum of the antenna gains is involved, and the term GAIN is used where

$$GAIN[dBi] = G_T[dBi] + G_R[dBi]. \tag{13}$$

For example, a radiated power of 10 dBW, a transmitting antenna gain of 10 dBi, and a receiving antenna gain of 6 dBi would result in 20 dBW EIRP, a 26 DBW EIRPG, and a 16 dBi GAIN. Effective radiated power (ERP) is similar to EIRP but is calculated with an antenna gain specified relative to a half-wave dipole; therefore, an EIRP value is 2.15 dB higher than an equivalent ERP value when the same radiated power is involved.

FACILITY ANTENNA TYPE OPTIONS These options involve the antenna gain pattern of the facility antenna. Some of the vertical plane patterns currently available include those illustrated in figures 45 and 46 where antenna gain, normalized to the maximum gain, is plotted against elevation angle (measured above the horizontal).

Figure 45 shows vertical patterns for the cosine, isotropic, TACAN RTA-2 [12], and Tull. The "cosine" (voltage) pattern [24, (67)] is used for a vertically polarized electric dipole or a horizontally polarized magnetic dipole such as the antenna associated with VOR. Measured gain data on the RTA-2 and modified RTA-2 antennas, supplied to DOC by FAA, were used in obtaining the patterns for these TACAN antenna types. The Tull pattern is the vertical radiation pattern associated with the localizer portion of the Tull Microwave Instrument Landing System and is a piecewise linear fit to data provided via the FAA.

Figure 46 shows vertical patterns for different Distance Measuring Equipment (DME) antennas. These patterns are all piecewise linear fits to information provided by the FAA. Dashed lines are used where the curves are extended beyond the data provided. The pattern labeled "DME-Specification" was developed from a FAA specification [17, sec. 3.5.7] by using minimum acceptable gain values.

One pattern is currently available that allows beam width and tilt to determine the pattern. This pattern is the JTAC pattern previously discussed under "Aircraft antenna beam width" where (10) defines the relative gain in terms of beam width and tilt. Program modifications can easily be made to accommodate

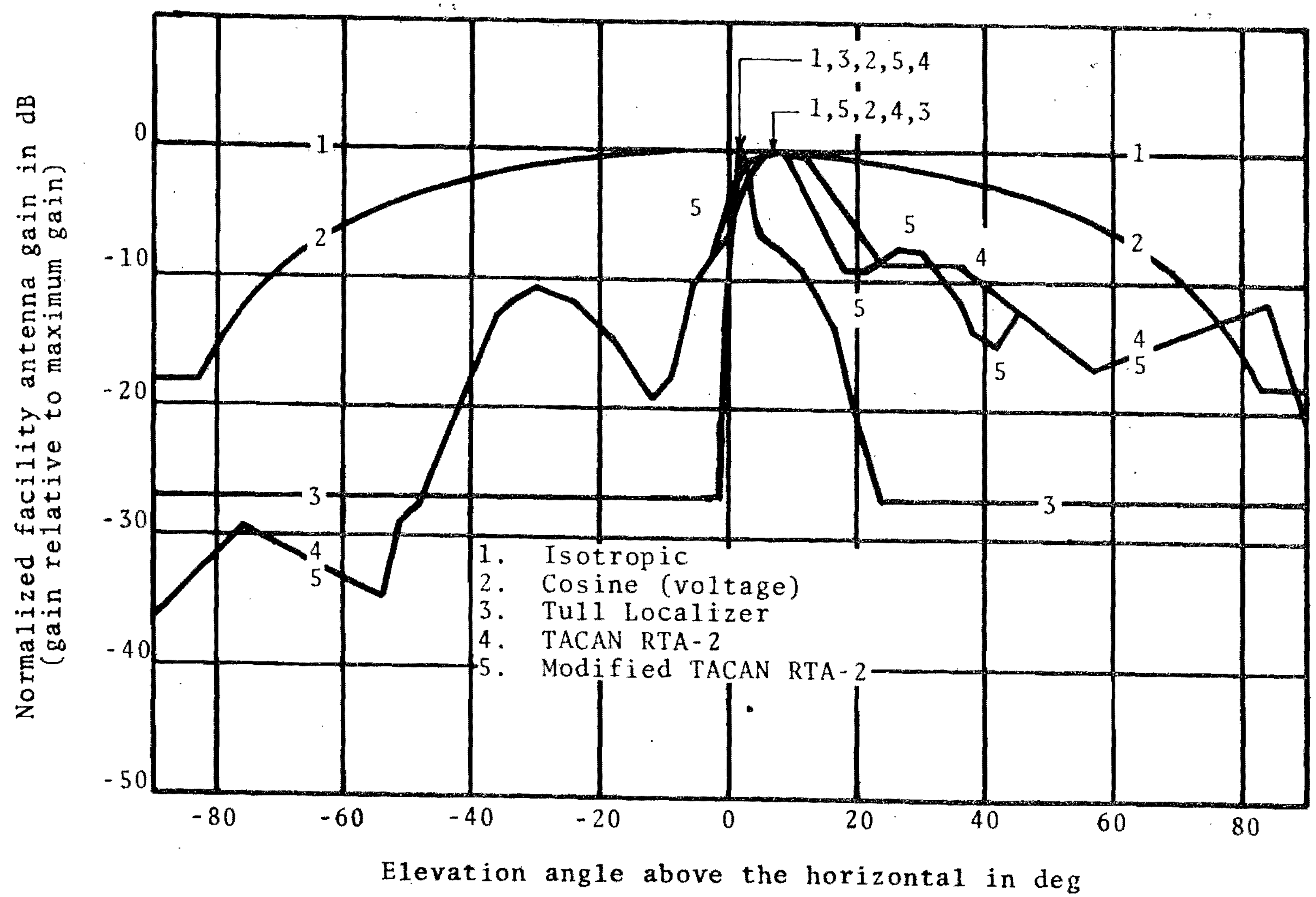


Figure 45. Normalized antenna gain vs. elevation angle.

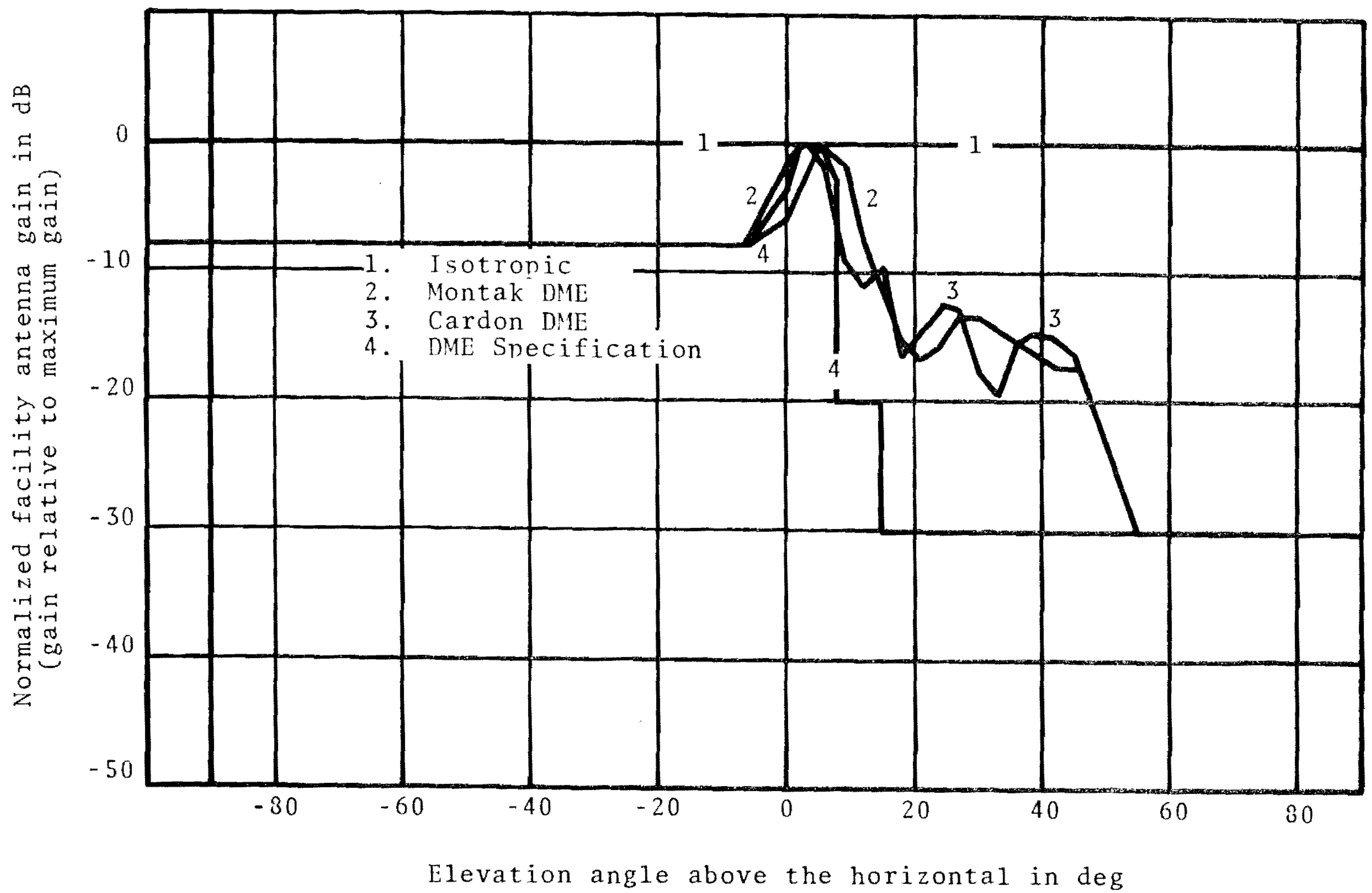


Figure 46. Normalized antenna gain vs. elevation angle, DME

other patterns that are specified in terms of gain versus elevation angle.

Program TWIRL is the only program which involves the use of horizontal plane (azimuth) antenna patterns (see ORIENTATION, fig. 35, discussion in sec. 3.2). An example of such a pattern is the localizer portion of an ILS 8-loop array antenna [22, fig. 1]. This pattern and preliminary patterns for other ILS localizer antennas are currently available, but program modifications can easily be made to accommondate other patterns that are specified in terms of gain versus azimuth angle.

Antenna pattern data are used to provide information on gain relative to main beam only. The extent to which the main beam antenna gain exceeds that of an isotropic antenna is listed in table 2 as a separate item (i.e., under GAIN) and is used in the specification of EIRP as per (11) when the antenna is transmitting.

FACILITY ANTENNA BEAM WIDTH This parameter is currently used only in connection with the JTAC antenna pattern given by (10).

FACILITY ANTENNA COUNTERPOISE DIAMETER The counterpoise was incorporated into the model for the VOR. It will not be included in the calculations if its diameter is specified as zero, and the parameters associated with it will not be printed. A diameter greater than 500 ft (152 m) will cause a warning note to be printed, but will not abort the run.

FACILITY ANTENNA COUNTERPOISE HEIGHT If the counterpoise height above the facility site surface (fss) is less than zero, it will be set equal to zero. An appropriate note will be printed and the run aborted if the height is (a) greater than 500 ft (152 m), or (b) greater than the facility antenna height. The facility antenna should be above the counterpoise by at least one-third of a wavelength, which is 3 ft (1 m) at 100 MHz, and by not more than 2,000 ft (610 m).

FACILITY ANTENNA COUNTERPOISE SURFACE OPTIONS Counterpoise surface options fix the conductivity and dielectric constant associated with the counterpoise surface. Values associated with each option are given in table 5.

FACILITY ANTENNA POLARIZATION OPTIONS These options include circular , horizontal, and vertical polarization [47, ch. 8]. Polarization for the aircraft antenna is always taken as being identical with that of the facility antenna. Therefore, losses associated with polarization sense mismatch are not included in the programs. However, provisions do exist to allow antenna gain patterns for horizontally and vertically polarized components to be individually specified for calculations involving circular polarization.

FACILITY ANTENNA TILT The facility antenna main beam tilt above horizontal is currently used only with the JTAC antenna pattern formulation of (10). However, it can also be used to adjust the tilt of other patterns.

FACILITY ANTENNA TRACKING OPTION If this tracking option is used, the main beam of the facility antenna will always point at the aircraft.

Table 5. Surface Types and Constants [25, table 6]

Type	Conductivity (mhos/m)	Dielectric Constant
Poor ground	0.001	4
Average ground	0.005	15
Good ground	0.02	25
Sea water	5*	81*
Fresh water	0.01*	81*
Concrete	0.01	5
Metal	10^7	10

*More appropriate values are calculated if surface sea temperature is specified.

FREQUENCY FRACTION This is the fraction of the carrier frequency that corresponds to half the bandwidth used for the spectral plot capability (fig. 15). For example, a carrier frequency of 125 MHz and a fraction of 0.0004 would result in a bandwidth of (2)(0.0004)(125) = 0.1 MHz = 100 kHz.

GAIN, RECEIVING ANTENNA This item is the main beam gain [dBi] of the receiving antenna. A 0 dBi value will be assumed if no gain is specified.

GAIN, TRANSMITTING ANTENNA This item is the main beam gain [dBi] of the transmitting antenna. A 0 dBi value will be assumed if no gain is specified.

TRANSMITTING ANTENNA LOCATION This item is included to provide a more complete specification of problem parameters and to allow the program operator to check for potential incorrect power density or D/U estimates. Other predictions have transmitter/receiver reciprocity. Power density and D/U calculations assume that the transmitting antenna is located at the facility.

HORIZON OBSTACLE DISTANCE FROM FACILITY If not specified, this distance will be calculated from horizon parameters that are specified and/or by using the terrain parameter Δh. When the distance is not within 0.1 to 3 times the smooth earth horizon distance, a warning note will be printed, but the run will not be aborted.

HORIZON OBSTACLE ELEVATION ANGLE ABOVE HORIZONTAL AT FACILITY If not specified, the horizon obstacle elevation angle at the facility will be calculated from horizon parameters that are specified and/or by using the terrain parameter Δh. When the angle exceeds 12°, a warning note will be printed, but the run will not be aborted.

HORIZON OBSTACLE HEIGHT If not specified, this height will be calculated from horizon parameters that are specified and/or by using the terrain parameter Δh. When the height is not within the 0 to 15,000 ft-msl (4572 m) range, a warning note will be printed, but the run will <u>not</u> be aborted.

<u>IONOSPHERIC SCINTILLATION FREQUENCY SCALING FACTOR</u> The use of this simple scaling factor is optional. It should only be used when estimates of the variability associated with ionospheric scintillation at a particular frequency (f in MHz) must be based on data collected at 136 MHz [55, sec. 3.4]. Use of this factor results in scaling by $(136/f)^n$ where n varies from 1 to 2 as a function of facility latitude [55, (27)].

<u>IONOSPHERIC SCINTILLATION INDEX GROUP</u> Variability associated with ionospheric scintillation for paths that pass through the ionosphere (e.g., earth station/satellite path) is considered via the distributions shown in figure 47. Input requirements involve the specification of the particular scintillation index group (fig. 47) of interest. Scintillation index is the ratio of peak excursion from mean power to mean power [46, (2); 58]. Provisions exist (table 2, index group = 6) to allow the signal level variability associated with ionospheric scintillation to change with earth facility latitude. Figure 48 shows the distributions currently used when this option is selected. These distributions were developed by mixing distributions for particular scintillation index groups in accordance with the estimated time for which they would be present at a frequency of 136 MHz [55, sec. 3.4] so that the frequency scaling factor discussed above should be used with these distributions. However, only minor program modifications would be necessary to incorporate other distributions that might be of interest.

<u>RAIN ATTENUATION OPTIONS</u> An allowance for rain attenuation may be made by using a fixed attenuation rate (dB/km) or by using rain attenuation statistics for a particular rain zone and storm size. Rain attenuation via the rain zone model is present for less than 2 percent of the time so that only time availabilities greater than 98 percent will be affected.

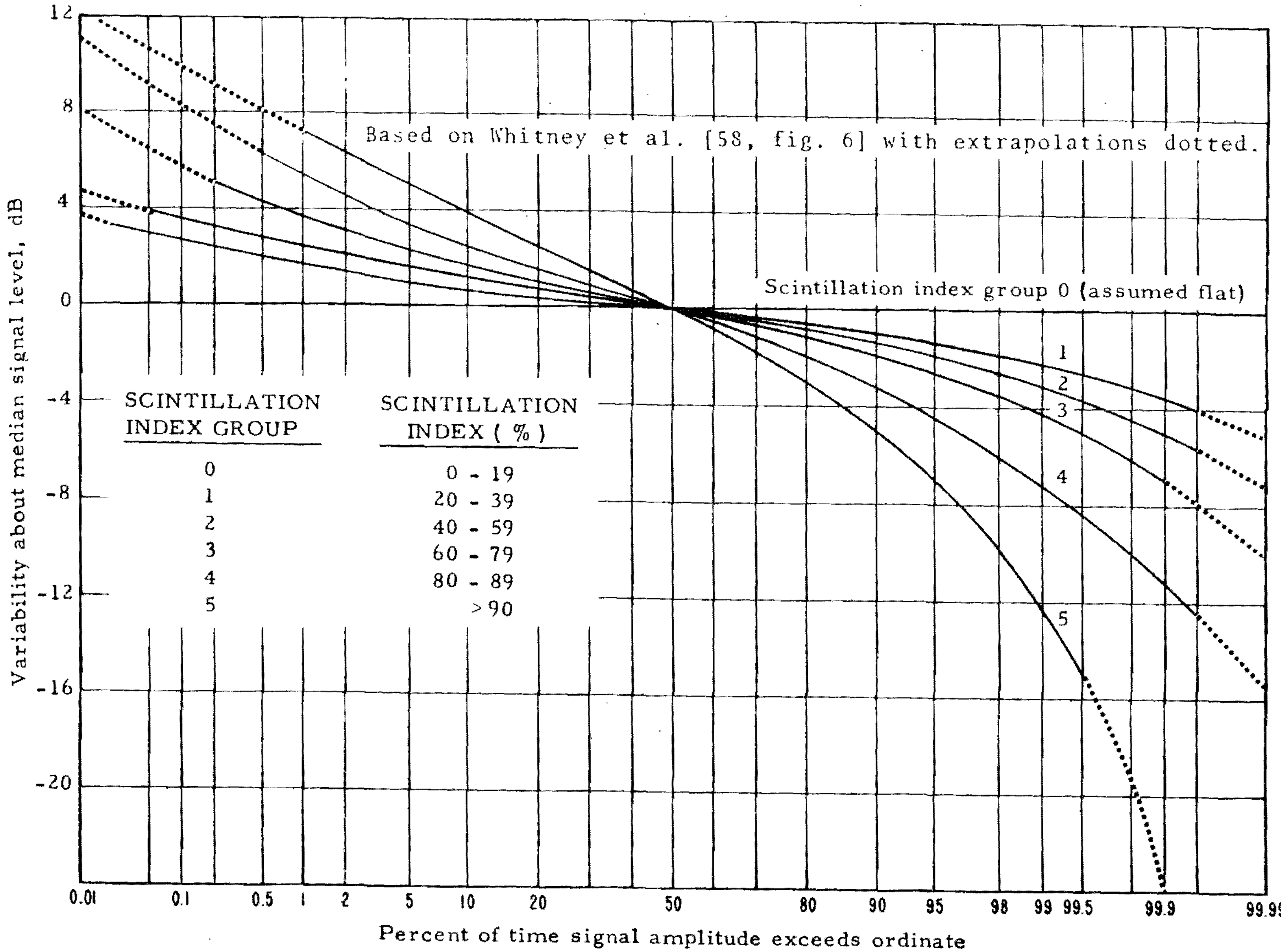


Figure 47. Signal-level distributions for ionospheric scintillation index groups.

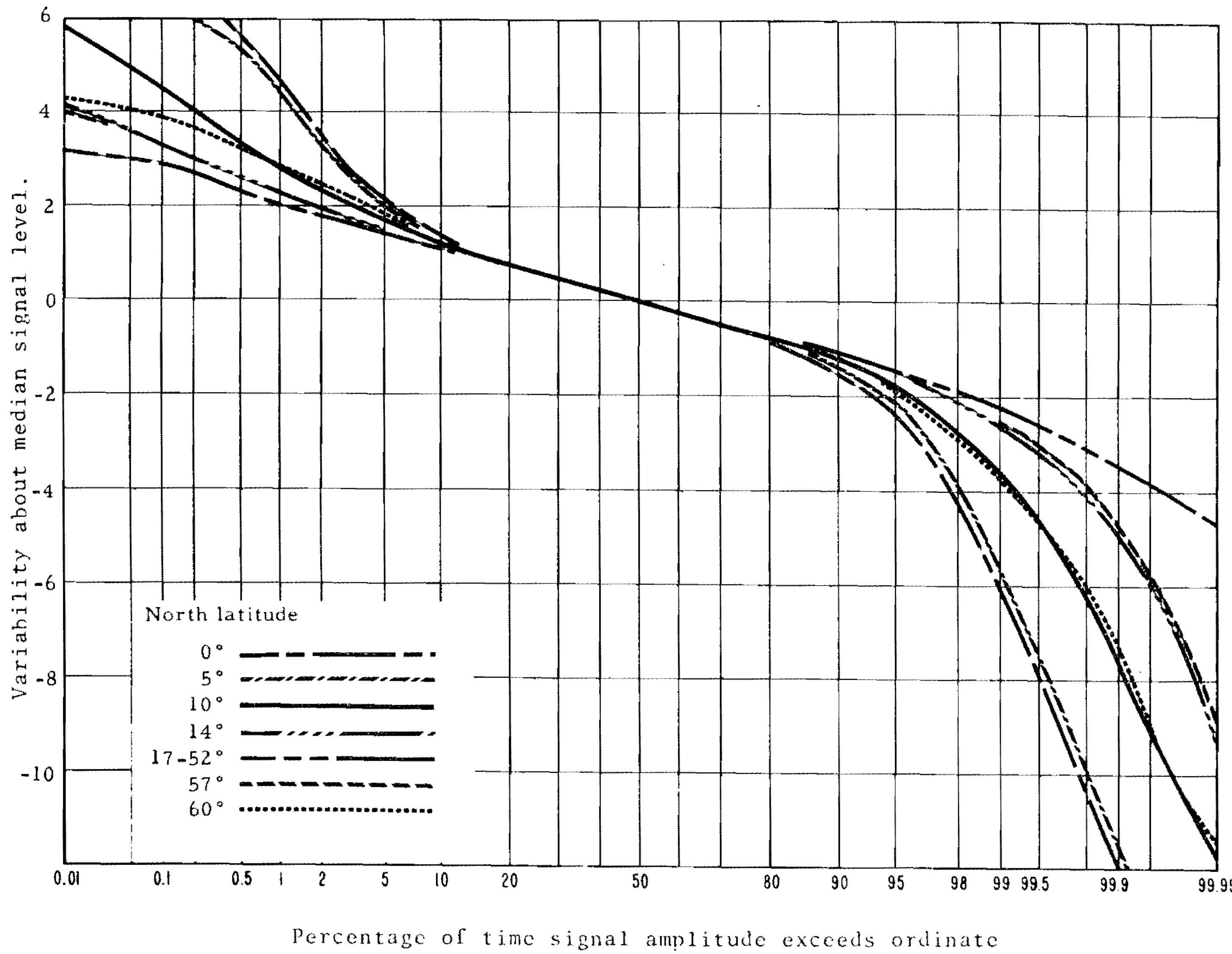


Figure 48. Signal-level distributions currently used with variable scintillation group option selected. These distributions were developed from data collected at 136 MHz [55, sec. 3.4] so that the frequency scaling factor should be used with them.

RAIN ATTENUATION/KM With this option, rain attenuation is calculated as the product of the attenuation rate and the length of the most direct ray path between the terminals that is within the storm.

RAIN STORM SIZE This is the length (or diameter) of the storm over the great-circle path connecting the terminals. It is assumed that this length is made up by a single storm that extends to an altitude above average terrain that is equal to the storm size and contains as much of the most direct ray path as possible. For the models used here the greatest length of path subjected to rain attenuation is limited to the rain storm length and the smallest is zero since the direct ray could be entirely above the storm for an air-to-air propagation path.

RAIN ZONE If the option involving statistical attenuation rates is desired, a rain zone number from either figure 49 for the continental United States or figure 50 for other parts of the world is selected [51, 52, 53, 54, 57]. Rain attenuation via this option is present for less than 2 percent of the time so that only time availabilities greater than 98 percent will be affected.

REFRACTIVITY Values for the minimum monthly mean surface refractivity referred to mean sea level (N_o) may be estimated from either figure 51 for the continental United States or figure 52 for other parts of the world. Other information [3, 4, 5, 50, 51, 52] which may be more appropriate for the particular conditions (e.g., time of year and location) involved can be used to estimate N_o or a minimum monthly mean value for effective earth radius. Specification of N_o outside the 200-to-400 N-unit range will result in N_o being set to 301. If the surface refractivity (N_s) calculated [49, (4.3)] from N_o is less than 200 N-units, N_s will be set to 200 N-units and an appropriate note printed. An N_s of 301 N-units corresponds to an effective earth radius factor of 4/3 [49, fig. 4.2], If desired, a value for effective earth radius can be specified directly.

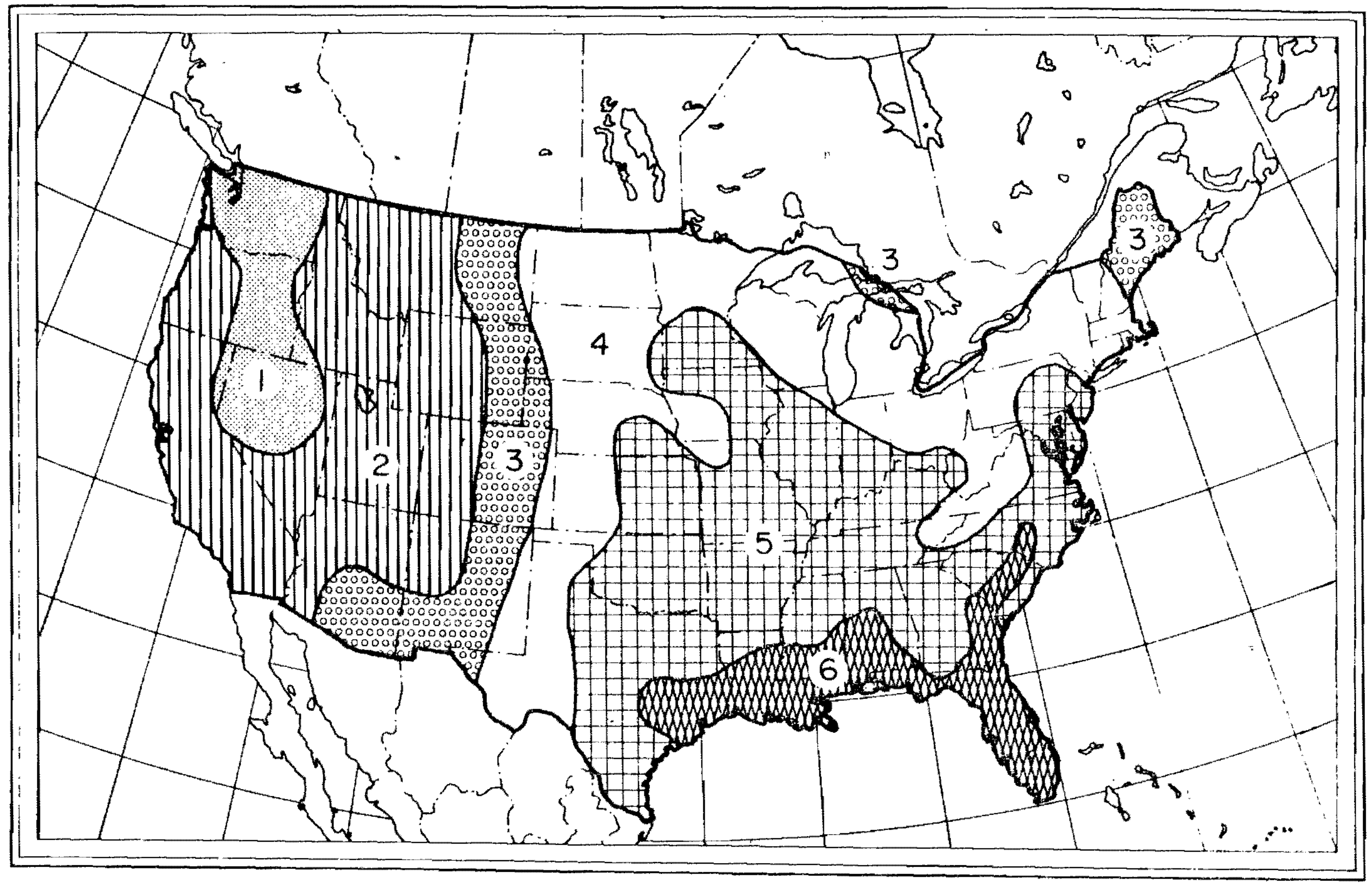


Figure 49. *Rain zones of the continental United States [54, fig. 10]. Areas where the 5-min rainfall rate in inches/hour is expected to occur once in 2 years on the average are shown; e.g., area 5 ranges from 4 1/2 to 5 1/2 in/hr (110 to 140 mm/hr). Rain rates of 1, 2, 3, 4, 5, and 6 in/hr are equivalent to rates of 25, 51, 76, 100, 130 and 150 mm/hr, respectively.*

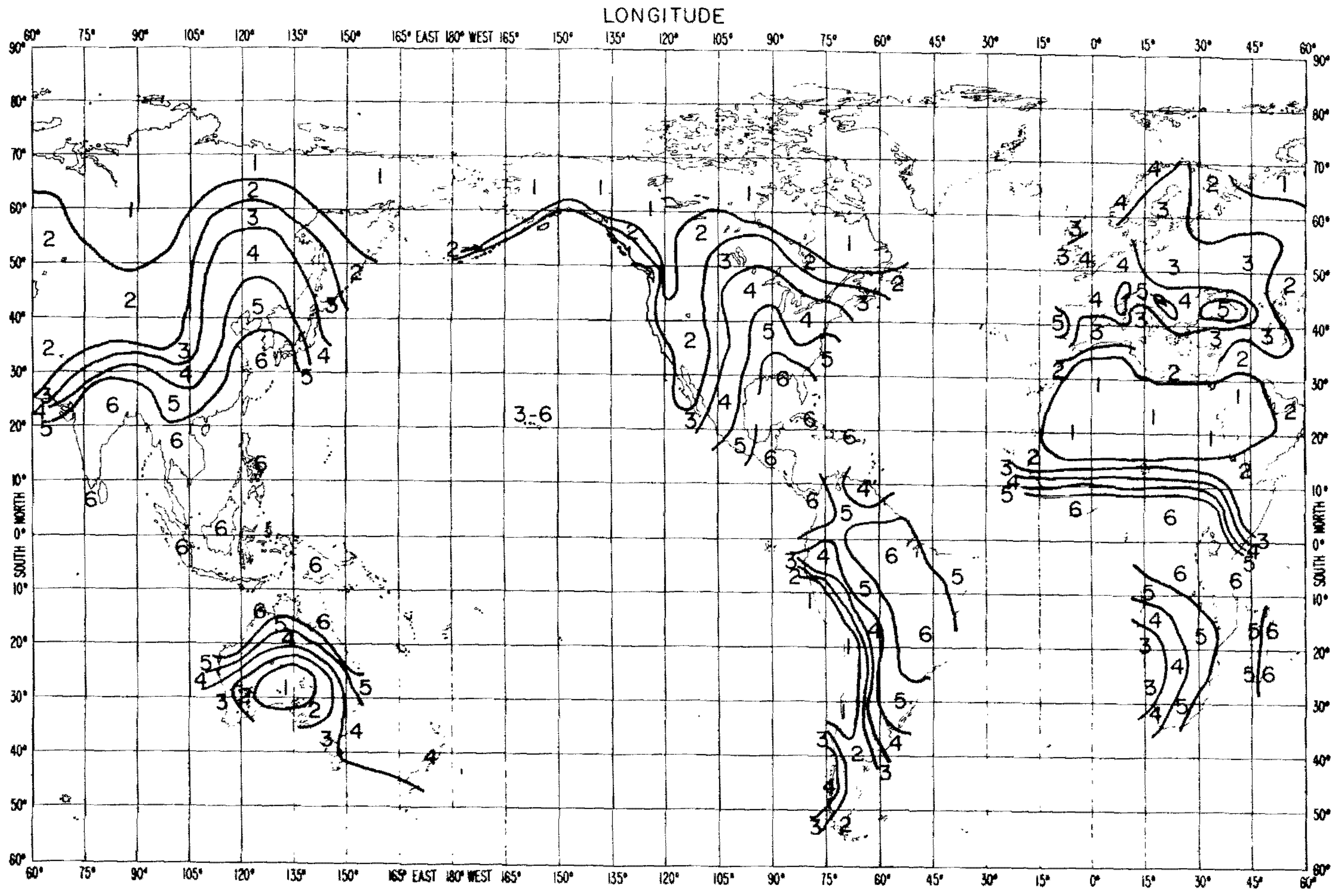


Figure 50. Rain zones of the world (Samson, DOC, informal communication). This map is based on much less data than the figure 49 and should be used only to provide a rough indication of the areas in which rain attenuation may be a significant factor. Zone numbers used here have the same significance as those used in figure 56.

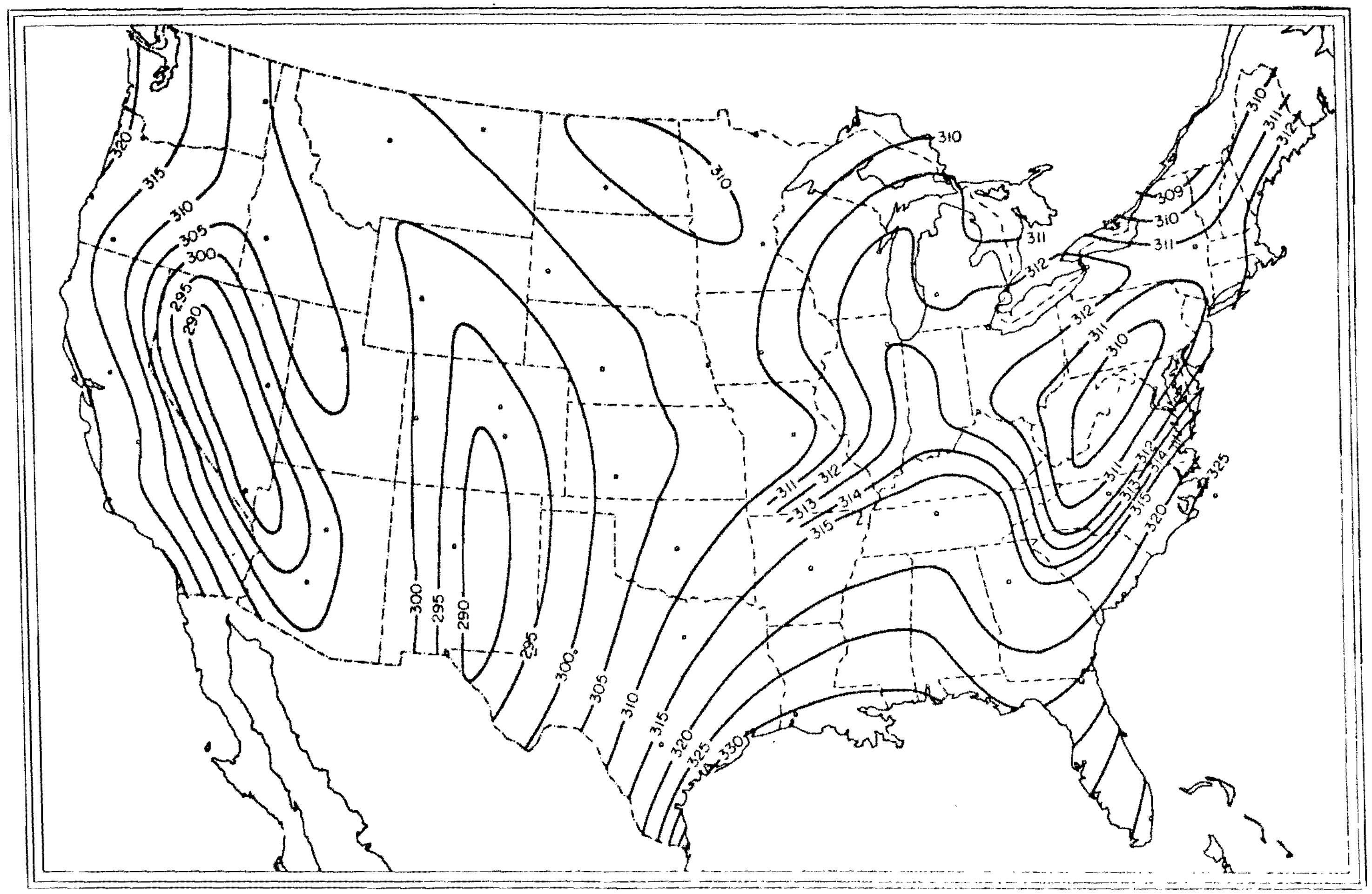


Figure 51. Surface refractivity for the continental United States [48, fig. 34]. Minimum monthly mean surface refractivity values shown are referred to mean sea level, N_o in N-units.

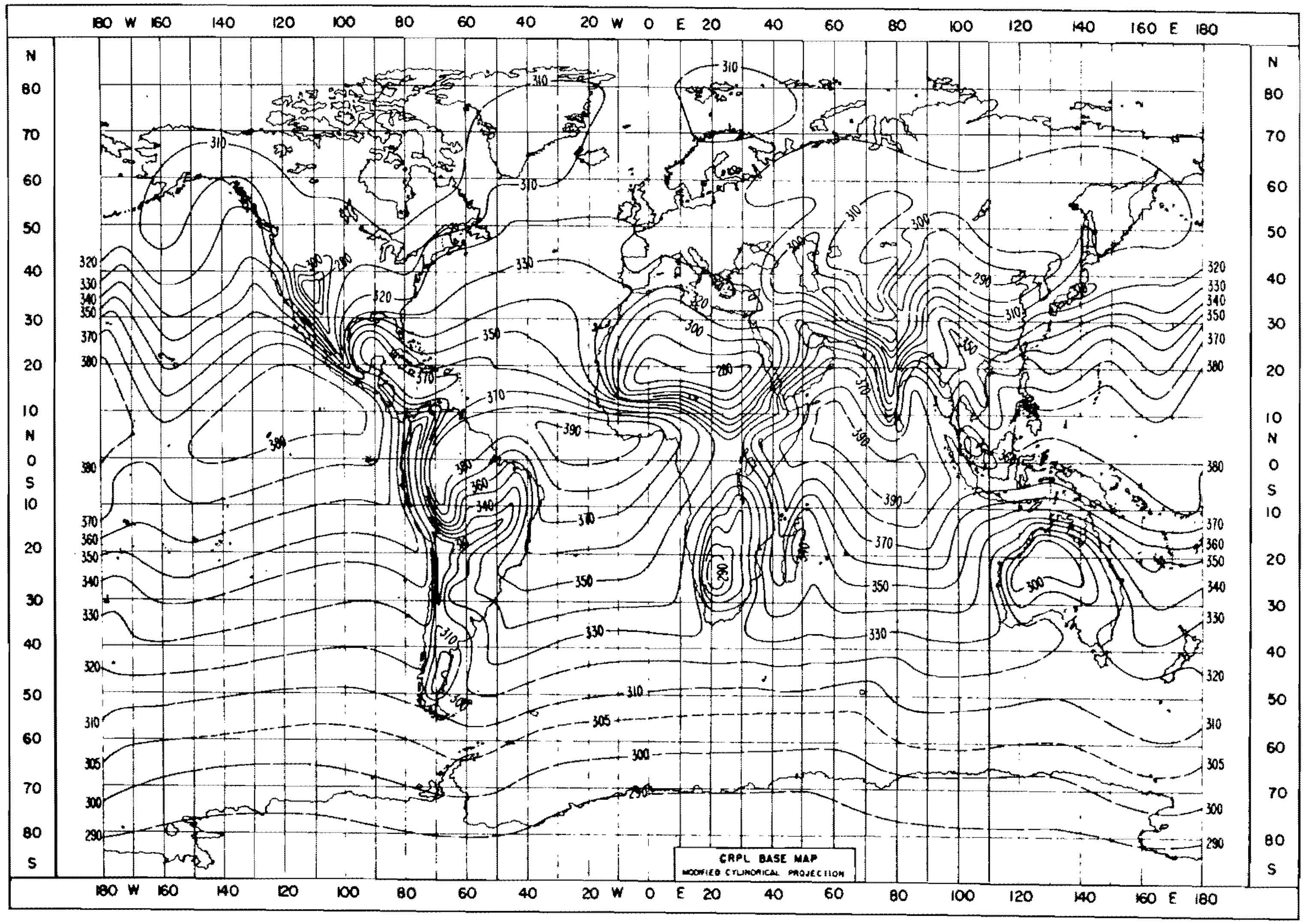


Figure 52. Surface refractivity for the world [49, fig. 4.1]. Minimum monthly mean surface refractivity values are referred to mean sea level, N_o in N-units.

SURFACE REFLECTION LOBING OPTIONS Lobing associated with the phase difference between direct and reflected rays in the line-of-sight region contributes to the short-term variability (within the hour fading) or is used to define the median level in the line-of-sight region. These options can result in predictions that are very different. The variability option provides a more reliable estimate of propagation statistics in most cases. However, the lobing pattern option is useful when selecting antenna heights to avoid low signal levels (nulls) in particular portions of air space. With the variability option, lobing is treated as part of the short-term (within-the-hour) variability when the reflected ray path length exceeds the direct ray path length by more than half a wavelength (inside horizon lobe) so that the lobing pattern is not plotted. The other option allows the median level to be determined by such lobing for the first ten lobes inside the radio horizon so that the lobing pattern will be plotted. Regardless of the option selected, lobing caused by reflection from the counterpoise (if present) is used in median level determination and does not contribute to the short-term fading; i.e., if present, counterpoise lobing is plotted with either option.

SURFACE TYPE OPTIONS These options fix the conductivity and dielectric constants associated with the effective reflecting surface. Values associated with each option are given in table 5. If the surface is water, the constants of table 5 may be used or surface constants may be calculated using surface sea temperature.

SURFACE SEA STATE If fresh or sea water is chosen, an allowance may be made for water roughness by specifying sea state or the root-mean-square deviation of surface excursions within the limits of the first Fresnel zone in the dominant reflecting plane (σ_h). Table 6 shows the relationship used to relate sea state to σ_h.

Values for a σ_h provided in table 6 were estimated using significant wave height ($H_{1/3}$) estimates from Sheets and Boatwright [53, table 1] with a formulation given by Moskowitz

Table 6. Estimates of σ_h for Sea States [27, p. CI-81].

Sea State Code[a]	Descriptive Terms[a]	Average Wave Height Range Meters (feet)	$H_{1/3}$[b] Meters (feet)	σ_h[c] Meters (feet)
0	Calm (glassy)	0 (0)	0 (0)	0 (0)
1	Calm (rippled)	0 - 0.1 (0 - 0.33)	0.09 (0.3)	0.00 (0.08)
2	Smooth (wavelets)	0.1 - 0.5 (0.33 - 1.6)	0.43 (1.4)	0.11 (0.35)
3	Slight	0.5 - 1.25 (1.6 - 4.0)	1 (3.3)	0.25 (0.82)
4	Moderate	1.25 - 2.5 (4 - 8)	1.9 (6.1)	0.46 (1.5)
5	Rough	2.5 - 4 (8 - 13)	3 (10)	0.76 (2.5)
6	Very rough	4 - 6 (13 - 20)	4.6 (15)	1.2 (3.8)
7	High	6 - 9 (20 - 30)	7.9 (26)	2 (6.5)
8	Very high	9 - 14 (30 - 46)	12 (40)	3 (10)
9	Phenomenal	>14 (>46)	>14 (>45)	>3.5 (>11)

(a) Based on international meteorological code [42, code 3700].

(b) Estimates significant wave heights, average of highest one-third, $H_{1/3}$ [53, table 1].

(c) Estimated using a formulation provided by Moskowitz [41, (1)] with $H_{1/3}$ estimates.

[41, (1)]. However, σ_h may also be specified directly.

SURFACE SEA TEMPERATURE The dielectric constants and the conductivity of water vary with frequency, salinity, and temperature [27, sec. CI-D.8]. The programs allow water surface constants to be calculated for either fresh water or average sea water (3.6% salt) and three water temperatures (0°, 10°, or 20°C).

TERRAIN ELEVATION This is the elevation of the facility site above msl (fig. 44). Values less than zero are set to zero, and a note will be printed if the 15,000 ft-msl (4572 m-msl) limit is exceeded, but the run will not abort.

TERRAIN PARAMETER The terrain parameter (Δh) is used to characterize irregular terrain. Values for it may be calculated from path profile data [37, annex 2] or estimated using table 7. When the aircraft is much higher ($\geq$ 10 times) than the facility, the terrain used to determine Δh should be that terrain between the facility and its radio horizon. Estimates can also be made using figure 53 when profile data or terrain type information is not conveniently available.

Table 7. Estimates of Δh [37, table 1]

Type of Terrain	Δh (feet)	Δh (meters)
Water or very smooth plains	0 - 20	0 - 5
Smooth plains	20 - 70	5 - 20
Slightly rolling plains	70 -130	20 - 40
Rolling plains	130 -260	40 - 80
Hills	260 -490	80 -150
Mountains	490 -980	150 -300
Rugged Mountains	980 -2000	300 -700
Extremely rugged mountains	>2,000	>700

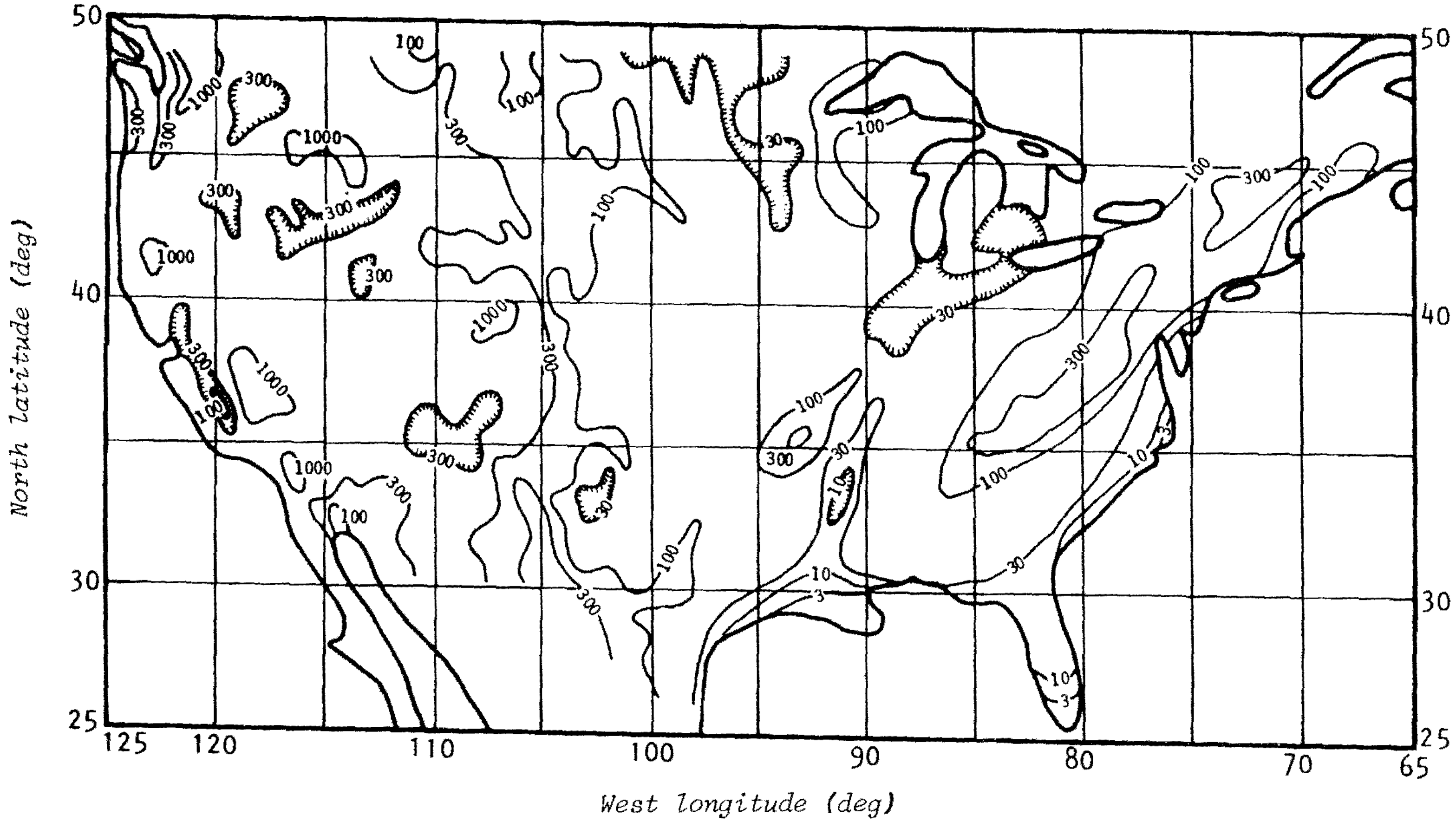


Figure 53. Contours of the terrain factor Δh in meters (informal communication, G. A. Hufford, DOC). The computations assumed random paths and homogeneous terrain in 50 km (30 n mi) blocks. Allowances should be made for other situations. Terrain parameter values of 3, 10, 30, 100, 300 and 1,000 m are equivalent to 9.8, 33, 98, 328, 984, and 3,281 ft.

TERRAIN TYPE OPTIONS If the smooth earth option is selected, all calculations will be based on smooth earth parameters even though parameters specified elsewhere imply irregular terrain. For example, smooth earth specification would cause specified horizon parameters to be neglected and smooth earth values used in their place.

TIME AVAILABILITY OPTIONS If the first option is selected, short-term (within-the-hour) fading will contribute to the variability, and time availability is applicable to instantaneous levels that are available for specific percentages of the time. With the second option, only long-term (hourly median) variations are included in the variability, and time availability is applicable to the hourly median levels that are available for a specific percentage of hours.

TIME AVAILABILITY CLIMATES OR TIME BLOCKS If no option is selected under climates, the programs will use the long-term (hourly median) variability as described in Gierhart and Johnson [24, sec. A.5]; i.e., continental all year climate. Climates similar to those defined by the CCIR [9] and described in table 8 are available. Variability functions for these climates were developed at the DOC (informal communication, A. G. Longley and G. A. Hufford). The factor used in the propagation model to avoid excessive variability for paths with a very high antenna (satellite) was developed for the continental all year climate [23, fig. 2], and the use of other climates for satellite paths may result in excessive variability. Time blocks for the continental temperate climate also are options. The time block periods are defined in table 9.

4.2 SPECIAL PARAMETERS (Table 3, p. 76)

Special parameters required for particular capabilities are covered in table 3. Some of these parameters are required for more than one capability, and the 13 capabilities associated with programs LOBING and ATOA (table 1) do not require parameters from

Table 8. Climate Types and Characteristics

CCIR Climate	Radio-Climate Designator	Approximate Latitude Range	Seasonal Temperature (^{o}F) Variation	Absolute Humidity (Surface)	Annual Precipitation Inches (cm)	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^{o}N-10^{o}S	Small	High all seasons	40-100 (102-254)	Maxima near equinoxes (Mar. 21 - Sept. 23); no completely dry season.	Prevailing easterlies; frequent calms.	360	0- 30	Shower type rain predominates; any anomalous propagation occurs in stable periods between showers.
2	Continental sub-tropical	10^{o}-20^{o}	Moderate	Winter: moderate to high; summer: high	10-100 (25-254)	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^{o}-20^{o}	Moderate	High	10-100 (25-254)	Dry winter, rainy summer.	Monsoonal shift in direction.	370	30- 60	Usually lowlands near sea.
4	Desert	20^{o}-30^{o}	Very large	Very low	<10 <(25)	Dry all seasons, large year-to-year variations.		280	20- 80	Scatter propagation poor, especially in summer.
5	Mediterranean	30^{o}-40^{o}	Moderate (mild winters and hot summers)	Moderate to high	15- 35 (38- 89)	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^{o}-60^{o}	Very large	Varies greatly with air mass changes; highest in summer.	15- 45 (38-114)	Spring & summer thunder-showers, winter snow. Prevailing winds off-shore (land to sea); shielded by mountains from on-shore moist winds.	Variable	320	20- 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^{o}-60^{o}	Moderate	Moderate to high (varies with wind direction & air mass changes)	25-100 (64-254)	Driest season tends to be spring or summer; high rain-fall 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 coast of continents or large island in latitudes of westerlies (United Kingdom, west Europe west coast N. America), Japan more nearly climate 6.
7b	Maritime temperate, Oversea	30^{o}-60^{o}	Moderate	High	25- 60 (64-152)			320	20- 30	Applies to coastal & oversea areas where both horizons of path are on sea. Ducts may occur frequently.
8	Polar	60^{o}-90^{o}	Very large	Low	5- 15 (13- 38)	Winter snow very dry; most precipitation in summer showers.		300	10- 40	

Table 9. Time Block Ranges [47, p. III-45]

No.	Months	Hours
1	November - April	0600 - 1300
2	November - April	1300 - 1800
3	November - April	1800 - 2400
4	May - October	0600 - 1300
5	May - October	1300 - 1800
6	May - October	1800 - 2400
7	May - October	0000 - 0600
8	November - April	0000 - 0600
Summer	May - October	all-hours
Winter	November - April	all-hours

table 3. Short discussion for each of the parameters given in table 3 are provided in this section. These discussions are ordered by order of appearance in table 3. Information as to how these parameters are related to particular capabilities can be obtained from the capability discussions provided in section 3.2 and table 1.

AIRCRAFT ALTITUDES These represent the altitudes (a) for which specific curves of power available (fig. 21), power density, (fig. 22) or transmission loss (fig. 23) curves will be developed, or (b) that are used to cover the altitude versus distance airspace for which volume (e.g., power available volume, fig. 24) or contour (e.g., EIRP contours, fig. 27) type graphs are desired. Estimates of the altitudes required for the latter can be made by the program operator from the graph format specifications of table 4 so that the specification altitudes in table 3 are not always required. Altitude is measured with respect to mean sea level (msl) and provision for the use of units of feet (ft-msl) or meters (m-msl) are made in table 3. The appropriate units should be circled or explicitly stated, if different from the choices provided.

TIME AVAILABILITY The specification of time availability (see sec. 4.1, TIME AVAILABILITY... discussions) is required for those capabilities where a single time availability is used. It may range from 0.01 to 99.99 percent. Statistical rain attenuation effects will only be present for time availabilities greater than 98 percent (see sec. 4.1, RAIN ZONE discussion). A time availability of 95 percent will be used when another value is not specified.

POWER AVAILABLE, POWER DENSITY, TRANSMISSION LOSS AND/OR EIRP Single and/or multiple values of power available, power density, transmission loss, and/or EIRP are needed for several capabilities.

STATION SEPARATION The specification of station separation (fig. 42) is required for those capabilities where a single station separation is used. The appropriate units should be circled or explicitly stated, if different from the choices provided.

DESIRED FACILITY-TO-AIRCRAFT DISTANCE This distance is required for the Signal Ratio-S (fig. 33) capability where the location of the aircraft is fixed (altitude and distance) relative to the desired facility. The appropriate units should be circled or explicitly stated, if different from the choices provided.

DESIRED-TO-UNDESIRED SIGNAL RATIO Specification of desired-to-undesired signal ratio (D/U) is required for those capabilities where a single D/U ratio is used.

PROTECTION POINT LOCATIONS Protection point locations must be specified for the orientation capability. These points are located relative to the desired facility as illustrated in figure 43 with angles relative to the desired facility course line, and desired facility to protection point distance. Protection point locations will be taken as those associated with figure 43 when they are required, but not specified. The appropriate units should be circled or explicitly stated, if different from the choices provided.

4.3 GRAPH FORMAT PARAMETERS (Table 4, p. 78)

Parameters associated with graph formats are covered in table 4. In many, if not most, cases, an adequate selection of these parameters can be made by the program operator so that complete specification via table 4 is not often required.

Some graphs have options associated with the ordinate (feet or meters) and/or abscissa (degrees, kilometers, nautical miles, or statute miles) units. These options are selected via table 4 by circling the choice desired. The degrees option involves the use of central angle instead of path distance (fig. 41). This option is useful when coverage estimates for a geostationary satellite are required.

Except for the spectral plot capability, the parameters required for table 4 are associated with the ordinate (lower-to-upper) and abscissa (left-to-right) scales. End points, increment between grid lines, and units are specified. The interval between end points should correspond to an integer number of increments. Except when transmission loss is plotted, the upper value should exceed the lower value. In all cases, the right value should exceed the left value and values less than zero should not be used.

Spectrum plots may be made with the spectral plot capability for any 5 consecutive lobes within 10 lobes of the radio-horizon where the first lobe is taken as the first lobe inside the radio horizon (see SPECTRAL PLOT, fig. 15, discussion in sec. 3.2). For example, specification to "plot lobe 3 through 7" would result in plots for lobes 3, 4, 5, 6, and 7.

5. SUMMARY AND SUBMISSION INFORMATION

The ten computer programs covered by this report are useful in estimating the service coverage of radio systems operating in the frequency band from 0.1 to 20 GHz. These programs and the propagation models (sec. 2) used in them are extensions of work previously reported [24; 25, sec. CII]. They may be used to obtain a wide variety of computer generated microfilm plots. Plotting capabilities are summarized in table 1 and discussed in section 3.2. Sample graphs are provided in section 3.1 and sample problem applications are given in section 3.3. Concise information on input parameter requirements is provided in tables 2 through 4 (sec. 4)

A potential user should

1) read the brief description of the propagation model provided in section 2 to see if the model is applicable to his problem,
2) select the program(s) whose output(s) are most appropriate from the information given in section 3 (table 1),
3) determine values for the input parameters discussed in section 4 (table 2 through 4),
4) request a cost estimate for appropriate computer runs, and
5) submit the formal request and/or purchase order that may be required.

FAA requests should be addressed to:

Federal Aviation Administration
Spectrum Management Staff, ARD-60
Systems Research and Development Service
2100 Second Street, S.W.
Washington, D. C. 20591

Attention: Navigation Specialist

Telephone contact is strongly encouraged, and Mr. Robert Smith, Navigation Specialist, can be reached at 426-3600 if the Federal Telecommunications System (FTS) is used, or (202)426-3600 if commercial telephone is used.

Other requests should be addressed to:

Department of Commerce
Spectrum Utilization Division, OT/ITS-1
325 Broadway
Boulder, CO 80303

Attention: Mary Ellen Johnson

Telephone contact is strongly encouraged and Mrs. Mary Ellen Johnson can be reached at 323-3587 if FTS is used or (303)499-1000 x 3587 if commercial telephone is used. If extension 3587 can't be reached, try extension 4162, which is the Spectrum Utilization Division office.

6. ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance and advice of several people at DOC; in particular, Dr. George A. Hufford for his general advice and help with the scatter model; Mrs. Anita Longley for her assistance with the long-term variability in regard to climates; Mr. Joe H. Pope for his assistance with the ionospheric scintillation model; Mr. C. A. Samson for his assistance with the rain attenuation; Mrs. Rita Reasoner for programming assistance; and, Mrs. Beverly Miranda and Mrs. Beverly Gould for manuscript preparation.

APPENDIX A. ADDITIONAL PROBLEM APPLICATIONS

This appendix provides additional problem applications similar to those of section 3.3. These problems were included to illustrate the effects of varying particular parameters on system performance. The subject of each problem is summarized in table A1, and these subjects have been used as headings in the text as an aid to the reader.

Table A1 Additional Problem Applications

Problem	System	Predicted Parameter	Variable Parameter
A1	ATC	Range	Polarization
A2	ATC	Range	Terrain Parameter
A3	TACAN	Range	Beam Tilt
A4	Satellite	Range	Scintillation Index
A5	Satellite	Margin	Sea State
A6	ILS	Separation	Site Elevation
A7	ILS	Separation	Surface Constants
A8	ILS	Separation	Terrain Parameter
A9	ILS	Separation	Terrain Profile

ATC, Range, Polarization

Problem A1: Estimate the gapless service range for the geometry illustrated in figure A1 and the ATC system with parameters of figure A2 for vertical, horizontal, and circular polarization by using both the lobing and variability options of the transmission loss capability. Use a time availability of 95 percent, and basic transmission loss, L_b (95%), value of 125 dB to determine service range. Here, gapless implies that satisfactory service, $L_b(95\%) \leq 125$ dB, is available at all distances within the service range; i.e., no gaps.

Solution: Key parameters associated with this problem are illustrated in figure A1. Figures A3 through A8 were developed in response to this problem and the values of maximum gapless range tabulated below were taken from them.

Polarization	Figures	Gapless Service Range [n mi (km)]	
		Lobing Option	Variability Option
Vertical	A3, A4	179 (332)	82 (152)
Horizontal	A5, A6	28 (52)	56 (104)
Circular	A7, A8	75 (139)	67 (124)

Note that (a) the use of vertical polarization results in the greatest range in all cases since it has the lowest reflection coefficient associated with it, (b) the variability option results in the lower range in two cases since it is usually more pessimistic when low (< about 0.5) reflection coefficients are involved, and (c) the lobing option results in the lowest range for horizontal polarization since it tends to be more pessimistic for high (> about 0.5) reflection coefficients.

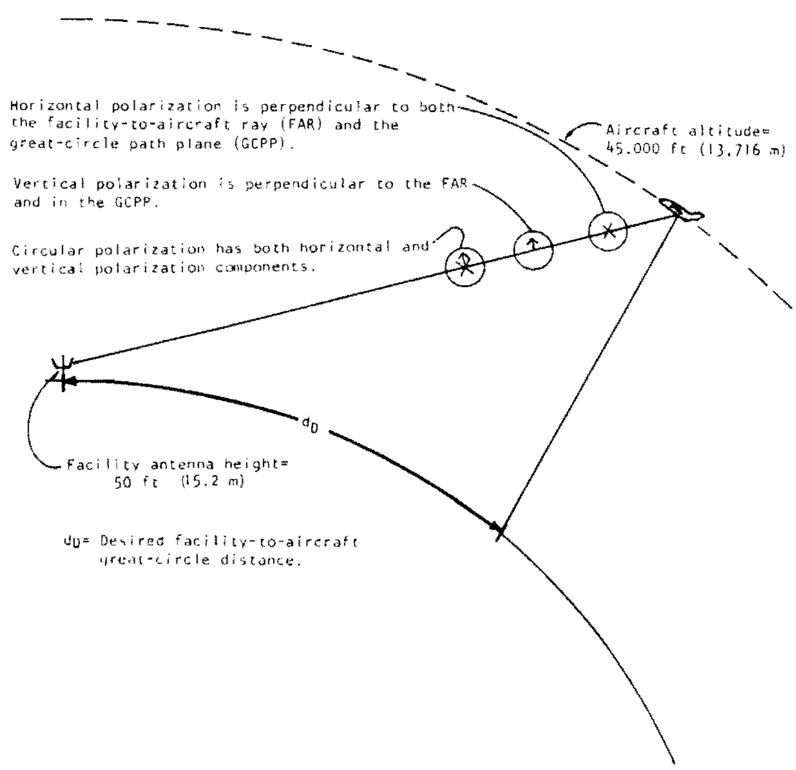


Figure A1. Problem A1, geometry sketch (not drawn to scale).

```
PARAMETERS FOR ITS PROPAGATION MODEL IF-77
          77/07/13.   22.15.49. RUN

      BASIC TRANSMISSION LOSS FOR ATC
          SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE:   45000. FT (13716.M) ABOVE MSL
FACILITY (OR LOWER ANTENNA HEIGHT:       50.0 FT (15.2M) ABOVE FSS
FREQUENCY:  125. MHZ

          SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE:  ISOTROPIC
     POLARIZATION: HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL:    0. FT (0.M)
GAIN SUM OF MAIN BEAMS:   0.0 DBI
FACILITY ANTENNA TYPE:  ISOTROPIC
     POLARIZATION: HORIZONTAL
HORIZON OBSTACLE DISTANCE:   8.69 N MI (16.09KM) FROM FACILITY*
     ELEVATION ANGLE:   -0/ 6/30 DEG/MIN/SEC ABOVE HORIZONTAL*
     HEIGHT:    0. FT (0.M) ABOVE MSL
REFRACTIVITY:
     EFFECTIVE EARTH RADIUS:  4586. N MI (8493.KM)*
     MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING:  CONTRIBUTES TO VARIABILITY
SURFACE TYPE:  AVERAGE GROUND
TERRAIN ELEVATION AT SITE:    0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER:   0. FT (0.M)
TIME AVAILABILITY:  FOR INSTANTANEOUS LEVELS EXCEEDED

* COMPUTED VALUE
```

Notes:
1) Polarization, surface reflection lobing option and terrain parameter used for figures A3 through A8 and A10 and A11 vary as indicated in the figure captions.

2) Parameter values (or options) not indicated are taken as the assumed values (or options) provided on the general parameter specification sheet (table 2).

3) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure A2. Problems A1 and A2, parameter sheet, ATC.

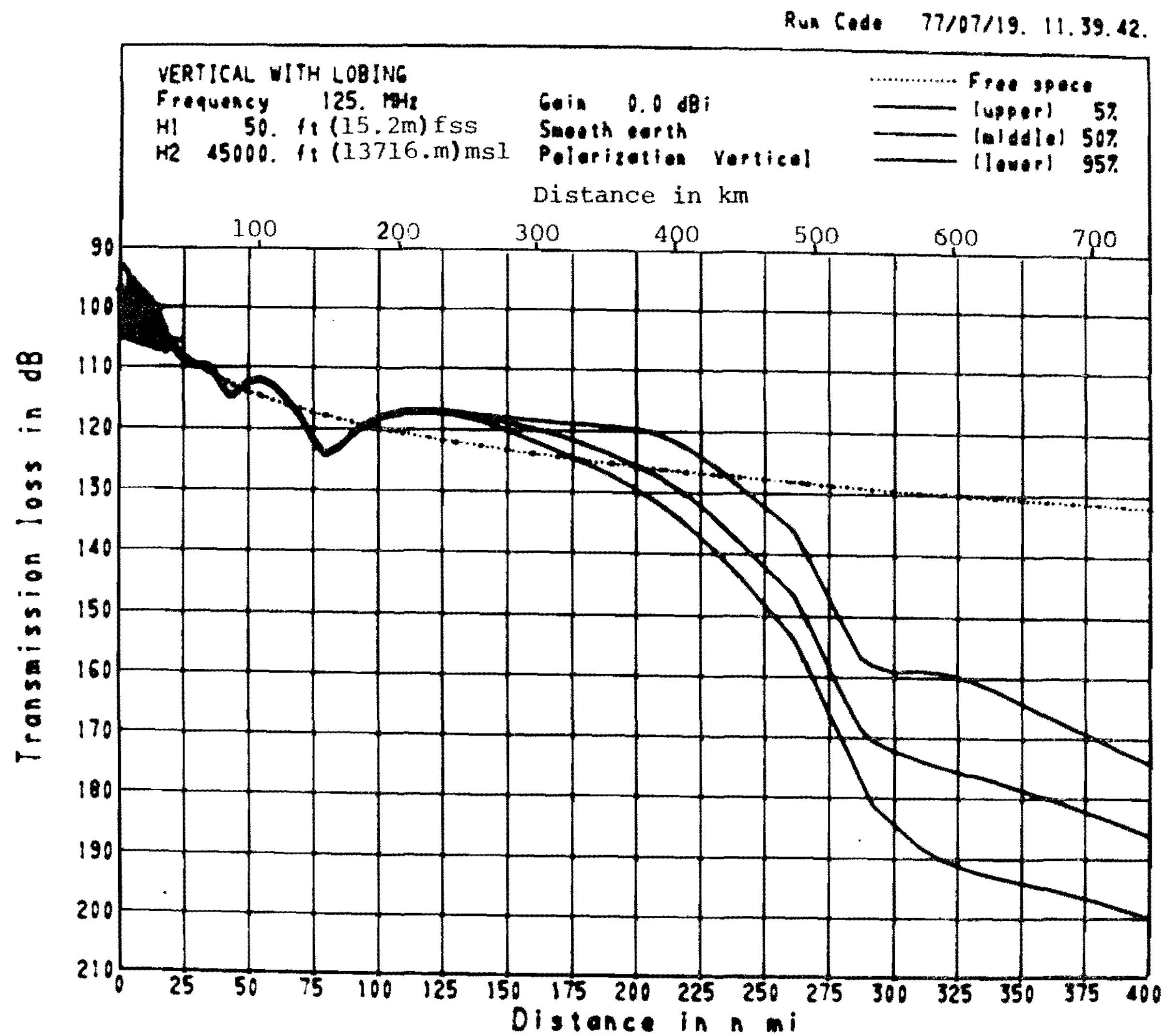


Figure A3. Transmission loss, ATC, vertical polarization, lobing option. Transmission loss values were computed with parameters in figure A2 except for polarization and lobing option.

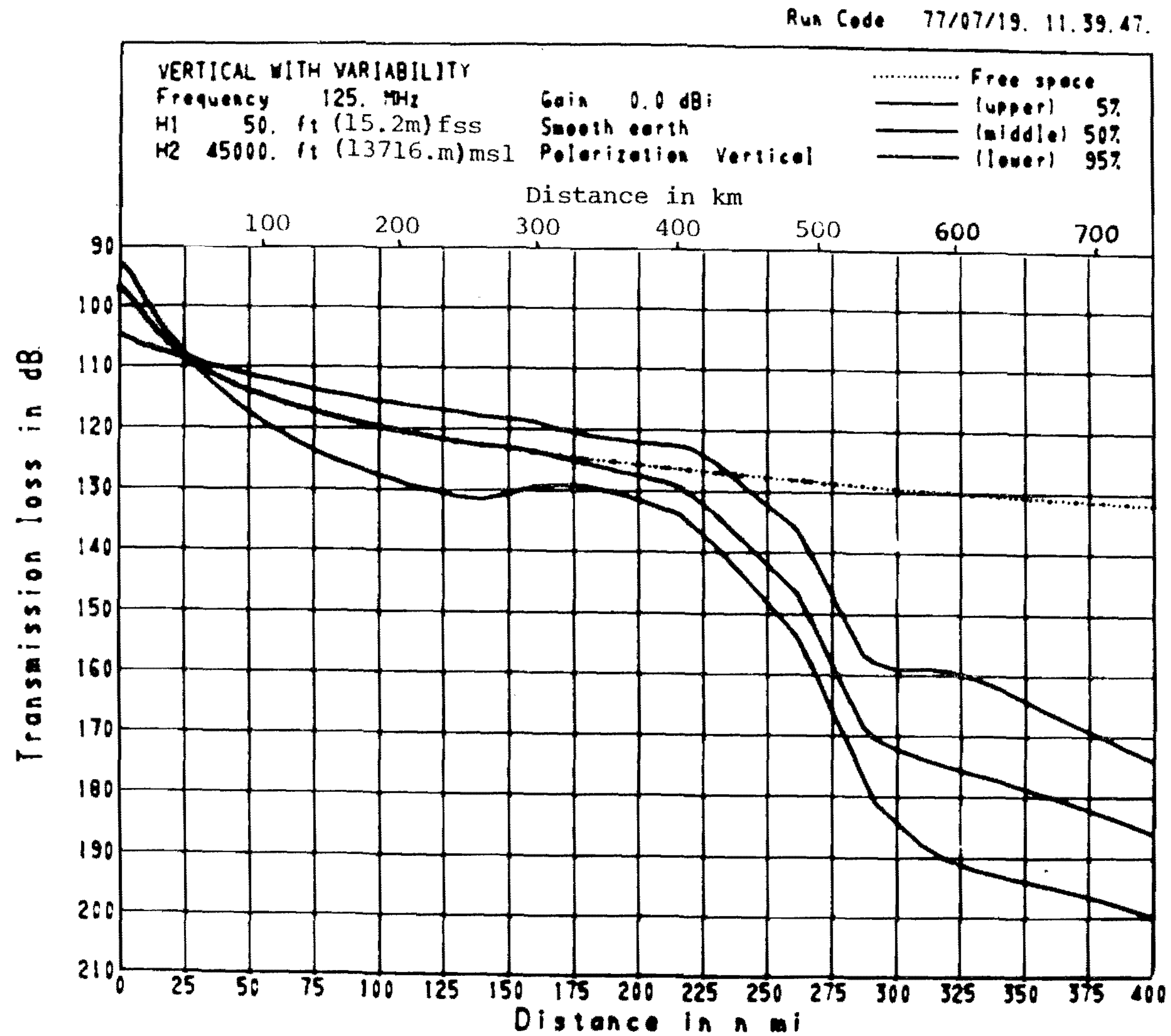


Figure A4. Transmission loss, ATC, vertical polarization, variability option. Transmission loss values were computed with parameters in figure A2 except for polarization.

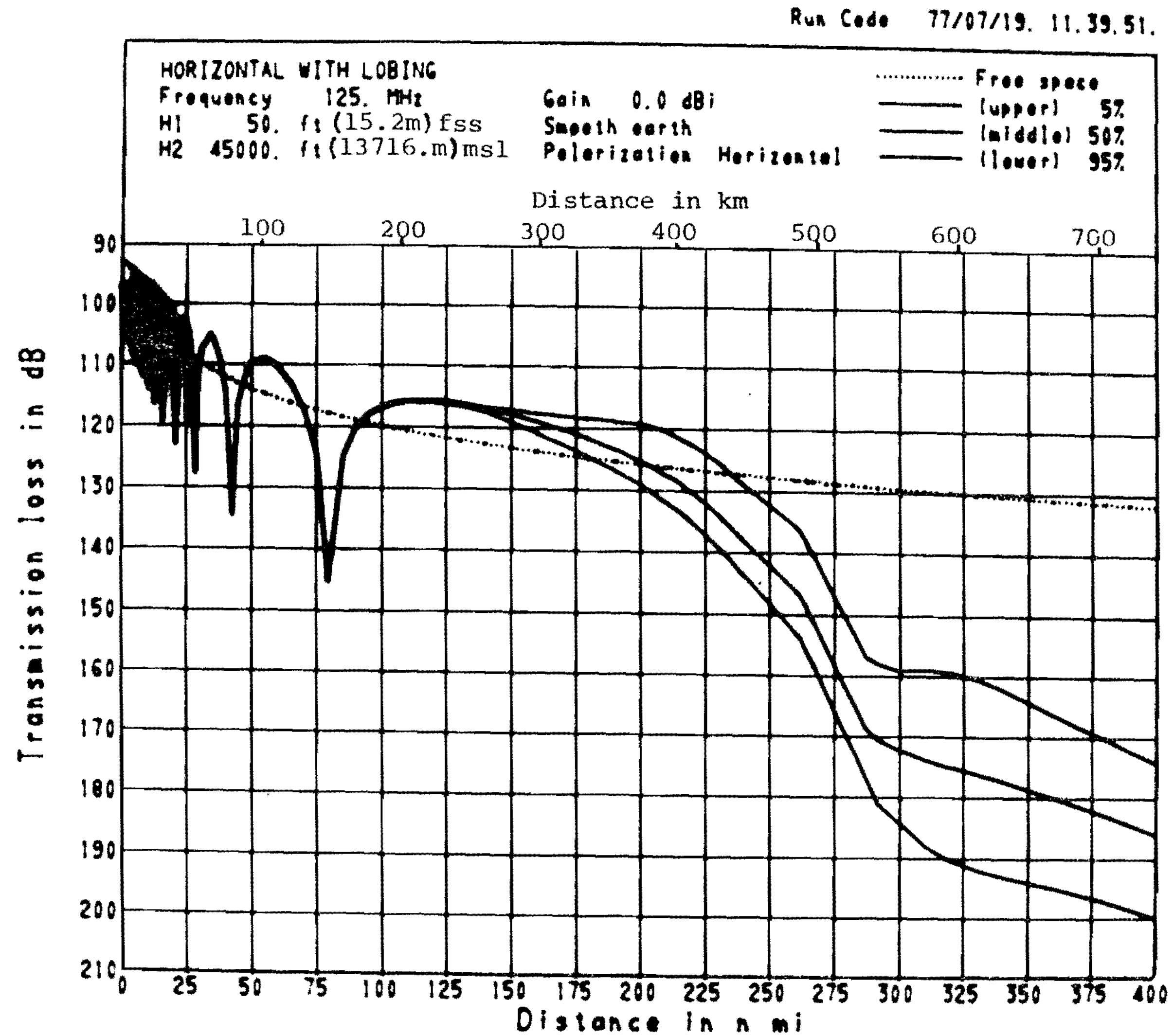


Figure A5. Transmission loss, ATC, horizontal polarization, lobing option. Transmission loss values were computed with parameters in figure A2 except for the lobing option.

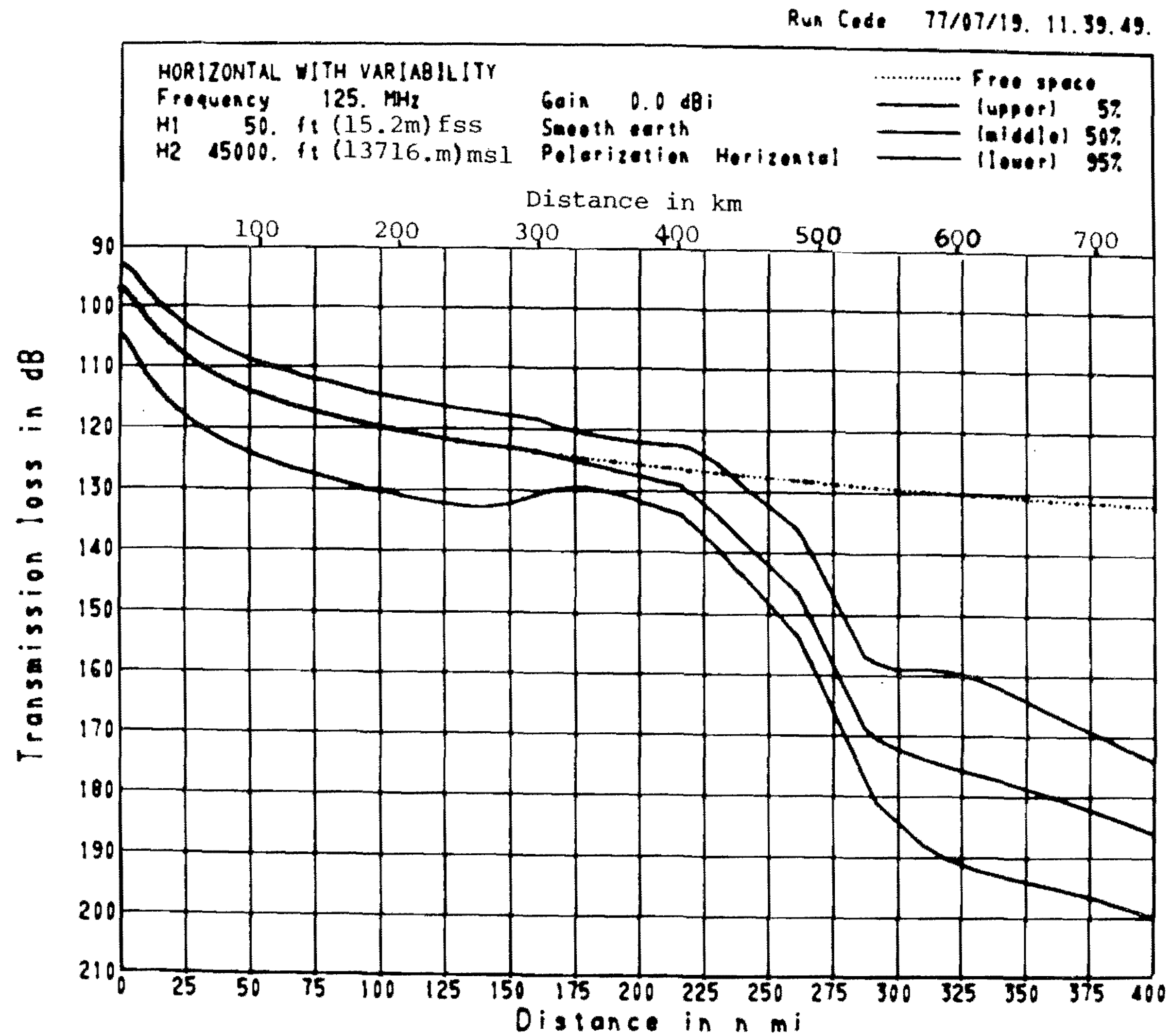


Figure A6. Transmission loss, ATC, horizontal polarization, variability option. Transmission loss values were computed with parameters in figure A2.

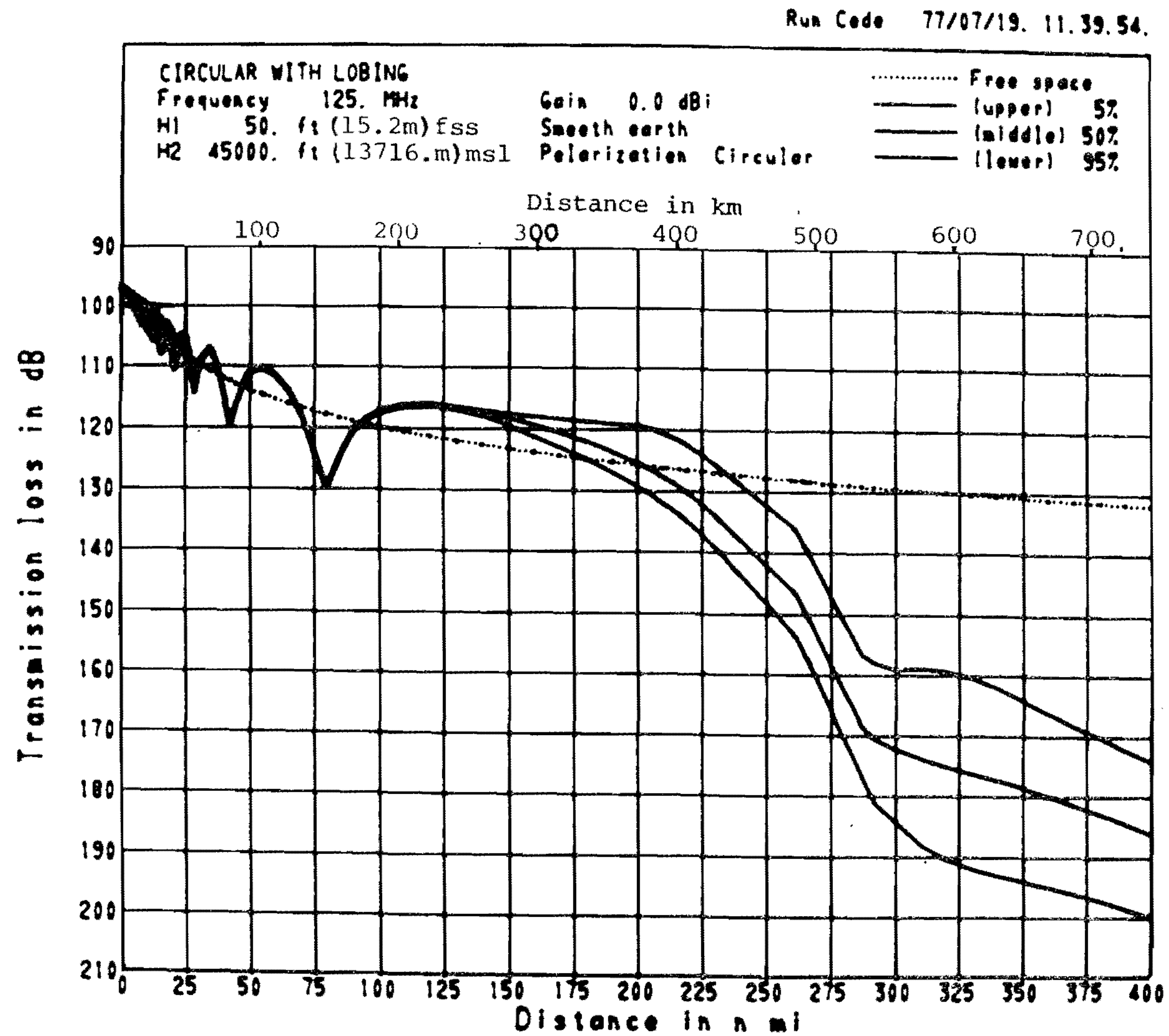


Figure A7. Transmission loss, ATC, circular polarization, lobing option. Transmission loss values were computed with parameters in figure A2 except for polarization and lobing option.

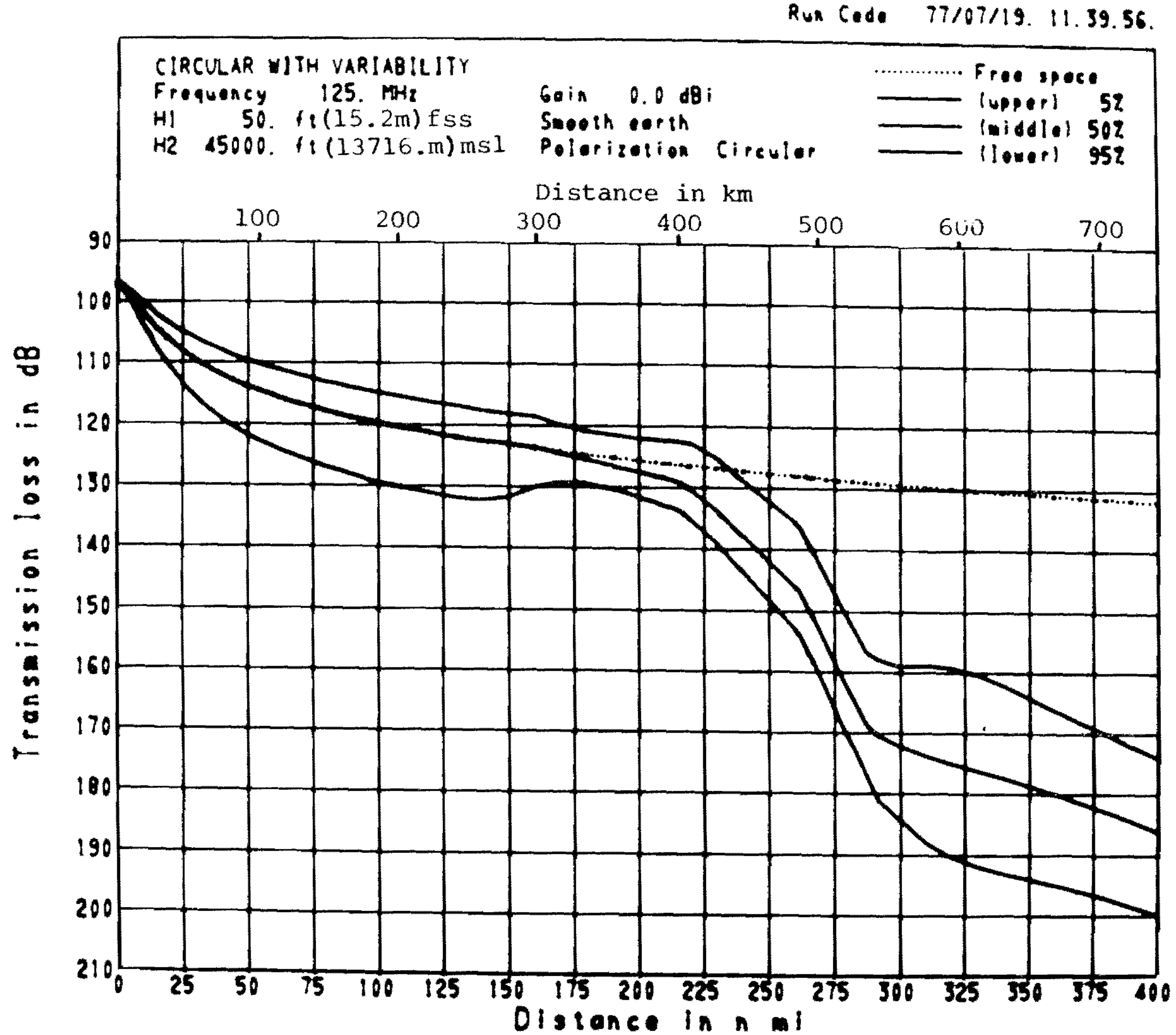


Figure A8. Transmission loss, ATC, circular polarization, variability option. Transmission loss values were computed with parameters in figure A2 except for polarization.

ATC, Range, Terrain Parameter

Problem A2: Estimate the maximum gapless service range for an ATC system with the geometry illustrated by figure A9 and the parameters of figure A2 with vertical polarization for smooth earth, rolling hills, and mountains by using the transmission loss capability with the variability option. Use a time availability of 95 percent and basic transmission losses of 130 and 150 dB.

Solution: Figures A4, A10 and A11 are applicable to this problem and the values of gapless range tabulated below were taken from them. The increase in service range with terrain irregularity for $L_b(95\%) = 130$ dB is caused by a decrease in the specular reflection coefficient as surface roughness increases, while the decrease for $L_b(95\%) = 150$ dB is caused by a decrease in radio horizon distance. Except for the last case (mountains, 150 dB) increasing irregularity tends to increase the service range because of a corresponding decrease in reflection coefficient. In the last case the decrease of service range occurs because of a decrease in radio horizon distance.

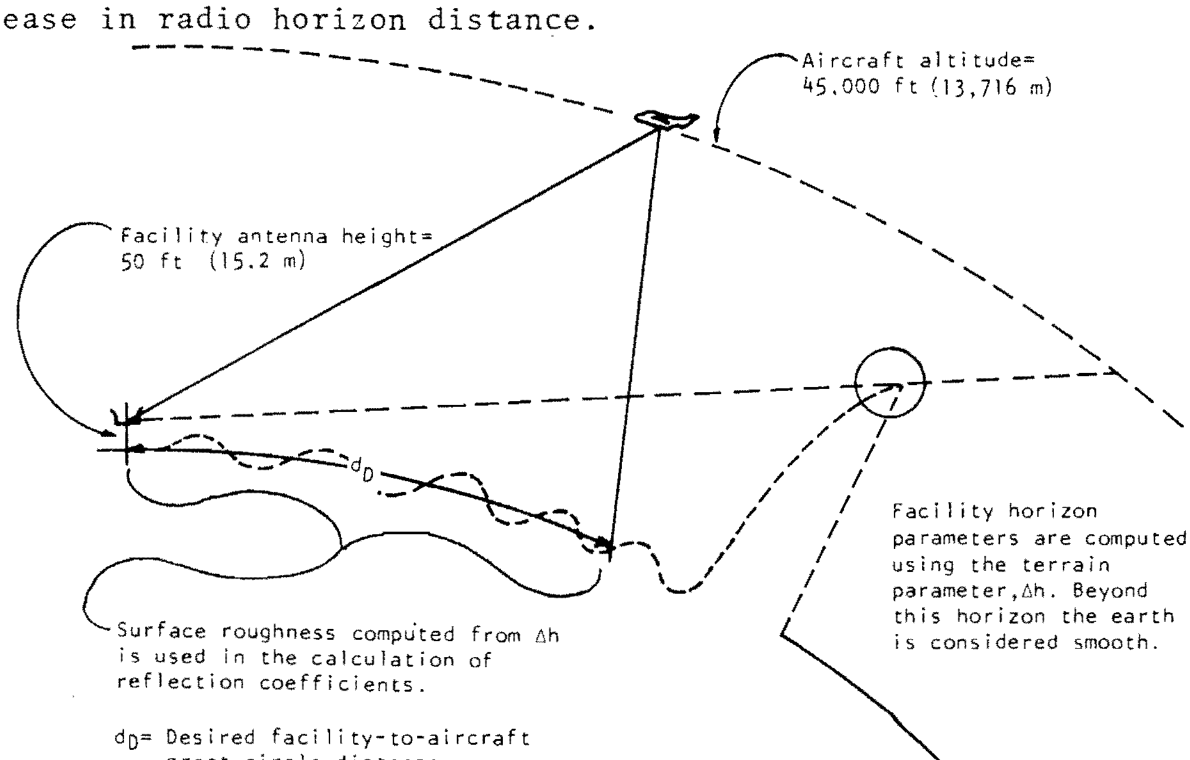


Figure A9. Problem A2, geometry sketch (not drawn to scale).

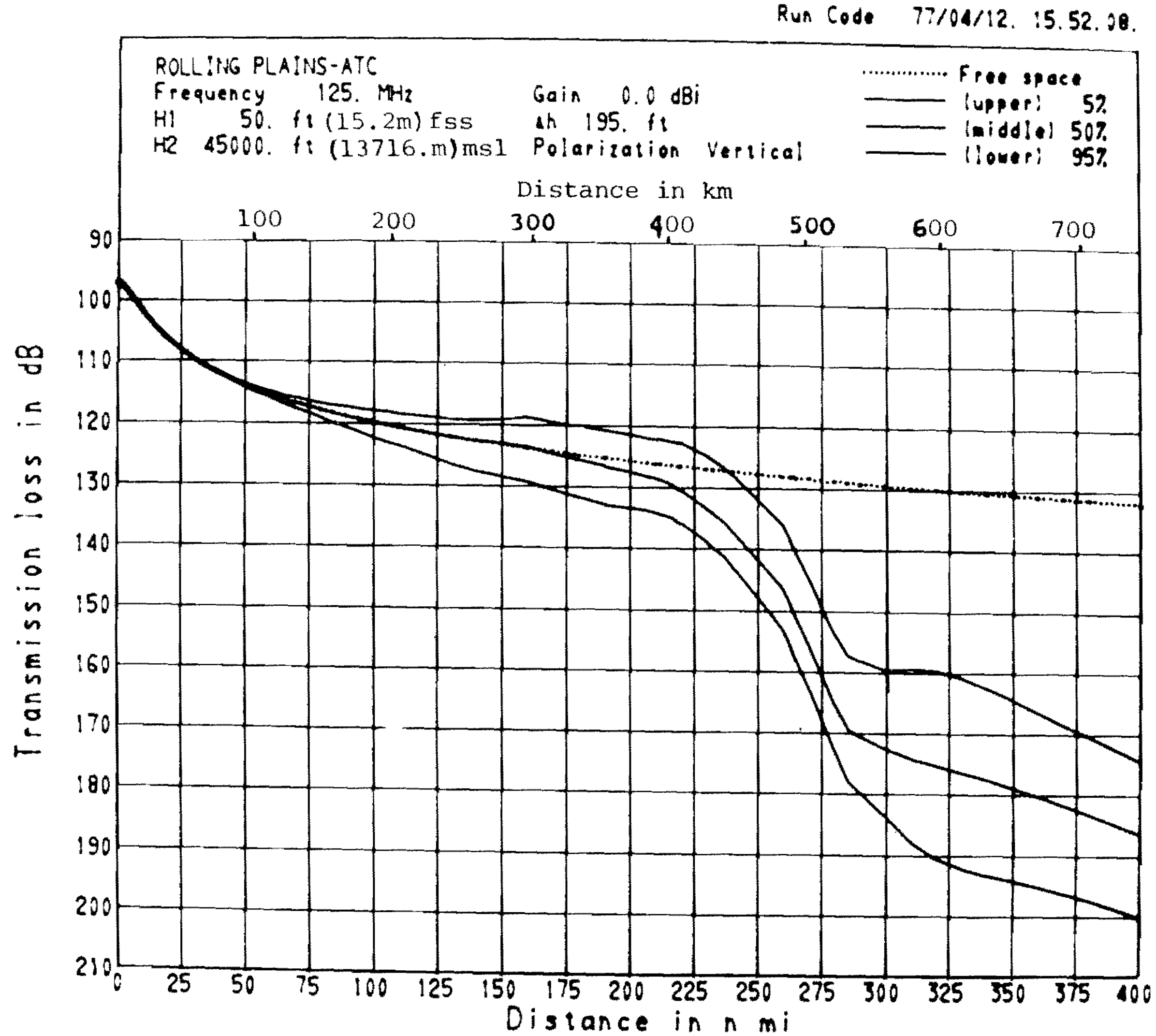


Figure A10. Transmission loss, ATC, vertical polarization, rolling plains. Transmission loss values were computed with parameters from figure A2 except for polarization and irregular terrain with Δh for rolling plains (195 ft, 59 m). Horizon parameters were calculated from Δh.

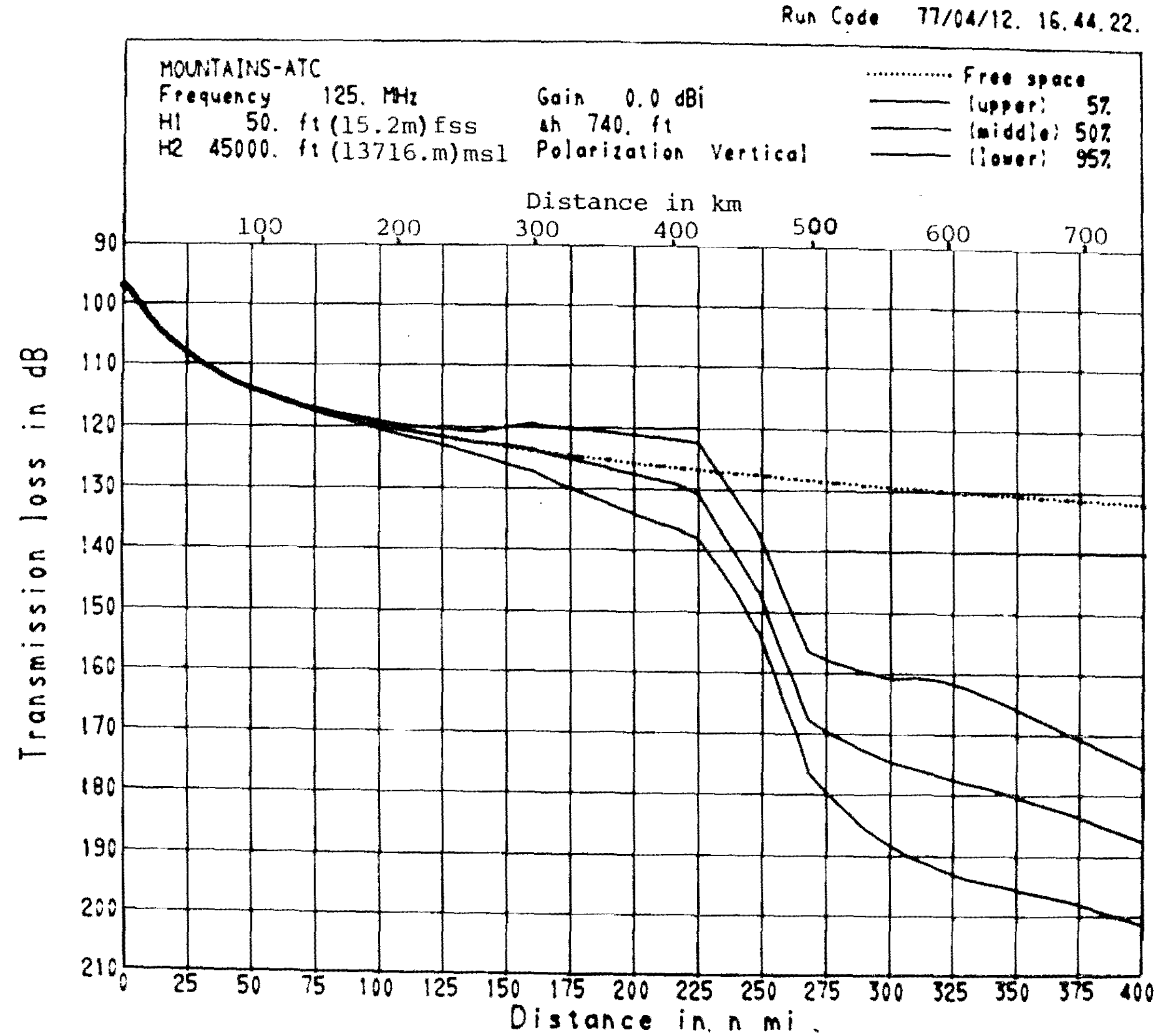


Figure A11. Transmission loss, ATC, vertical polarization, mountains. Transmission loss values were computed with parameters from figure A2 except for polarization and irregular terrain with Δh for mountains (740 ft, 226 m). Horizon parameters were calculated from Δh.

Terrain	Figure	Gapless Service Range [n mi (km)]	
		$L_b(95\%) = 130$ dB	$L_b(95\%) = 150$ dB
Smooth earth	A4	118 (219)	254 (470)
Rolling plains	A10	165 (306)	254 (470)
Mountains	A11	175 (324)	244 (452)

TACAN, Range, Beam Tilt

Problem A3: Estimate the maximum service range for the geometry illustrated in figure A12 and the TACAN parameters given in figure A13 for three antenna main beam tilts, (a) normal, (b) 0°, and (c) adjusted to track the aircraft. Use -86 dB-W/sq m of power density and a time availability of 95 percent to define maximum service range.

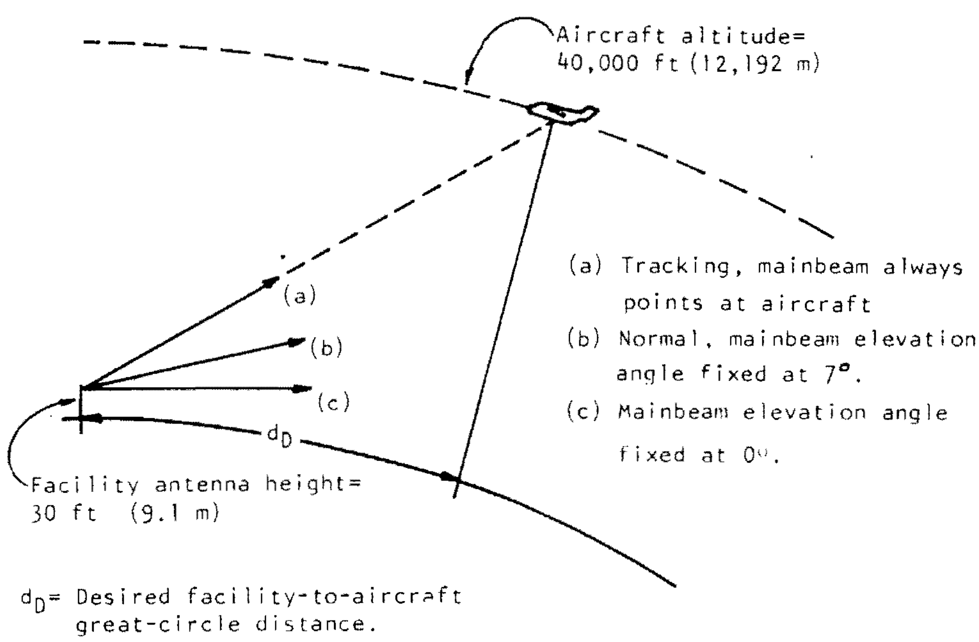


Figure A12. Problem A3, geometry sketch (not drawn to scale).

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/04/12. 16.48.40. RUN

POWER DENSITY FOR TACAN
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 40000. FT (12192.M) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 30.0 FT (9.14M) ABOVE FSS
FREQUENCY: 1150. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: ISOTROPIC
POLARIZATION: VERTICAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 0. FT (0.M)
EQUIVALENT ISOTROPICALLY RADIATED POWER: 39.0 DBW
FACILITY ANTENNA TYPE: TACAN (RTA-2)
POLARIZATION: VERTICAL
HORIZON OBSTACLE DISTANCE: 6.73 N MI (12.46KM) FROM FACILITY*
ELEVATION ANGLE: -0/ 5/02 DEG/MIN/SEC ABOVE HORIZONTAL*
HEIGHT: 0. FT (0.M) ABOVE MSL
REFRACTIVITY:
EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: CONTRIBUTES TO VARIABILITY
SURFACE TYPE: AVERAGE GROUND
TERRAIN ELEVATION AT SITE: 0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER: 0. FT (0.M)
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

POWER DENSITY (DB-W/SQ M) VALUES MAY BE CONVERTED TO POWER AVAILABLE AT THE TERMINALS OF A PROPERLY POLARIZED ISOTROPIC ANTENNA (DBW) BY ADDING -22.7 DB-SQ M.

* COMPUTED VALUE

Notes: 1) Aircraft antenna information is not actually used in power density calculations.

2) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).

3) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure A13. Problem A3, parameter sheet, TACAN.

Solution: Figures A14 through A16 were developed for this problem and the values tabulated below were taken from them. The larger range for the normal tilt angle is caused by better surface reflection discrimination associated with the antenna pattern tilt.

Beam Tilt	Figure	Gapless Service Range [n mi (km)]
Normal	A14	125 (232)
0°	A15	100 (185)
Tracking	A16	108 (200)

Satellite, Range, Scintillation Index

Problem A4: Estimate the maximum north latitude for which satisfactory service is available for a VHF geostationary satellite with the geometry illustrated in figure A17 and the parameters of figure A18. Let the ionospheric scintillation index group be fixed at 0 or 5. Also, use the variable scintillation option (table 2, scintillation index group code of 6) with the frequency scaling factor option (table 2). Use a power available at the receiving antenna terminal of -140 dBW and a time availability of 95 percent to define satisfactory service.

Solution: Figures A19 through 21 are applicable to this problem, and the values tabulated below were taken from them. The maximum north latitude occurs along the subsatellite meridian.

Scintillation Index Group	Figure	Maximum North Latitude
0	A19	79°
5	A20	68°
Variable	A21	79°

During worst case conditions (group 5), the power available 95 percent of the time never exceeds -137 dBW so that a 3 dB increase of the received power requirements would result in unsatisfactory service for all angles. However, the same increase in received power requirement would not decrease coverage to a maximum north latitude significantly for the other two conditions examined.

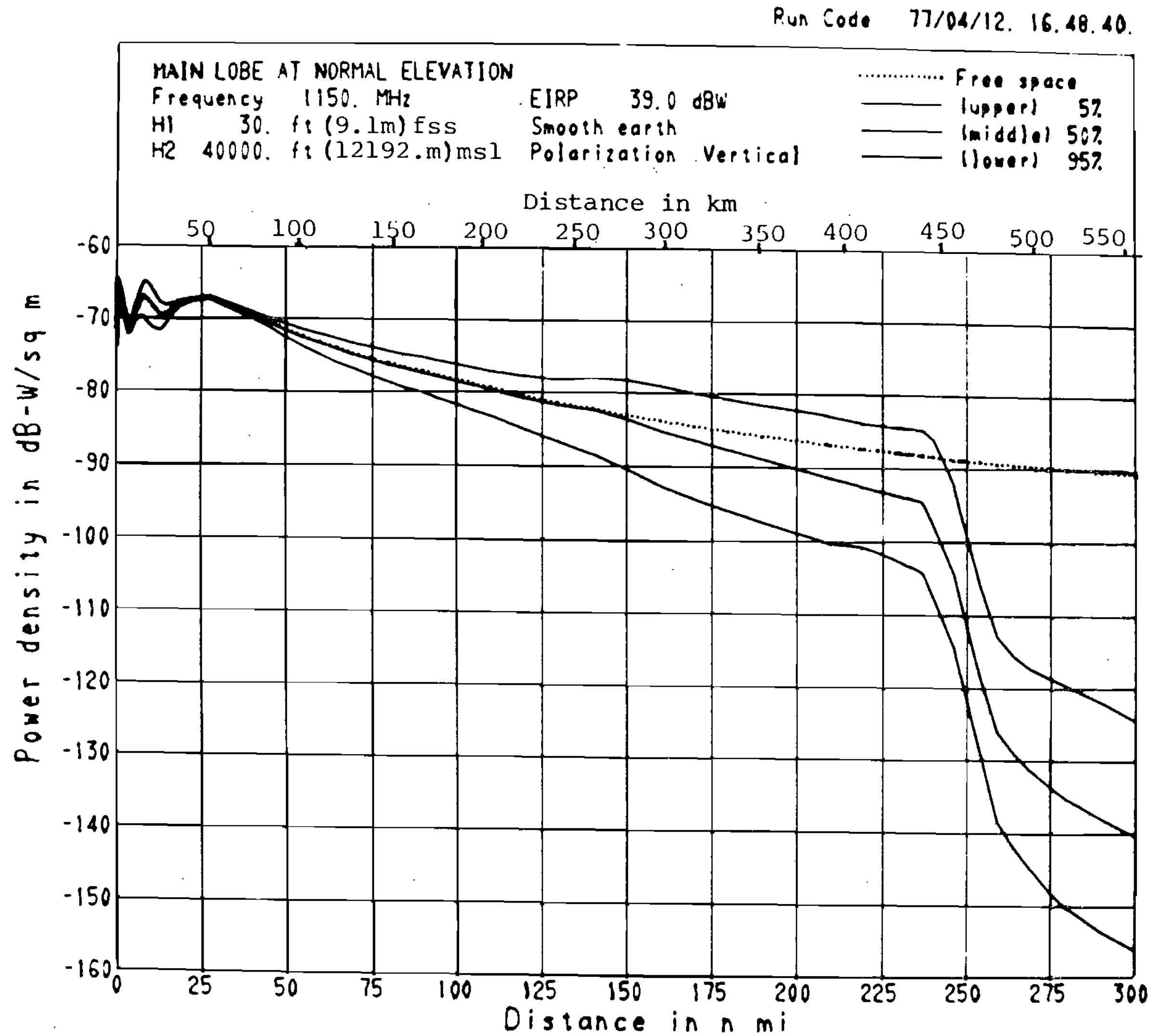


Figure A14. Power density, TACAN, main lobe at normal elevation angle. Power density values were computed with the parameters from figure A13.

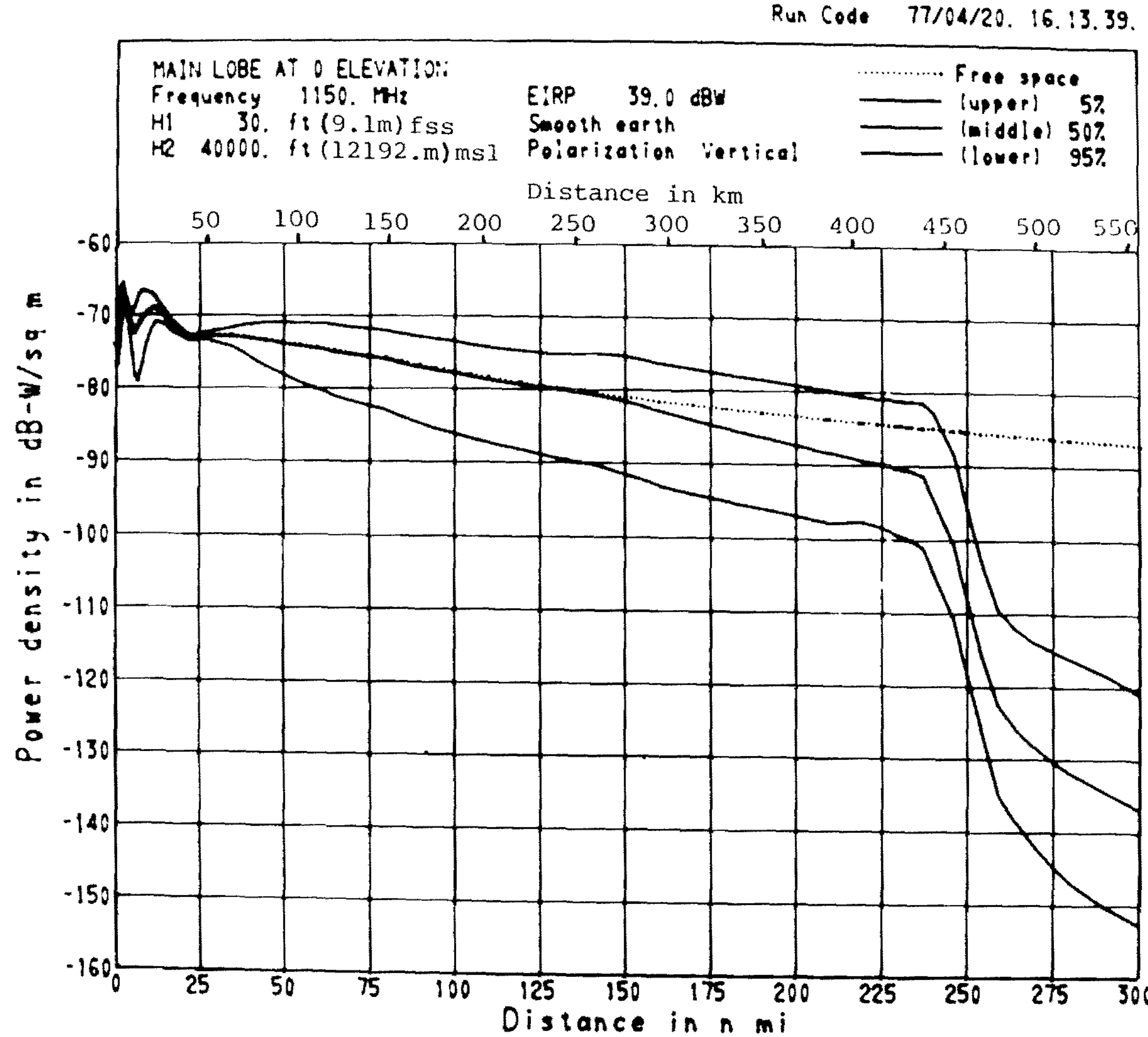


Figure A15. Power density, TACAN, main lobe at 0° elevation. Power density values were computed with parameters from figure A13 except for elevation angle.

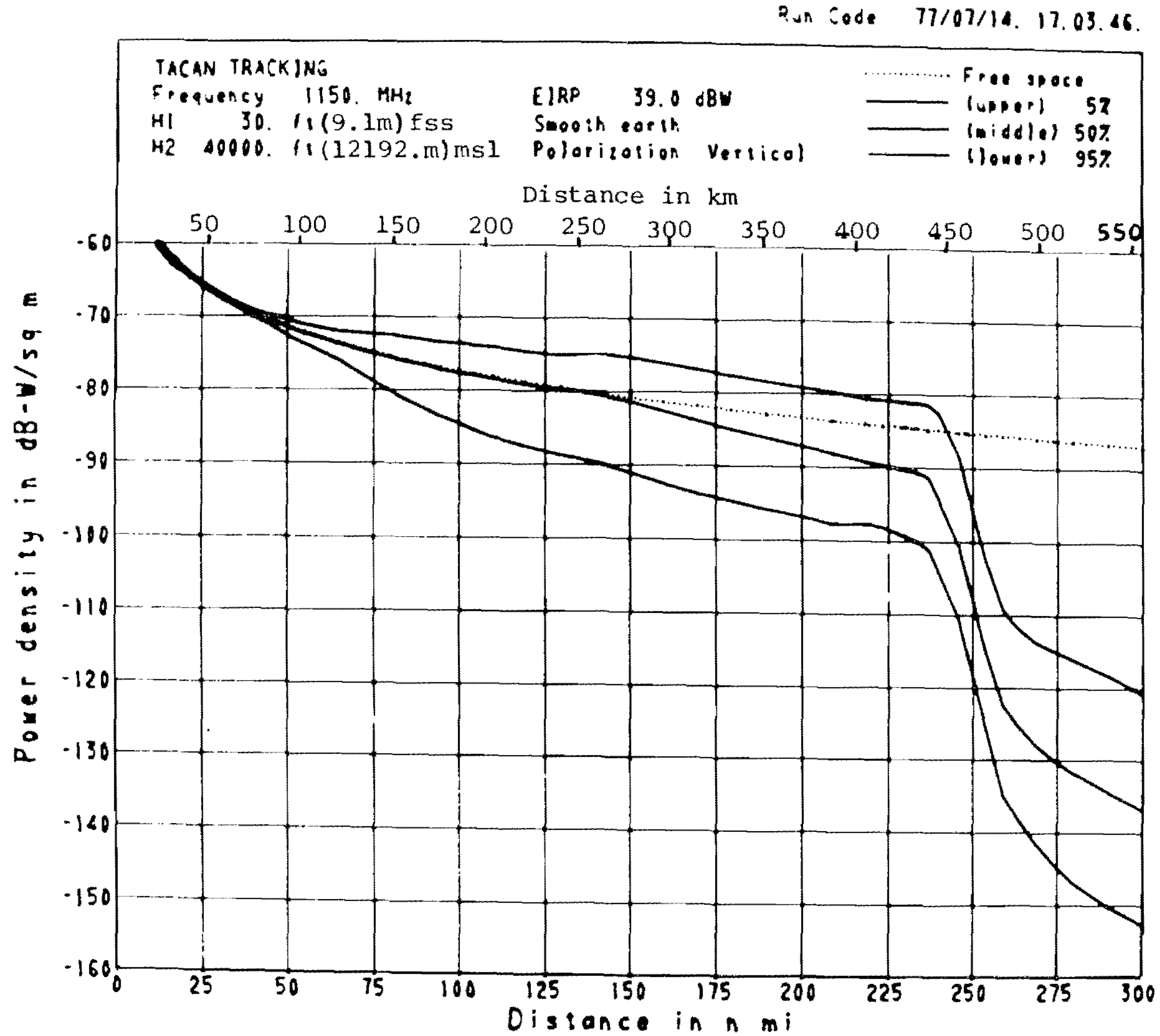


Figure A16. Power density, TACAN, main lobe tracking aircraft. Power density values were computed with parameters from figure A13 except for tracking option.

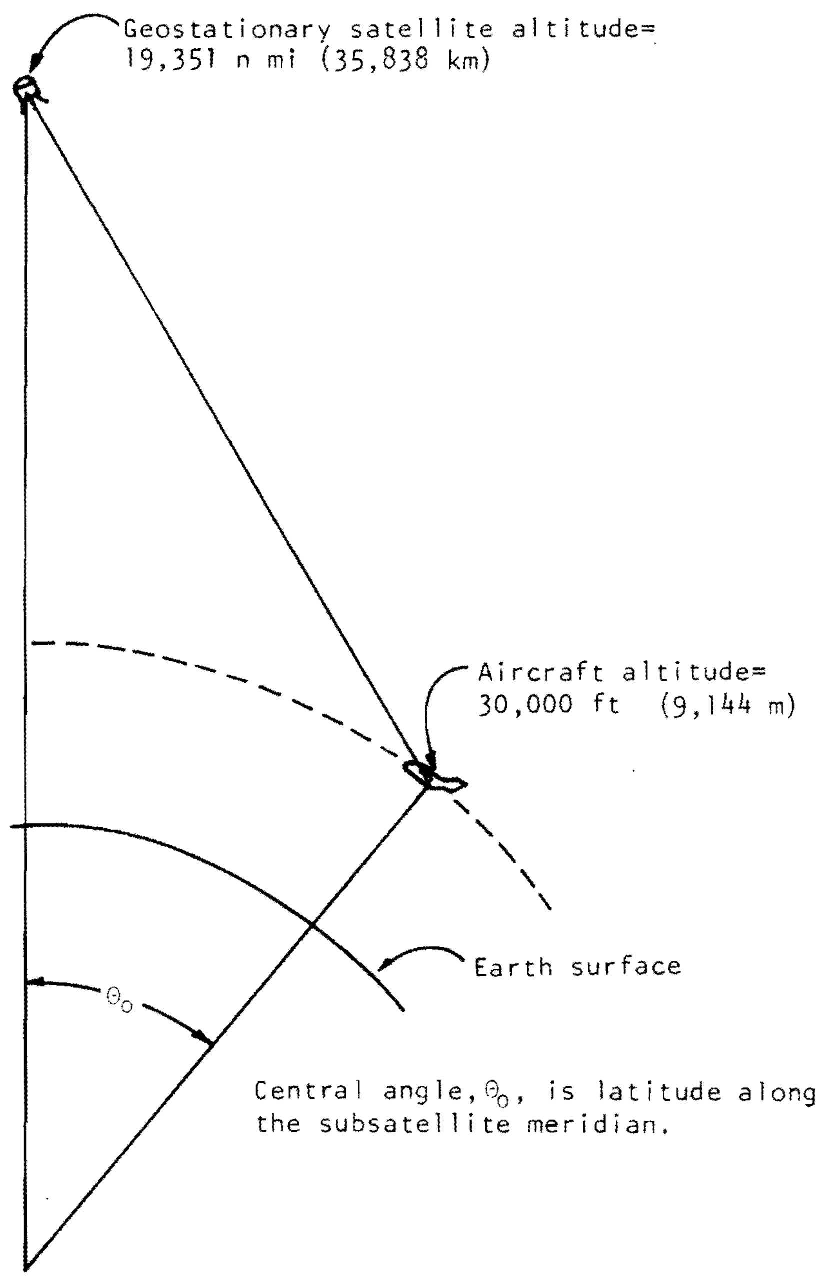


Figure A17. Problems A4 and A5, geometry sketch (not drawn to scale).

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/09/01. 17.42.47. RUN

POWER AVAILABLE FOR VHF SATELLITE SEA STATE 0
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 19351. N MI (35838.KM) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 30000.0 FT (9144.M) ABOVE FSS
FREQUENCY: 125. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: JTAC
BEAMWIDTH, HALF-POWER: 10.00 DEGREES
POLARIZATION: CIRCULAR
TILT IS -90.0 DEGREES ABOVE HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 0. FT (0.M)
EIRP PLUS RECEIVING ANTENNA MAIN BEAM GAIN: 35.0 DBW
FACILITY ANTENNA TYPE: JTAC
BEAMWIDTH, HALF-POWER: 20.00 DEGREES
POLARIZATION: CIRCULAR
ANTENNA IS TRACKING
HORIZON OBSTACLE DISTANCE: 208.85 N MI (385.79KM) FROM FACILITY*
ELEVATION ANGLE: -2/49/36 DEG/MIN/SEC ABOVE HORIZONTAL*
HEIGHT: 0. FT (0.KM) ABOVE MSL
IONOSPHERIC SCINTILLATION INDEX GROUP: 0
REFRACTIVITY:
EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: CONTRIBUTES TO VARIABILITY
SURFACE TYPE: SEA WATER
STATE: 0
CALM (GLASSY)
0.00 FT (0.00M) RMS WAVE HEIGHT
TEMPERATURE: 10. DEG CELSIUS
3.6 PERCENT SALINITY
TERRAIN AT ELEVATION SITE: 0. FT (0.M) ABOVE MSL
TERRAIN PARAMETERS: 0. FT (0.M)
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

* COMPUTED VALUE

Notes: 1) Parameter values (or options) not included are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).

2) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure A18. Problems A4 and A5, parameter sheet, VHF satellite.

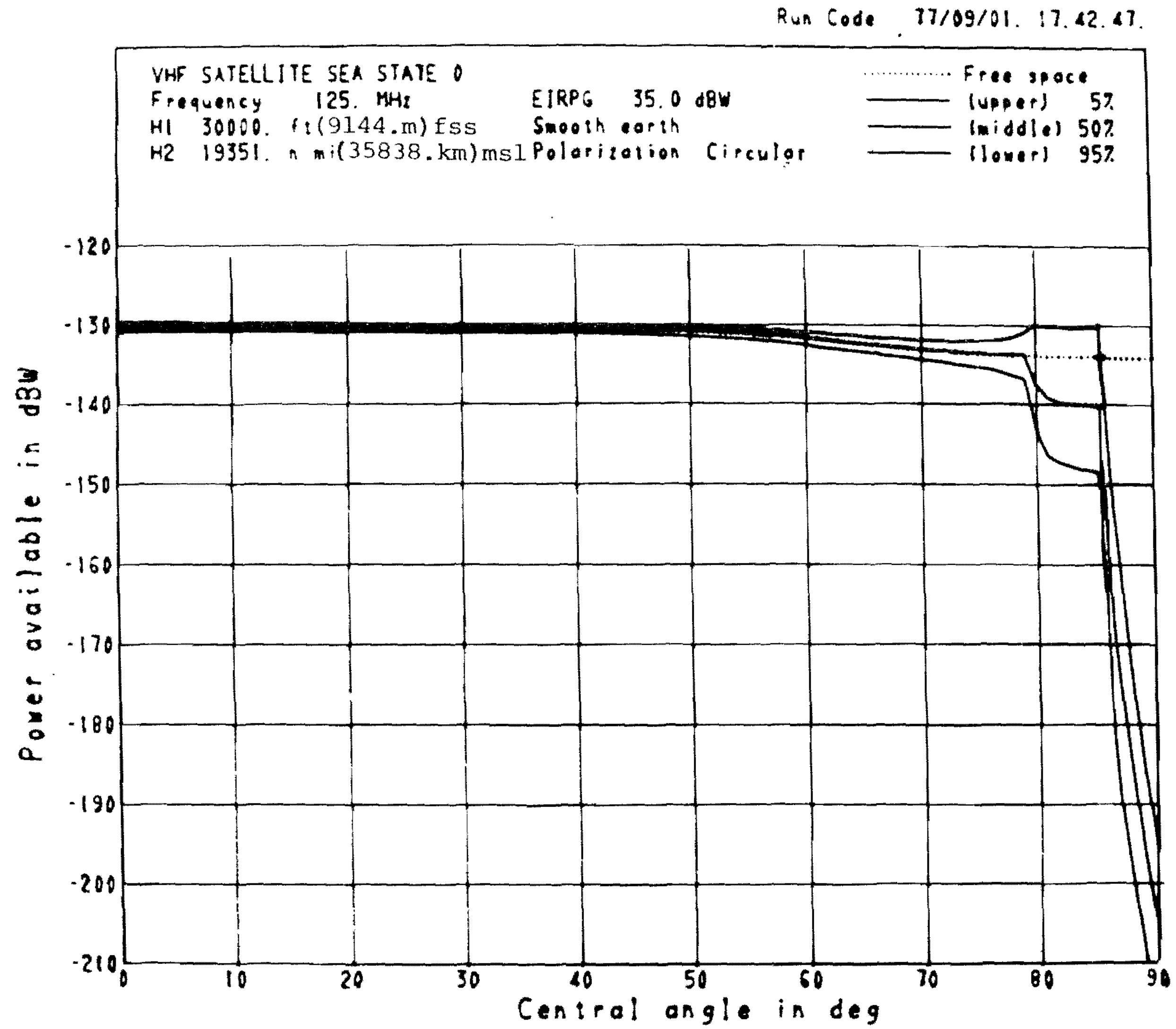


Figure A19. Power available, VHF satellite, scintillation index group 0, sea state 0. Power available values were calculated for the parameters of figure A18.

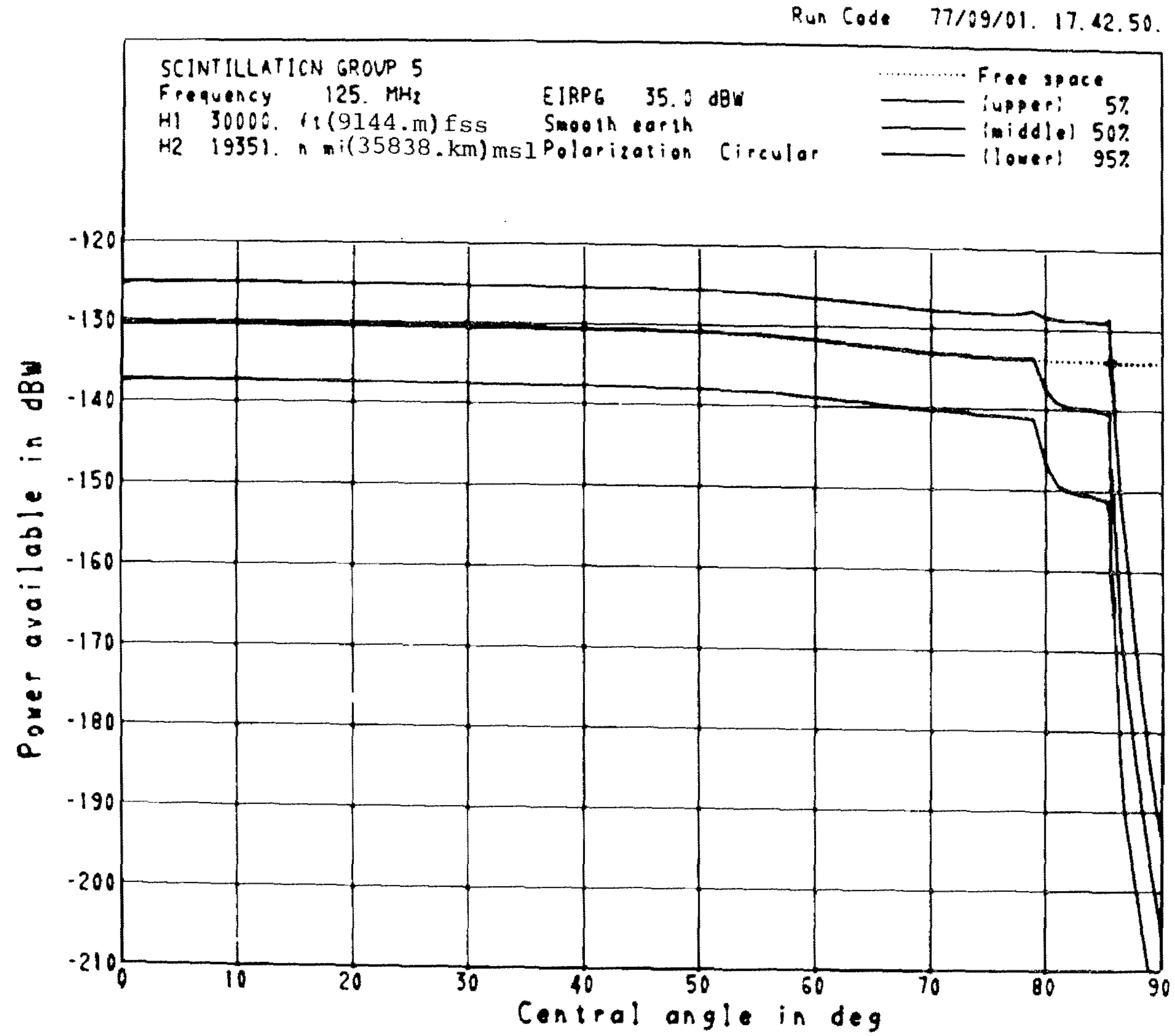


Figure A20. Power available, VHF satellite, scintillation index group 5, sea state 0. Power available values were calculated for the parameters of figure A18 except for scintillation index group 5, and the use of the frequency scaling factor.

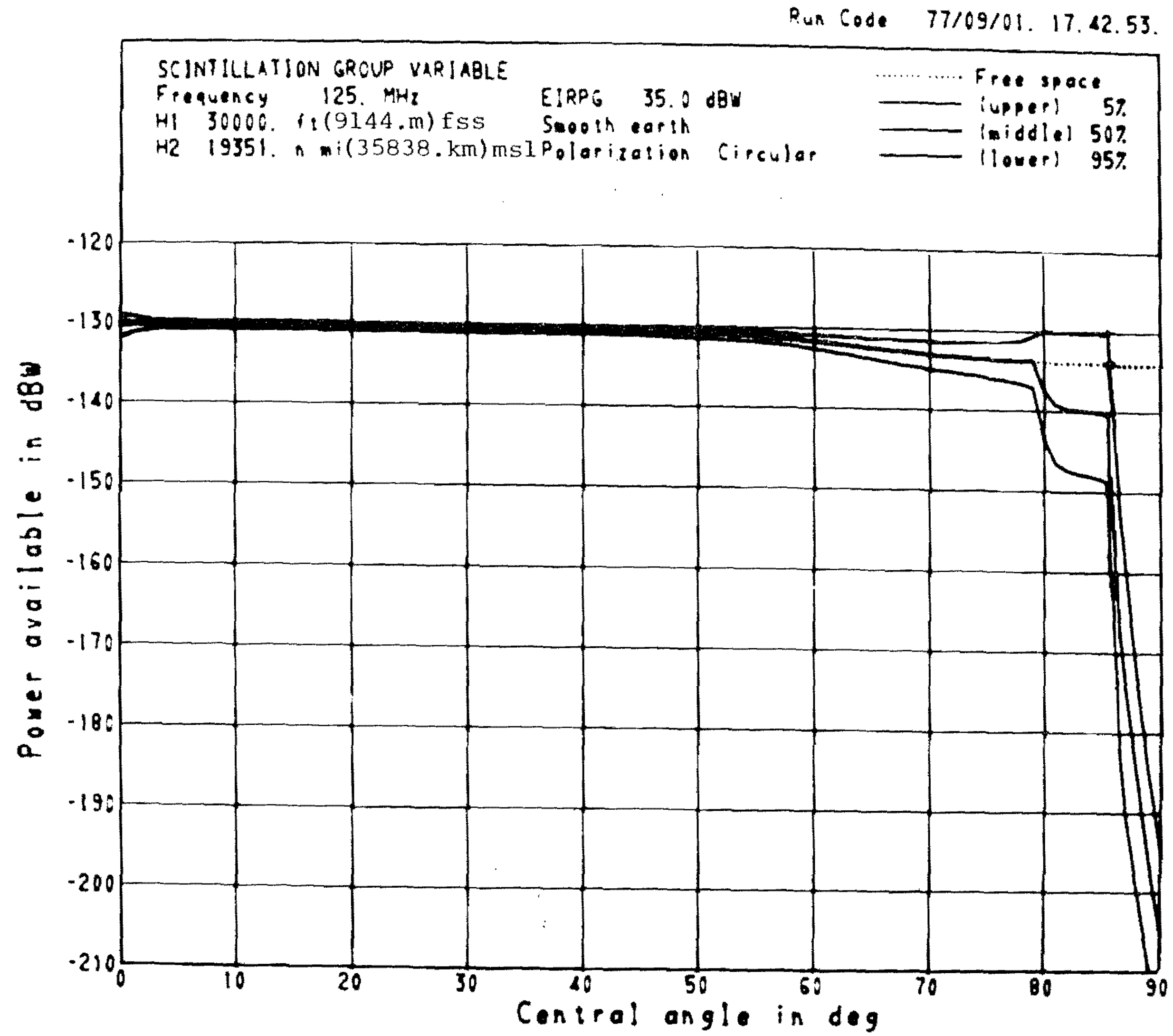


Figure A21. *Power available, VHF satellite, variable scintillation index group, sea state 0. Power available values were calculated for the parameters of figure A18 except for a variable scintillation index group, and the use of the frequency scaling factor.*

Satellite, Margin, Sea State

Problem A5: Estimate the fade margin required for the VHF and UHF satellite systems with the parameters of figures A18 and A22 at a central angle (fig. A17) of 70° when the sea state is 0 or 6 and ionosphere scintillation is neglected. Take the required fade margin as the difference between power available curves for a time availability of 50 and 95 percent.

Solution: Figures A19, A23, A24, and A25 are applicable, and the values tabulated below were obtained from them.

Satellite	Sea State	Figure	Fade Margin [dB]
VHF	0	A19	1
VHF	6	A23	0.5
UHF	0	A24	1
UHF	6	A25	<0.5

Fade margins required for smooth sea (sea state 0) are greater than those required for very rough sea (sea state 6, table 6) because the roughness of the reflecting surface lowers the magnitude of the specular reflection coefficient so that the short term variability associated with surface reflection multipath is reduced for higher sea states. The factor used to reduce the specular reflection coefficient [24, (66)] provides more reduction at higher frequencies (i.e., roughness expressed in wavelength increases with frequency), but is unity for a smooth surface regardless of frequency.

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PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/09/01.    17.43.34. RUN

POWER AVAILABLE FOR UHF SATELLITE SEA STATE 0
SPECIFICATION REQUIRED
----------------------

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 19351. N MI (35838.KM) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT:  30000.0 FT (9144.M) ABOVE FSS
FREQUENCY:  1550. MHZ

SPECIFICATION OPTIONAL
----------------------
AIRCRAFT ANTENNA TYPE: JTAC
     BEAMWIDTH, HALF-POWER:  10.00 DEGREES
     POLARIZATION: CIRCULAR
     TILT IS -90.0 DEGREES ABOVE HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL:    0. FT (0.M)
EIRP PLUS RECEIVING ANTENNA MAIN BEAM GAIN:  41.0 DBW
FACILITY ANTENNA TYPE:  JTAC
     BEAMWIDTH, HALF-POWER:   20.00 DEGREES
     POLARIZATION:  CIRCULAR
     ANTENNA IS TRACKING
HORIZON OBSTACLE DISTANCE:  208.85 N MI (385.79KM) FROM FACILITY*
     ELEVATION ANGLE:    -2/49/36 DEG/MIN/SEC ABOVE HORIZONTAL*
     HEIGHT:     0. FT (0.M) ABOVE MSL
IONOSPHERIC SCINTILLATION INDEX GROUP: 0
REFRACTIVITY:
     EFFECTIVE EARTH RADIUS: 4586. N MI  (8493.KM)*
     MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING:  CONTRIBUTES TO VARIABILITY
SURFACE TYPE:  SEA WATER
                 STATE:  0
                         CALM (GLASSY)
                          0.00 FT (0.00M) RMS WAVE HEIGHT
                 TEMPERATURE: 10. DEG CELSIUS
                         3.6 PERCENT SALINITY
TERRAIN ELEVATION AT SITE:    0. FT (0.M) ABOVE MSL
TERRAIN PARAMETER:   0. FT (0.M)
TIME AVAILABILITY:  FOR INSTANTANEOUS LEVELS EXCEEDED

* COMPUTED VALUE
```

Notes: 1) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).

2) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure A22. Problem A5, parameter sheet, UHF Satellite

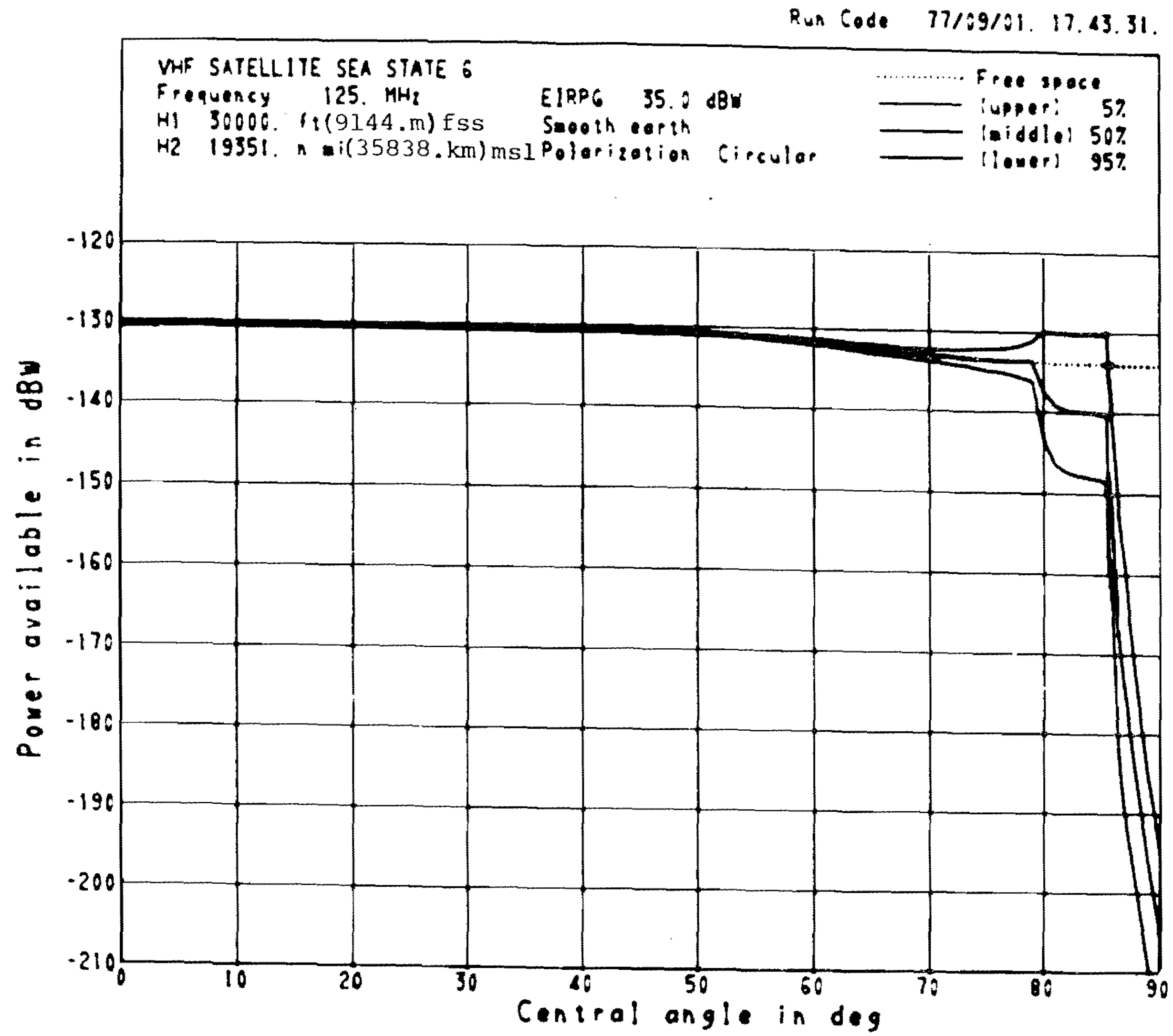

Figure A23. Power available, VHF satellite, scintillation index group 0, sea state 6. Power available values were calculated for the parameters of figure A18 except for sea state.

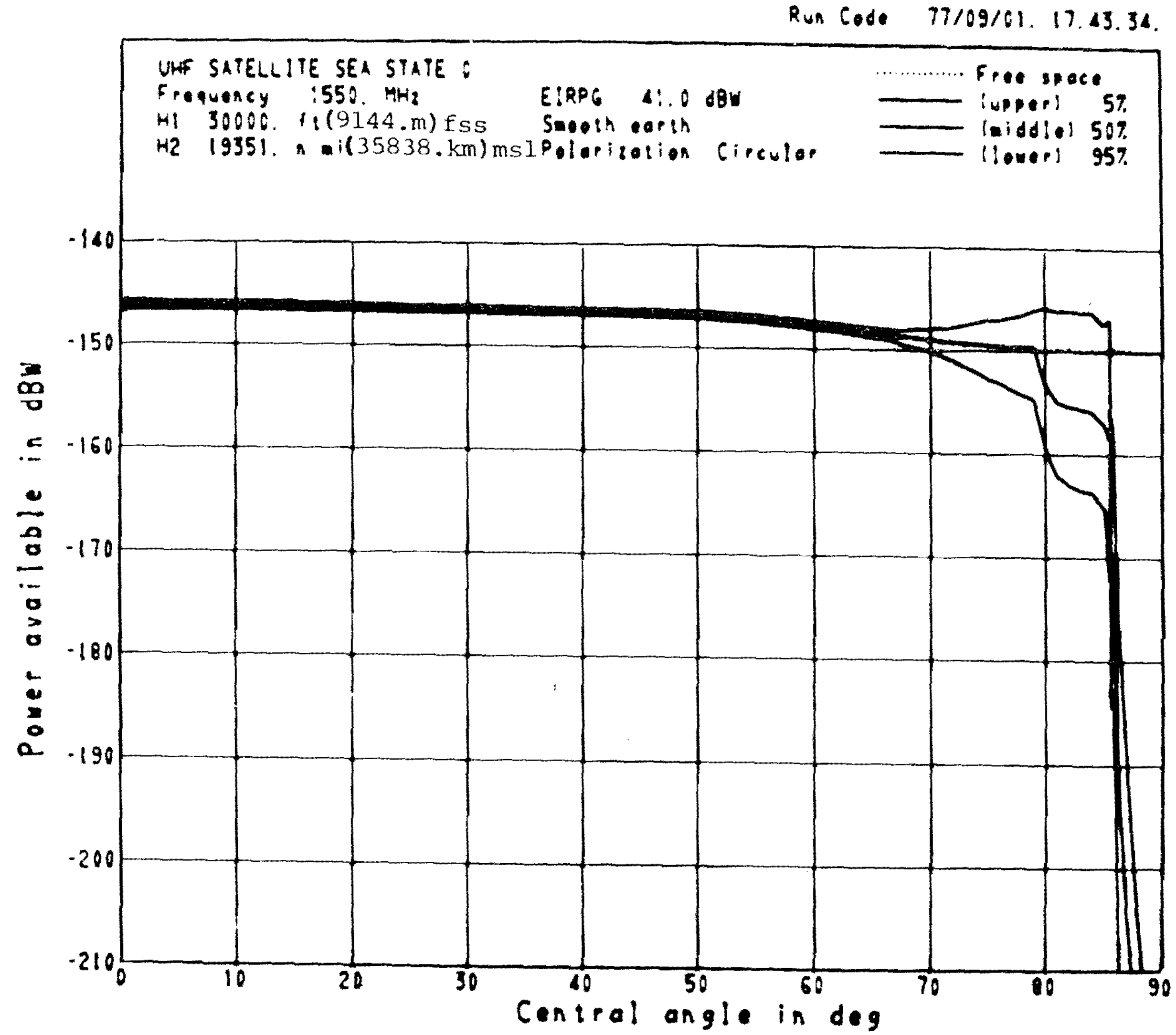

Figure A24. Power available, UHF satellite, scintillation index group 0, sea state 0. Power available values were calculated with the parameters of figure A22.

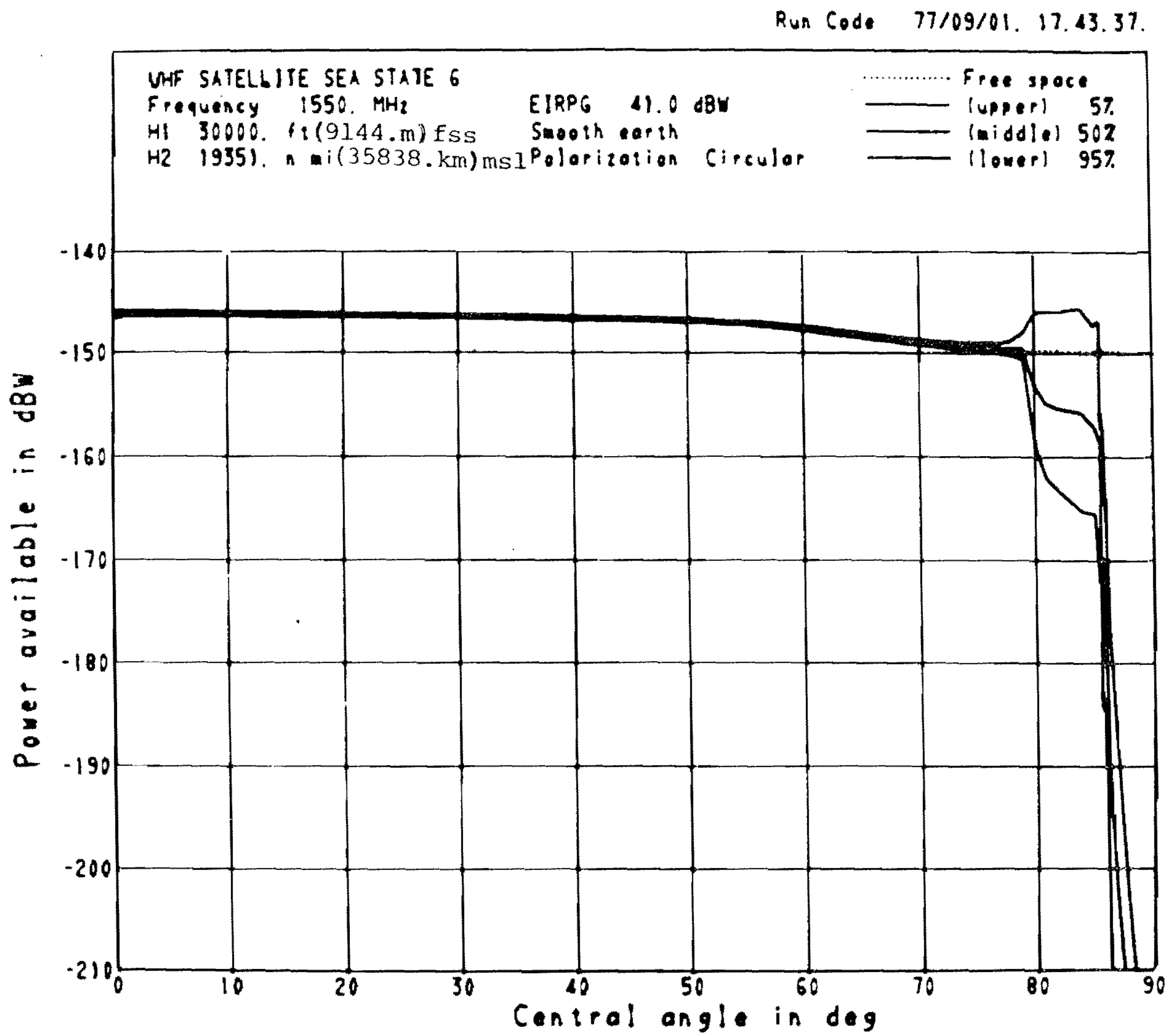

Figure A25. Power available, UHF satellite, scintillation index group 0, sea state 6. Power available values were calculated with parameters from figure A22 except for sea state.

ILS, Separation, Site Elevation

Problem A6: For the geometry illustrated in figure A26 and the desired ILS localizer facility parameters of figure A27, determine the station separation required to obtain a 23 dB desired-to-undesired localizer signal ratio at the aircraft with a time availability of 95 percent when the parameters for the undesired localizer are identical to those of the desired localizer except that its site elevation is (a) 1,000 ft (305 m) higher, (b) 0 ft higher, and (c) 1,000 ft (305 m) lower.

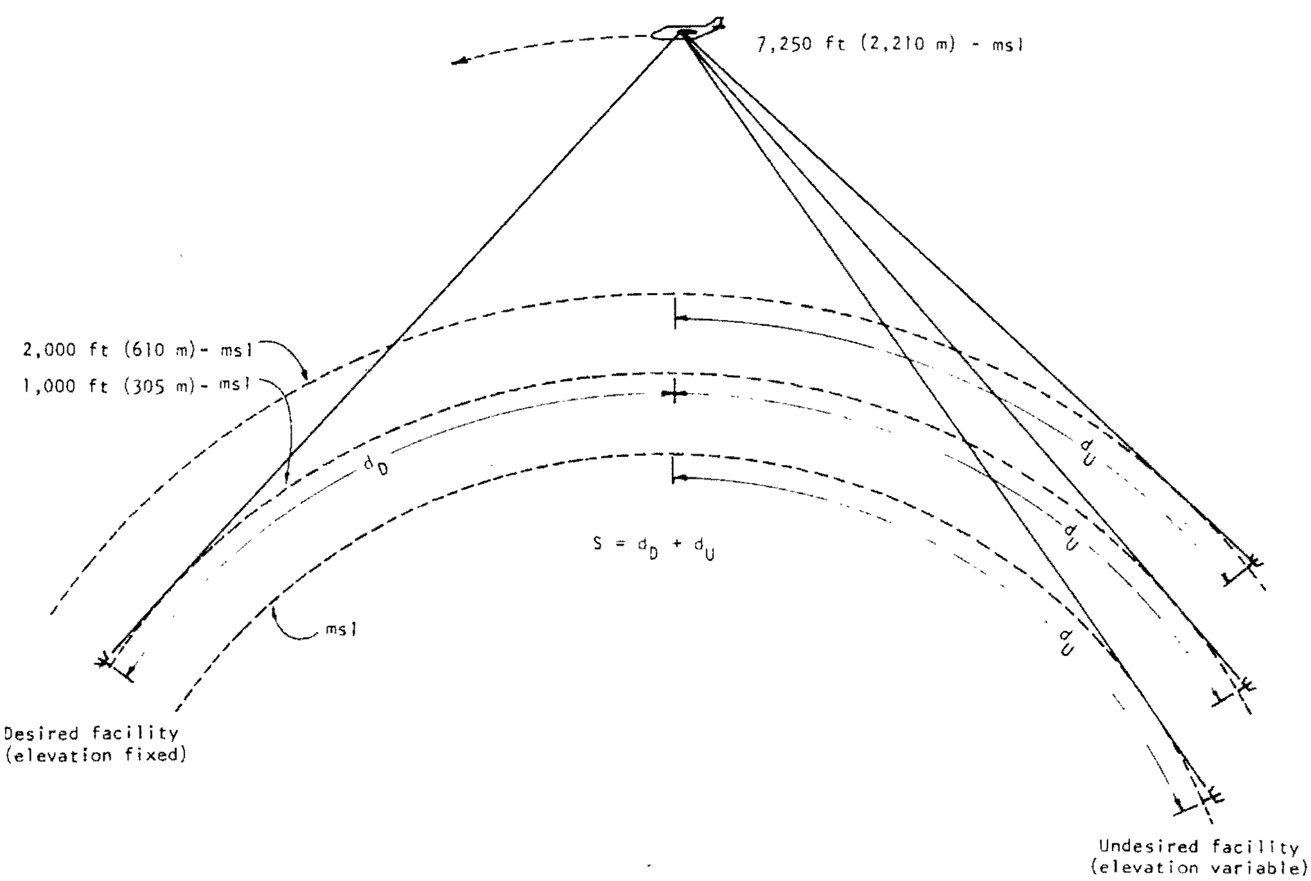

Figure A26. Problem A6, geometry sketch (not drawn to scale).

PARAMETERS FOR ITS PROPAGATION MODEL IF-77
77/07/13. 22.16.15. RUN

DESIRED STATION IS LOCALIZER
SPECIFICATION REQUIRED

AIRCRAFT (OR HIGHER) ANTENNA ALTITUDE: 7250. FT (2210.M) ABOVE MSL
FACILITY (OR LOWER) ANTENNA HEIGHT: 5.5 FT (1.68M) ABOVE FSS
FREQUENCY: 110. MHZ

SPECIFICATION OPTIONAL

AIRCRAFT ANTENNA TYPE: ISOTROPIC
POLARIZATION: HORIZONTAL
EFFECTIVE REFLECTION SURFACE ELEVATION ABOVE MSL: 1000. FT (305.M)
EQUIVALENT ISOTROPICALLY RADIATED POWER: 24.0 DBW
FACILITY ANTENNA TYPE: 8-LOOP ARRAY (COSINE VERTICAL PATTERN)
POLARIZATION: HORIZONTAL
HORIZON OBSTACLE DISTANCE: 2.88 N MI (5.33 KM) FROM FACILITY*
ELEVATION ANGLE: -0/ 2/09 DEG/MIN/SEC ABOVE HORIZONTAL*
HEIGHT: 0. FT (0.M) ABOVE MSL
REFRACTIVITY:
EFFECTIVE EARTH RADIUS: 4586. N MI (8493.KM)*
MINIMUM MONTHLY MEAN: 301. N-UNITS AT SEA LEVEL
SURFACE REFLECTION LOBING: CONTRIBUTES TO VARIABILITY
SURFACE TYPE: AVERAGE GROUND
TERRAIN ELEVATION AT SITE: 1000. FT (305.M) ABOVE MSL
TERRAIN PARAMETER: 0. FT (0.M)
TIME AVAILABILITY: FOR INSTANTANEOUS LEVELS EXCEEDED

* COMPUTED VALUE

Notes:
1) The aircraft is 25 n mi (46.3 km) from desired facility, on the desired facility course line, and on an extension of the undesired facility course line, i.e., the course lines are directed toward each other.
2) These parameters, except as specifically modified in problem statements, also apply to the undesired facility.
3) Although the configuration assumed here may be taken as worst case in that a station separation sufficient to provide protection at the critical point considered (i.e., point C of fig. 43 with $\phi_D=0$ and $\phi_U=180°$) would probably provide sufficient protection at other critical points, difference in terrain and/or facility antenna gains associated with these points could make a more extensive analysis necessary (see sec. 3.2 ORIENTATION discussion, fig. 35).
4) Parameter values (or options) not indicated are taken as the assumed values (or options) provided in the general parameter specification sheet (table 2).
5) To simulate computer output, only upper case letters are used. Dual units are not provided on actual computer output.

Figure A27. Problems A6 through A9, parameter sheet, ILS.

Solution: Examination of figure A26 shows that the aircraft is at a constant elevation with respect to both mean-sea level (msl) and the desired ILS site surface for all three parts of the problem, but that aircraft elevation with respect to the undesired ILS site surface changes for each part of the problem. Lower aircraft altitude with respect to the undesired facility means that the undesired signal level at the aircraft is expected to be lower for a particular undesired facility-to-aircraft distance which will translate in the context of this problem to a decrease in the station separation requirement. Conversely, a higher aircraft altitude with respect to the undesired facility would be expected to result in a larger station separation requirement.

Site surface elevations for various parts of the problem are drawn as dashed lines in figure A26 and are extended from facility-to-facility to show that use of different site elevations is not compatable with the use of a smooth earth for all of the terrain between the facilities since different elevations result in different earth radii. Desired and undesired signal levels are computed independently for the parameters applicable to each facility so that this difficulty is not recognized by the programs, but must be considered in using the computer output. One way to do this is to assume that each site elevation is valid at least to the smooth earth horizon distance for its facility antenna and that the computed results are invalid when terrain at the higher site elevation is visible to the other antenna. These conditions are illustrated in figure A28 and result in a minimum station separation (S_{min}) for which predictions are valid. Values for S_{min} can be estimated from

$$S_{min} = \sqrt{2aH_D} + \sqrt{2aH_{\Delta e}} + \sqrt{2aH_U} \qquad \text{(A1)}$$

where

a = effective earth radius,

$H_{D,U}$ = height of desired or undesired facility antenna above its site surface elevation and $H_{\Delta e}$ = Magnitude of the difference in site elevations.

Each term of (A1) is a smooth earth horizon type distance as illustrated in figure A28.

Figures A29 through A31 were developed for this problem and the station separation requirements resulting from them are tabulated below along with S_{min} values obtained from (A1):

Site Elevation Above msl [ft (m)] Desired	Undesired	Figure	Required Station Separation [n mi (km)]	S_{min} [n mi (km)]
1,000(305)	2,000(610)	A29	100 (185)	45 (83)
1,000(305)	1,000(305)	A30	107 (198)	Not Applicable
1,000(305)	0	A31	113 (209)	45 (83)

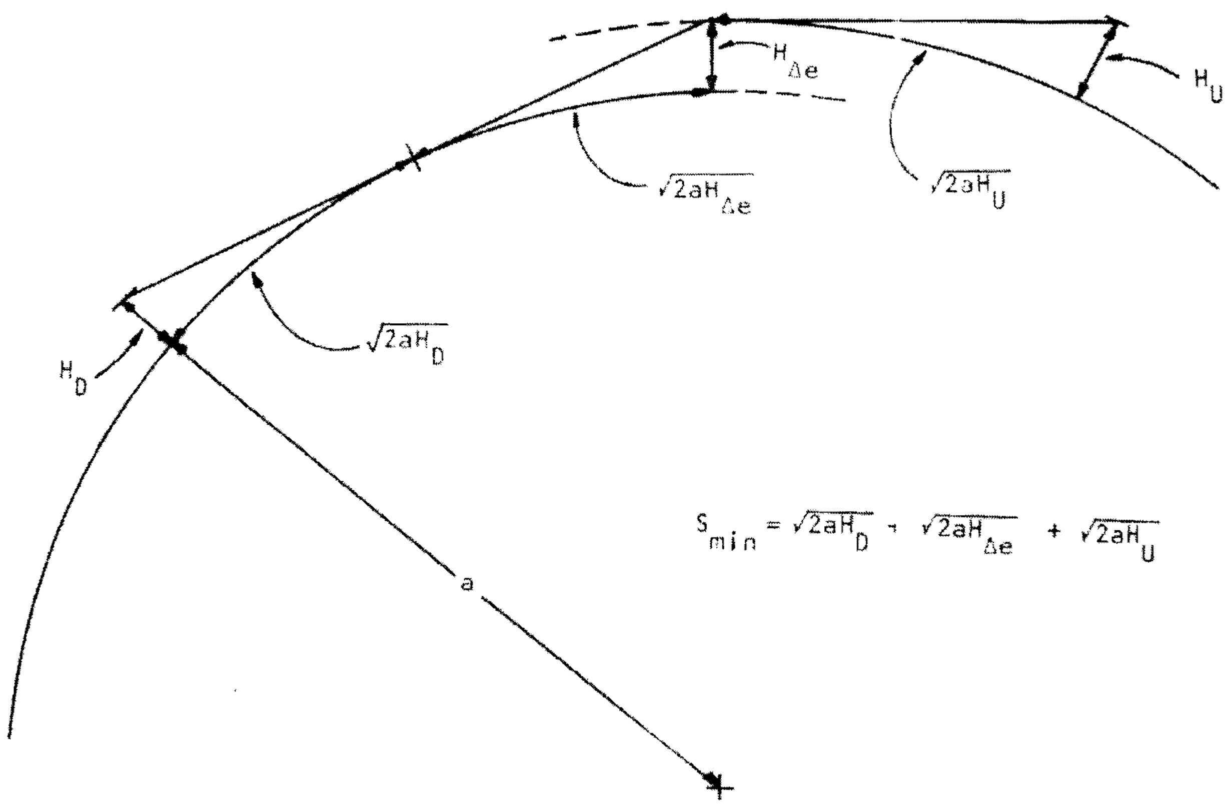

Figure A28. Geometry for S_{min} (not drawn to scale.)

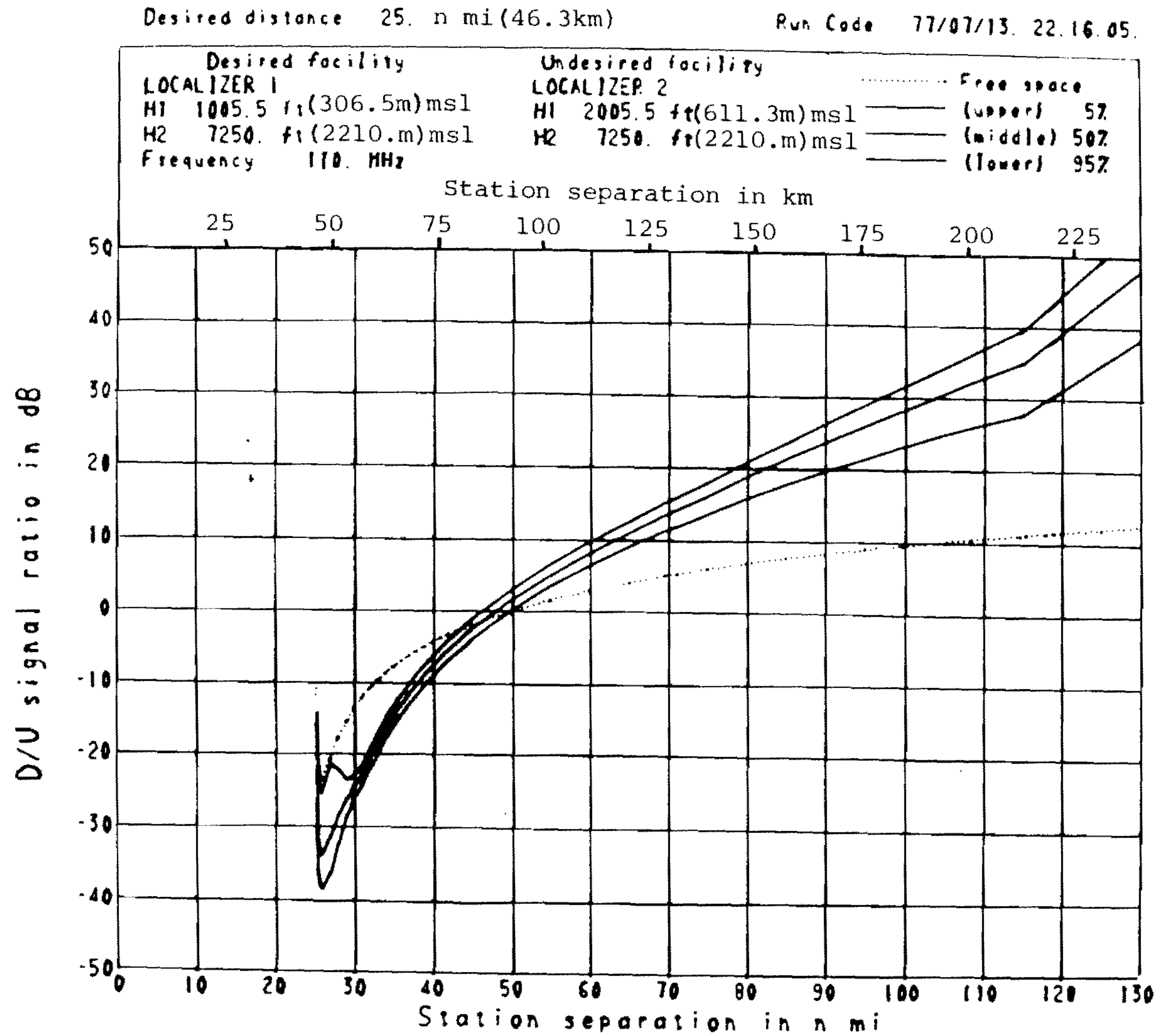

Figure A29. *Signal ratio-S, ILS, higher undesired facility elevation. Parameters are as given in figure A27 except that the undesired facility site elevation is 2,000 ft (610 m).*

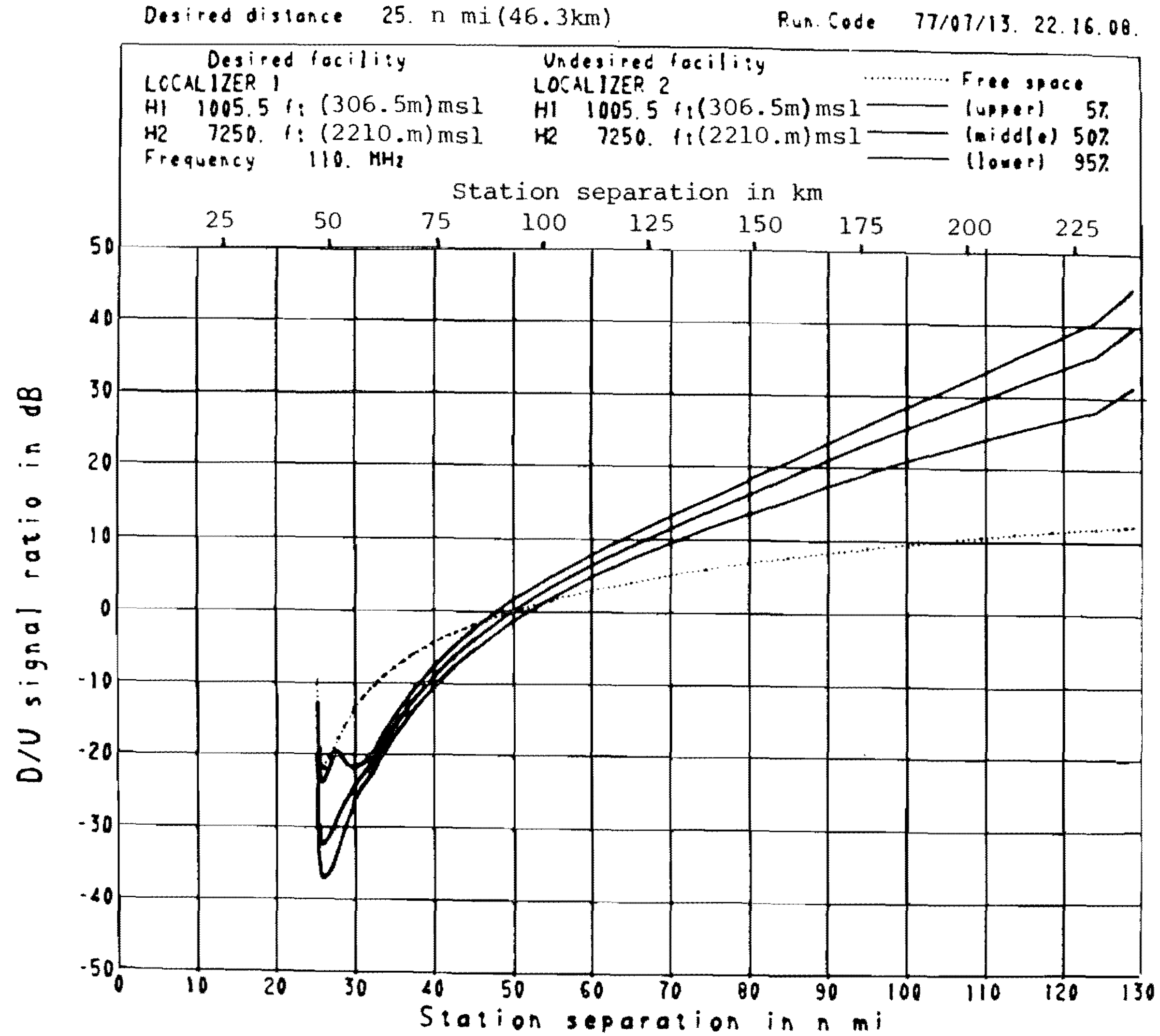

Figure A30. Signal ratio-S, ILS, equal site elevations. Parameters are as given in figure A27.

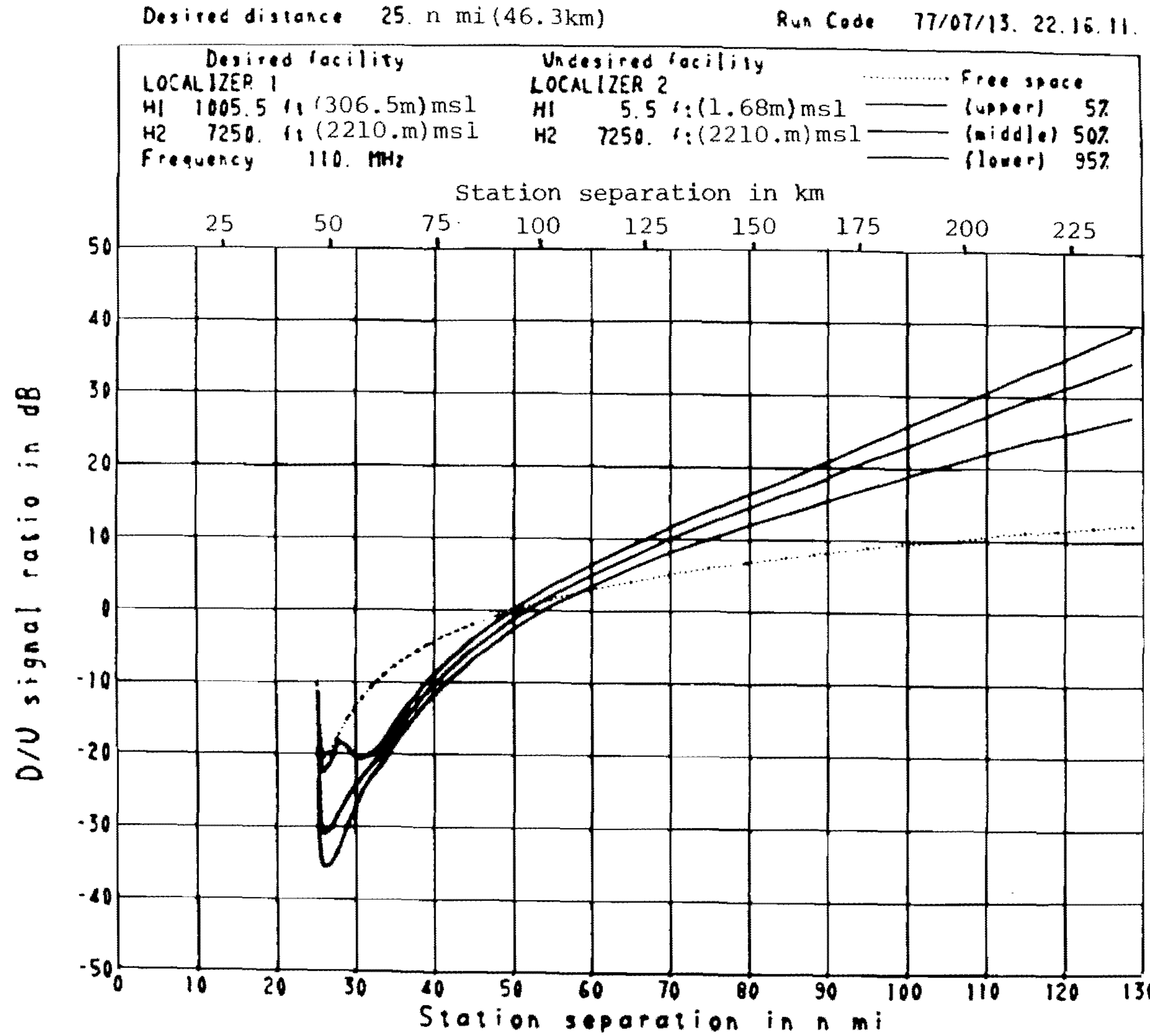

Figure A31. Signal ratio-S, ILS, lower undesired facility elevation. Parameters are as given in figure A27 except that the undesired facility site elevation is 0 ft (0 m).

ILS, Separations, Surface Constants

Problem A7: For the geometry illustrated by the equal site elevation portion of figure A26 and the ILS localizer parameters of figure A27, determine the station separation required to obtain a 23 dB desired-to-undesired localizer signal ratio at the aircraft with a time availability of 95 percent when the surface constants (table 5) are taken as those associated with (a) poor ground, (b) average ground, (c) good ground, (d) fresh water, or (e) sea water

Solution: Figures A32 through A36 were developed for this problem, and the station separation requirements listed below were taken from them.

Surface Type	Figure	Station Separation [n mi (km)]
Poor ground	A32	107 (198)
Average ground	A33	107 (198)
Good ground	A34	107 (198)
Sea water	A35	107 (198)
Fresh water	A36	107 (198) .

Hence, for this problem, surface type is not an important parameter. Other situations where vertical or circular polarization and large (> 1°) grazing angles (ψ of fig. 40) are involved would be expected to show greater dependence on surface type [49, figs. III.1 through III.8]. Even then the dependence may be masked by surface roughness (probs. A5 and A8), which makes the specular reflection coefficients smaller as roughness increases.

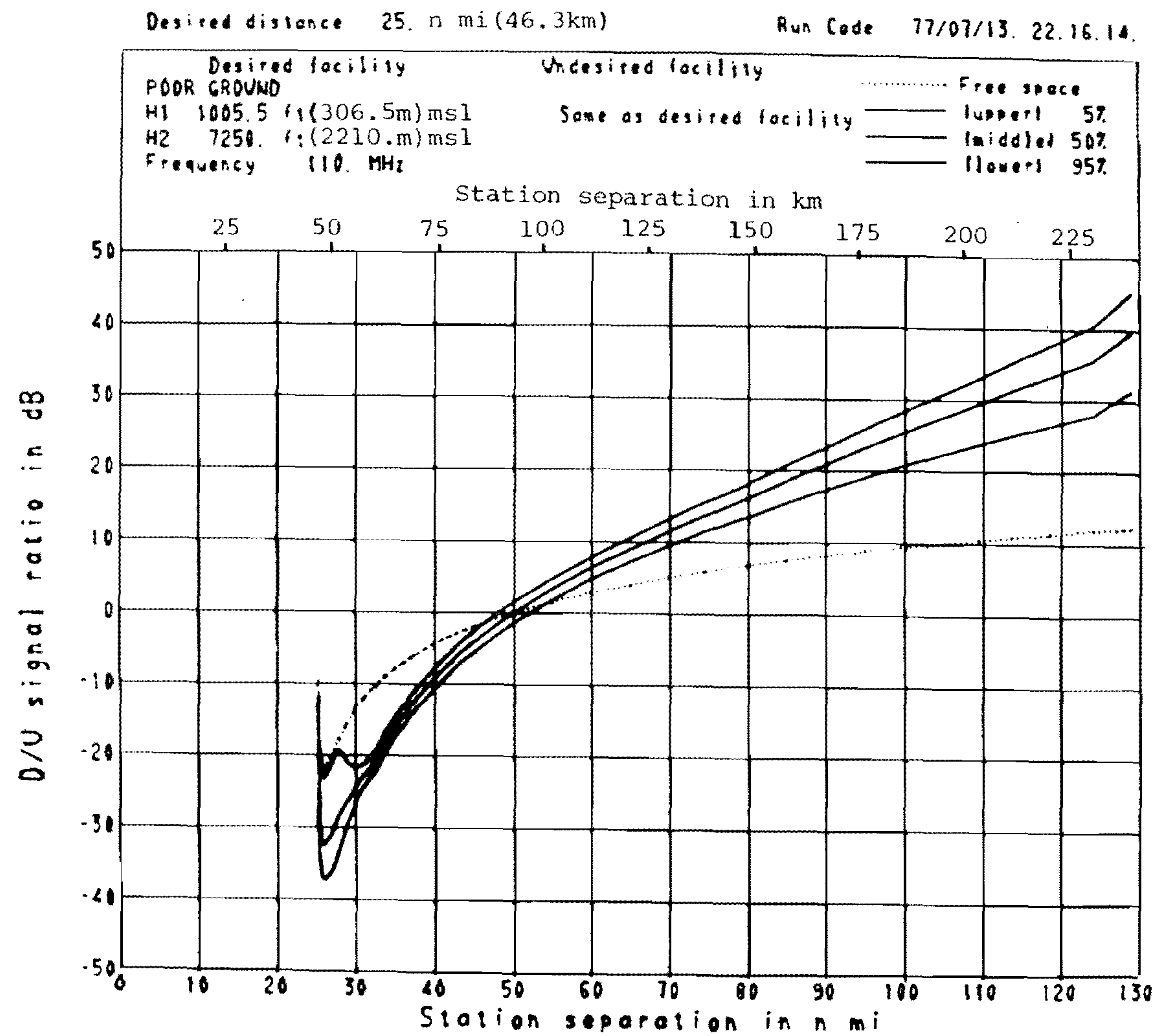

Figure A32. Signal ratio-S,.ILS, poor ground. Parameters are as given in figure A27 except for surface type.

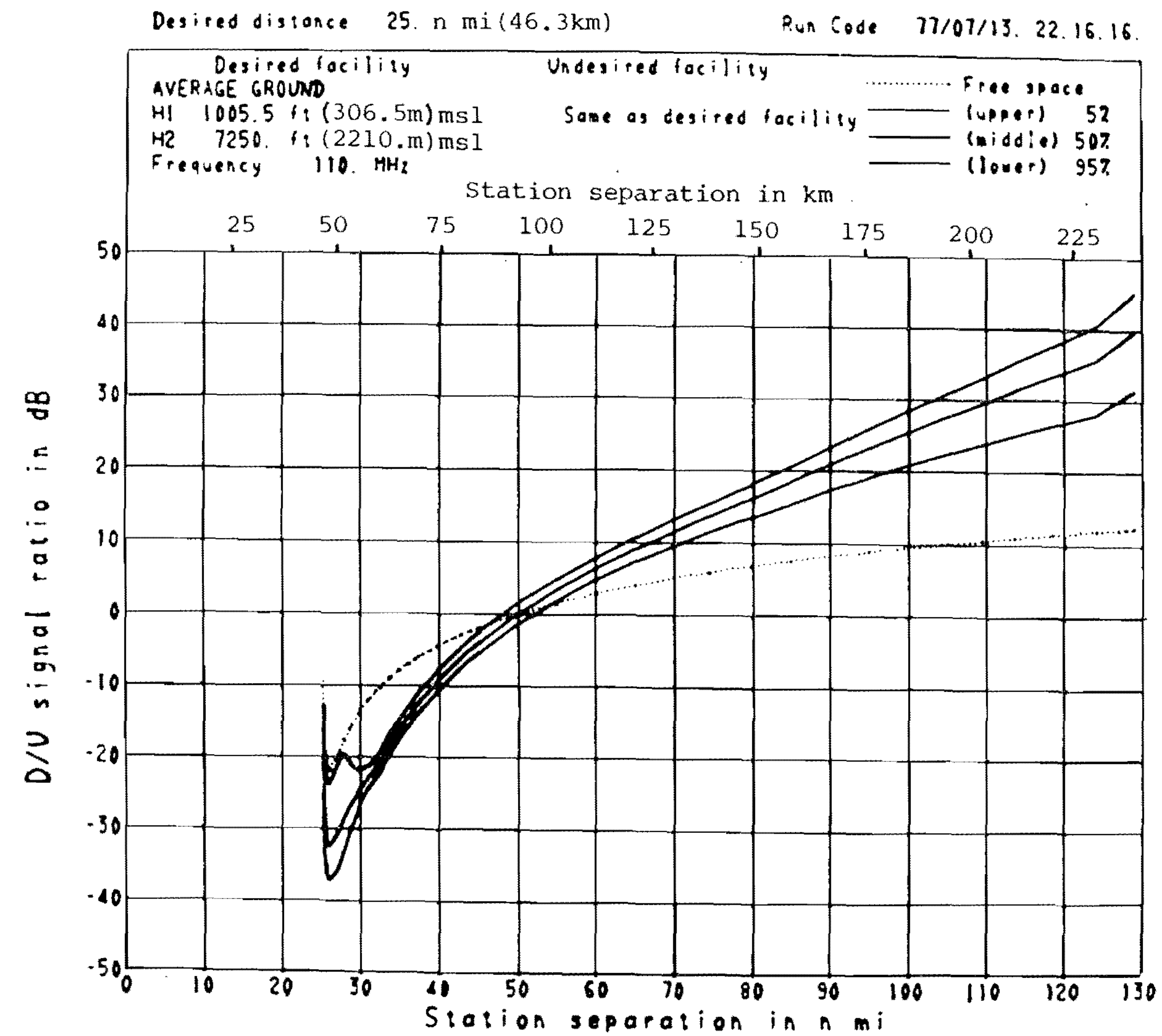

Figure A33. Signal ratio-S, ILS, average ground. Parameters are as given in figure A27.

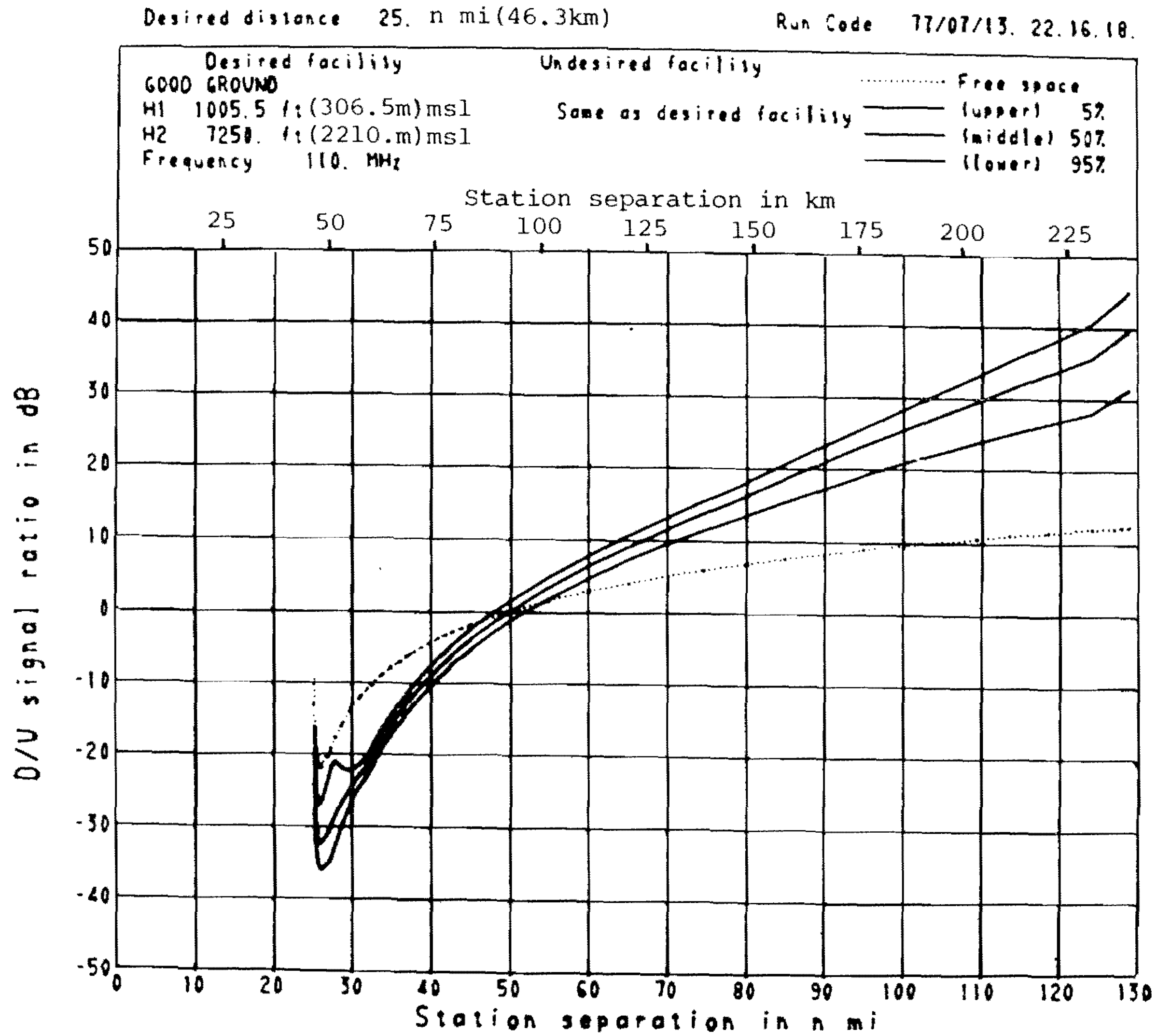

Figure A34. Signal ratio-S, ILS, good ground. Parameters are as given in figure A27 except for surface type.

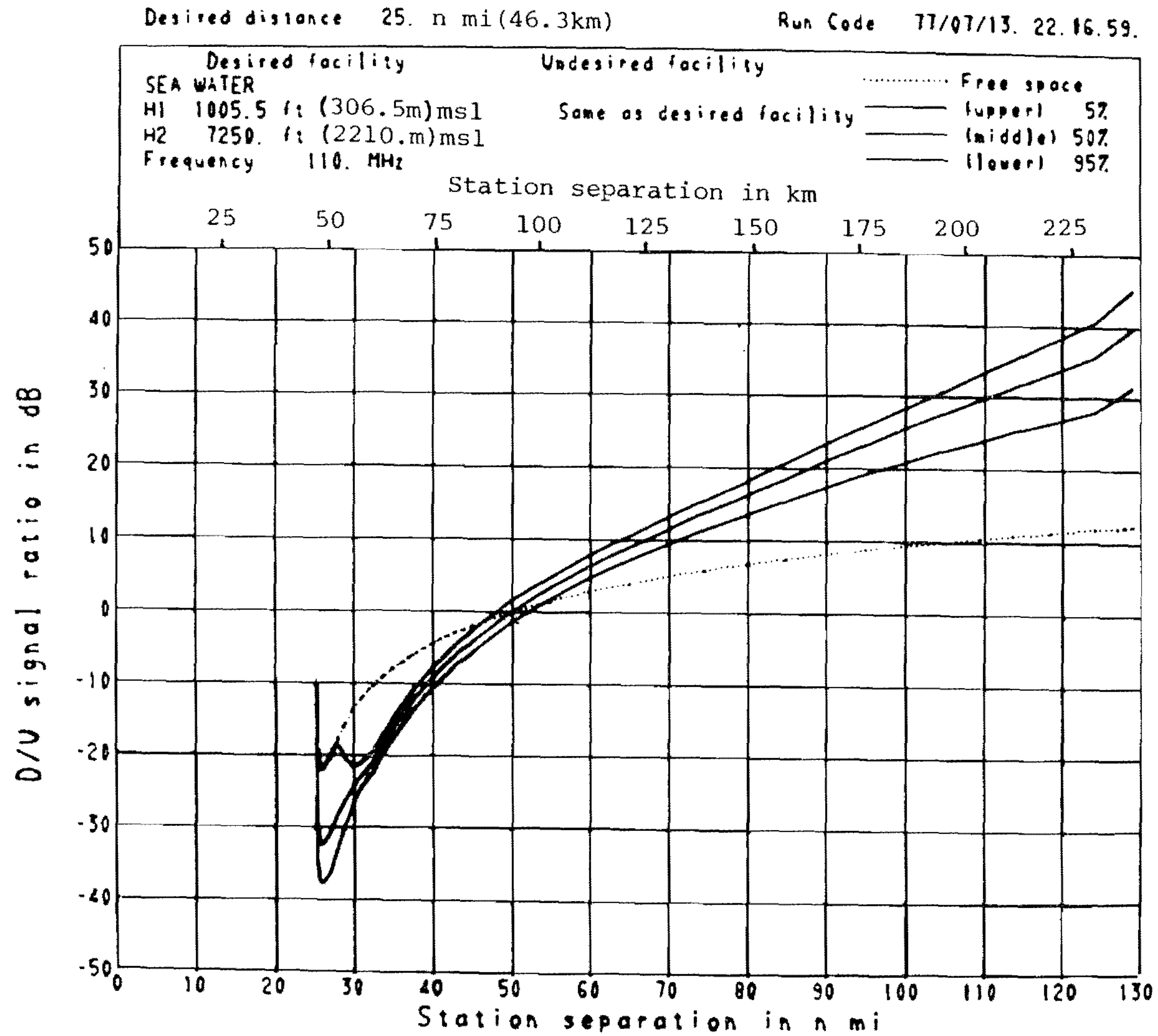

Figure A35. Signal ratio-S, ILS, sea water. Parameters are as given in figure A27 except for surface type.

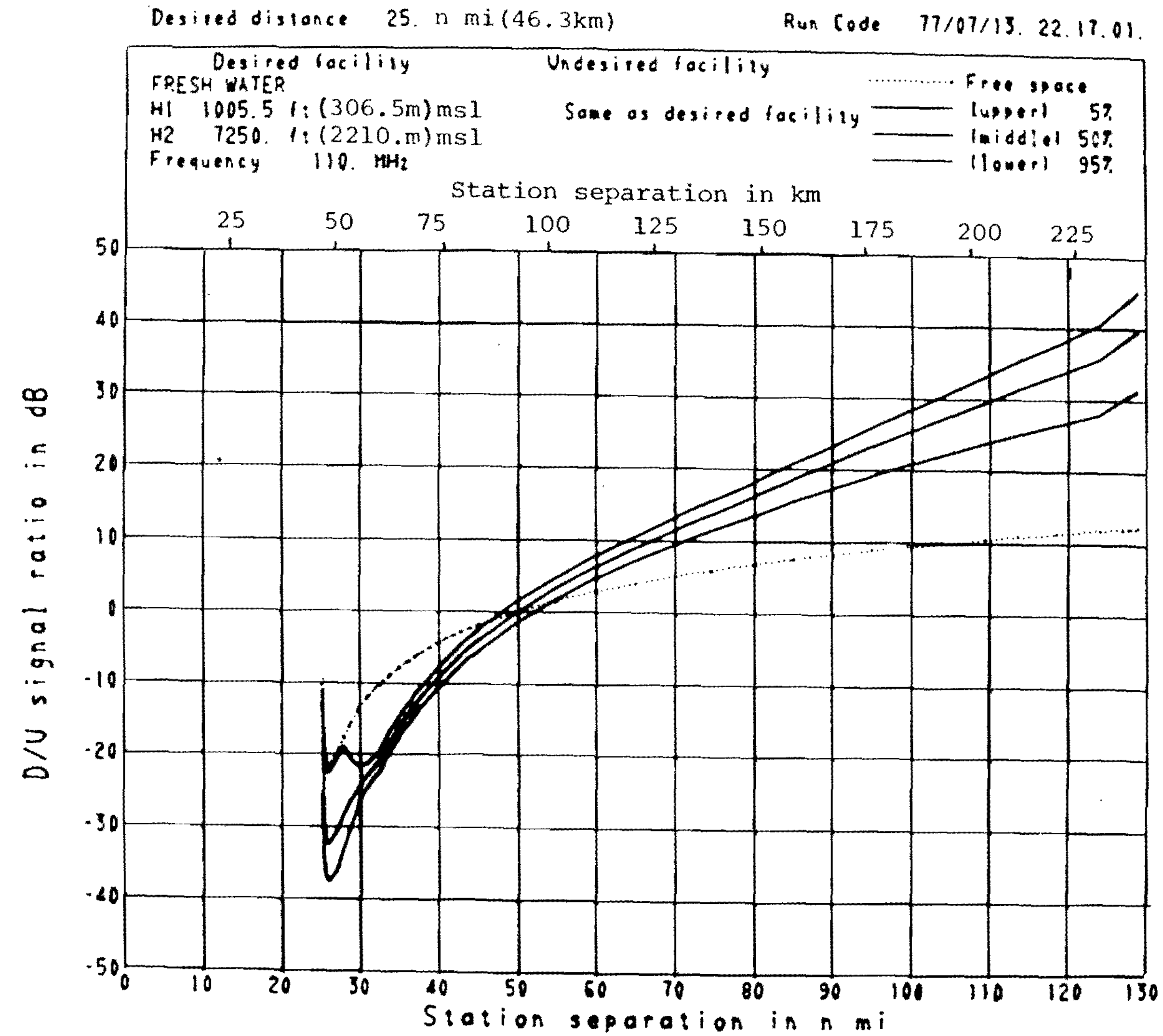

Figure A36. Signal ratio-S, ILS, fresh water. Parameters are as given in figure A27 except for surface type.

ILS, Separation, Terrain Parameter

Problem A8: For the geometry illustrated by the equal site elevation portion of figure A26 and the ILS localizer parameters of figure A27, determine the station separation required to obtain a 23 dB desired-to-undesired localizer signal ratio at the aircraft with a time availability of 95 percent when the terrain parameter is selected as (a) smooth, (b) smooth plains, (c) rolling plains, (d) hills, (e) mountains, and (f) extremely rugged mountains.

Solution: Figures A33 and A37 through A41 are applicable to this problem, and the station separation requirements taken from them are listed below along with the terrain parameter (Δh) value used for each terrain type (see table 7):

Terrain Type	Figure	Terrain Parameter [ft (m)]		Station Separation [n mi (km)]	
Smooth	A33	0	(0)	107	(198)
Smooth plains	A37	40	(12)	108	(200)
Rolling plains	A38	195	(59)	106	(196)
Hills	A39	375	(114)	93	(172)
Mountains	A40	740	(226)	70	(130)
Extremely rugged mountains	A41	2625	(800)	>125	(>232).

The following comments concerning these results are appropriate:

(a) the station separation increase for the smooth to smooth plains case is caused by a decrease in the reflection coefficient associated with the undesired facility which increases the undesired signal level,

(b) the station separation decrease that occurs from smooth plains through mountains is caused by a decrease in the line-of-sight range associated with the undesired facility which decreases the undesired signal level,

(c) the large station separation increase for the mountains to extremely rugged mountains case is caused by a decrease in the line-of-sight range associated with the desired facility

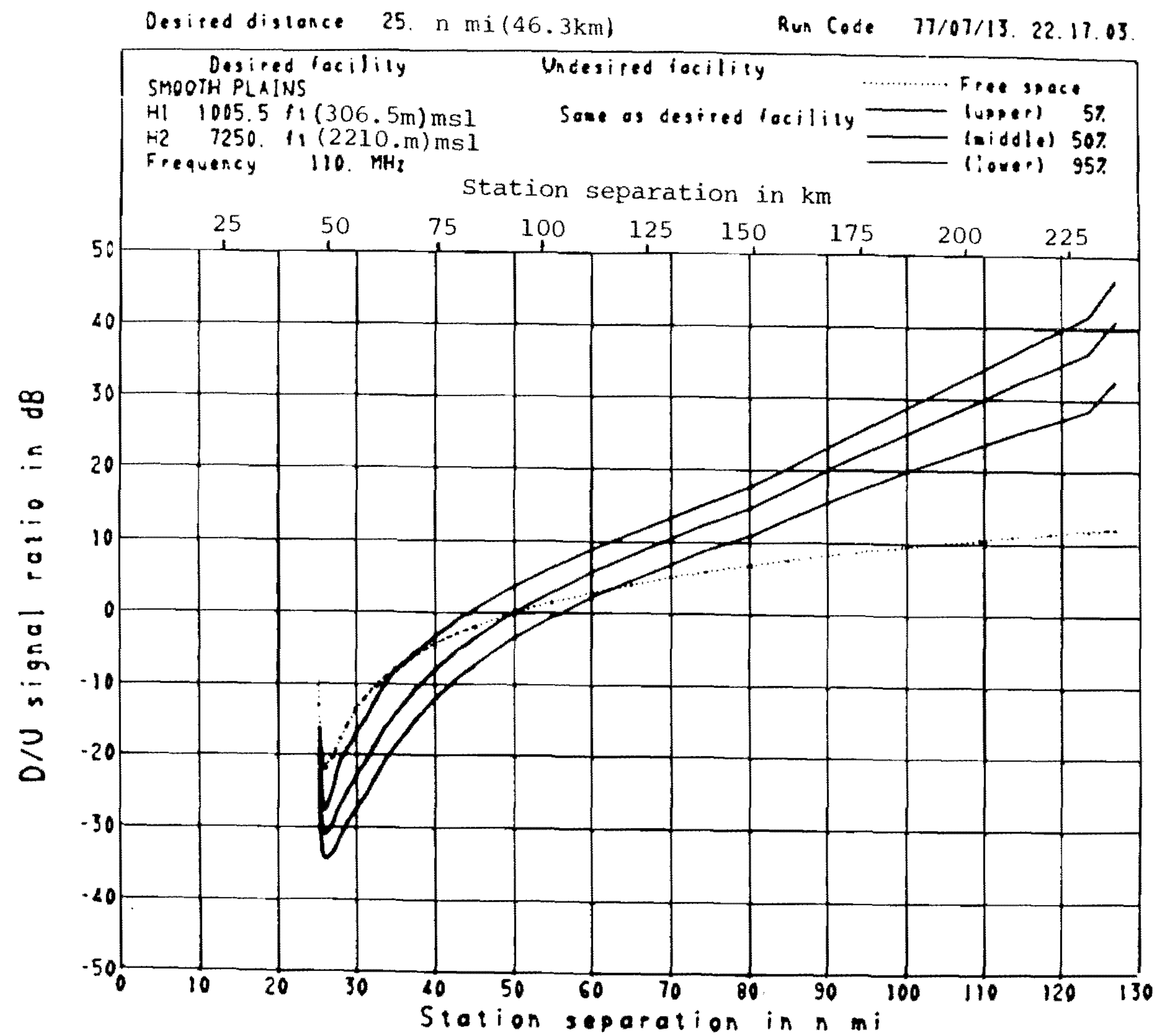

Figure A37. *Signal ratio-S, ILS, smooth plains. Calculations were made for the parameters of figure A27 except with a Δh for smooth plains (40 ft, 12 m). Horizon parameters were calculated from Δh.*

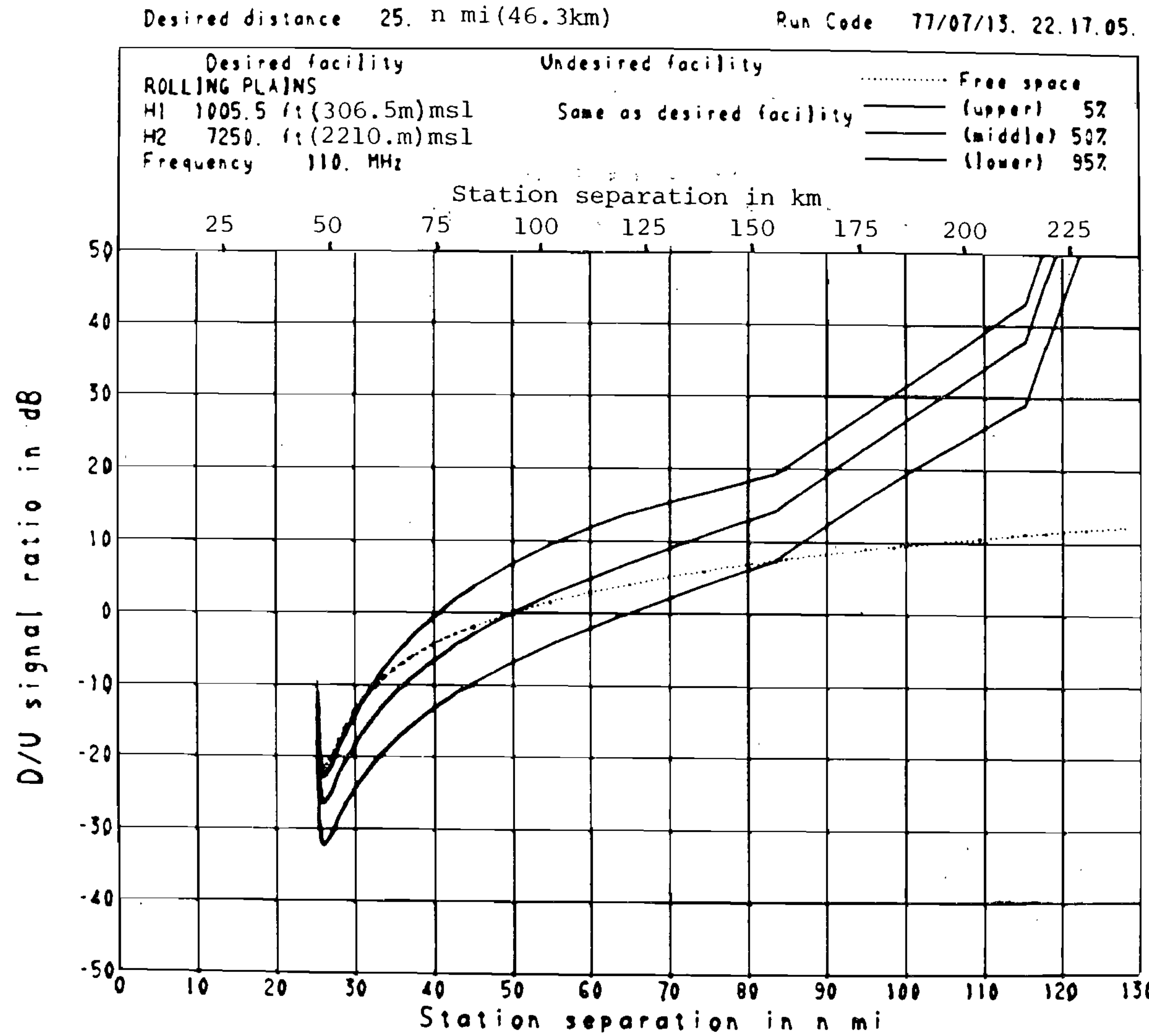

Figure A38. Signal ratio-S, ILS, rolling plains. Calculations were made for the parameters of figure A27 except with a Δh for rolling plains (195 ft, 59 m). Horizon parameters were calculated from Δh.

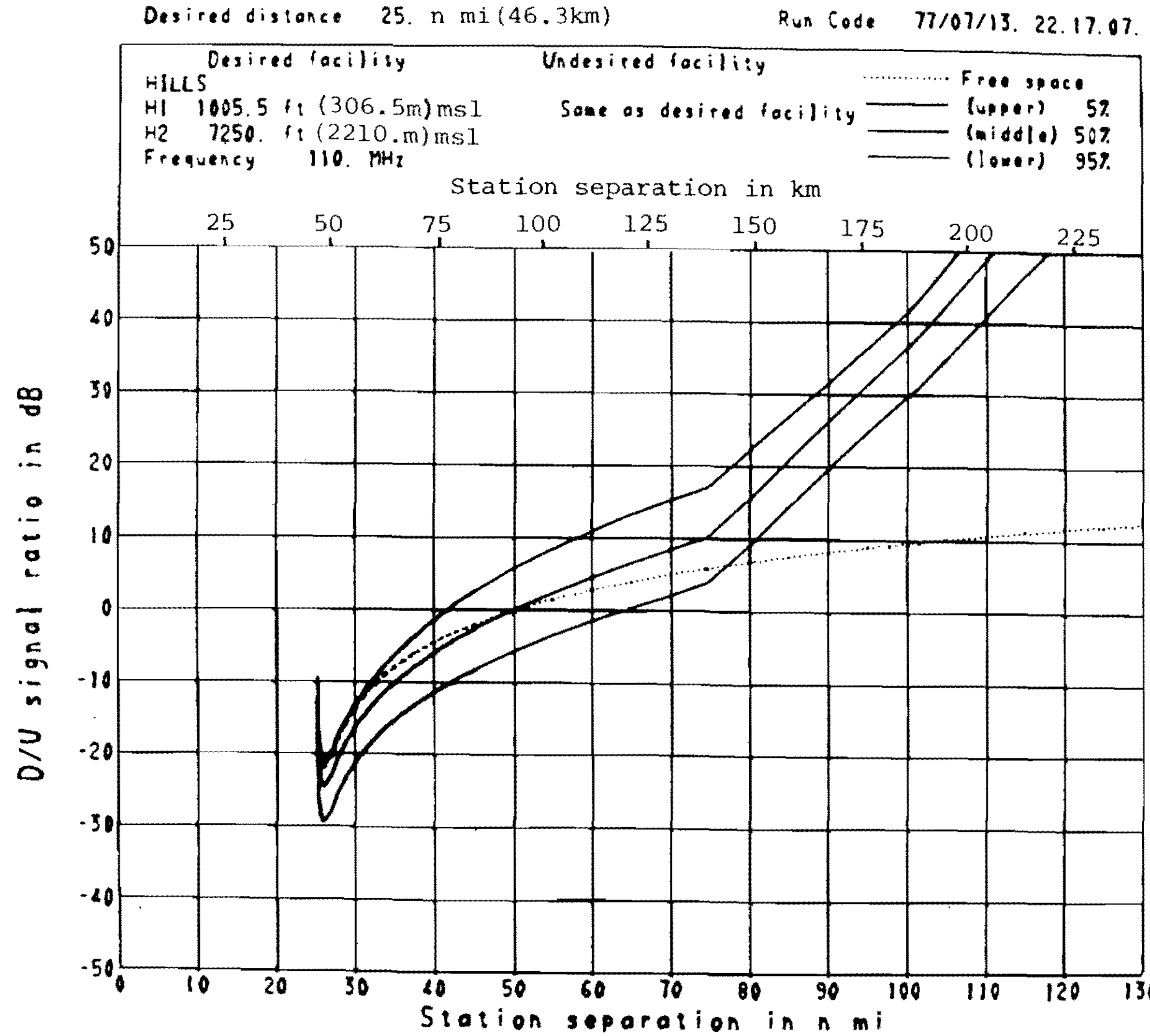

Figure A39. Signal ratio-S, ILS, hills. Calculations were made for the parameters of figure A27 except with a Δh for hills (375 ft, 114 m). Horizon parameters were calculated from Δh.

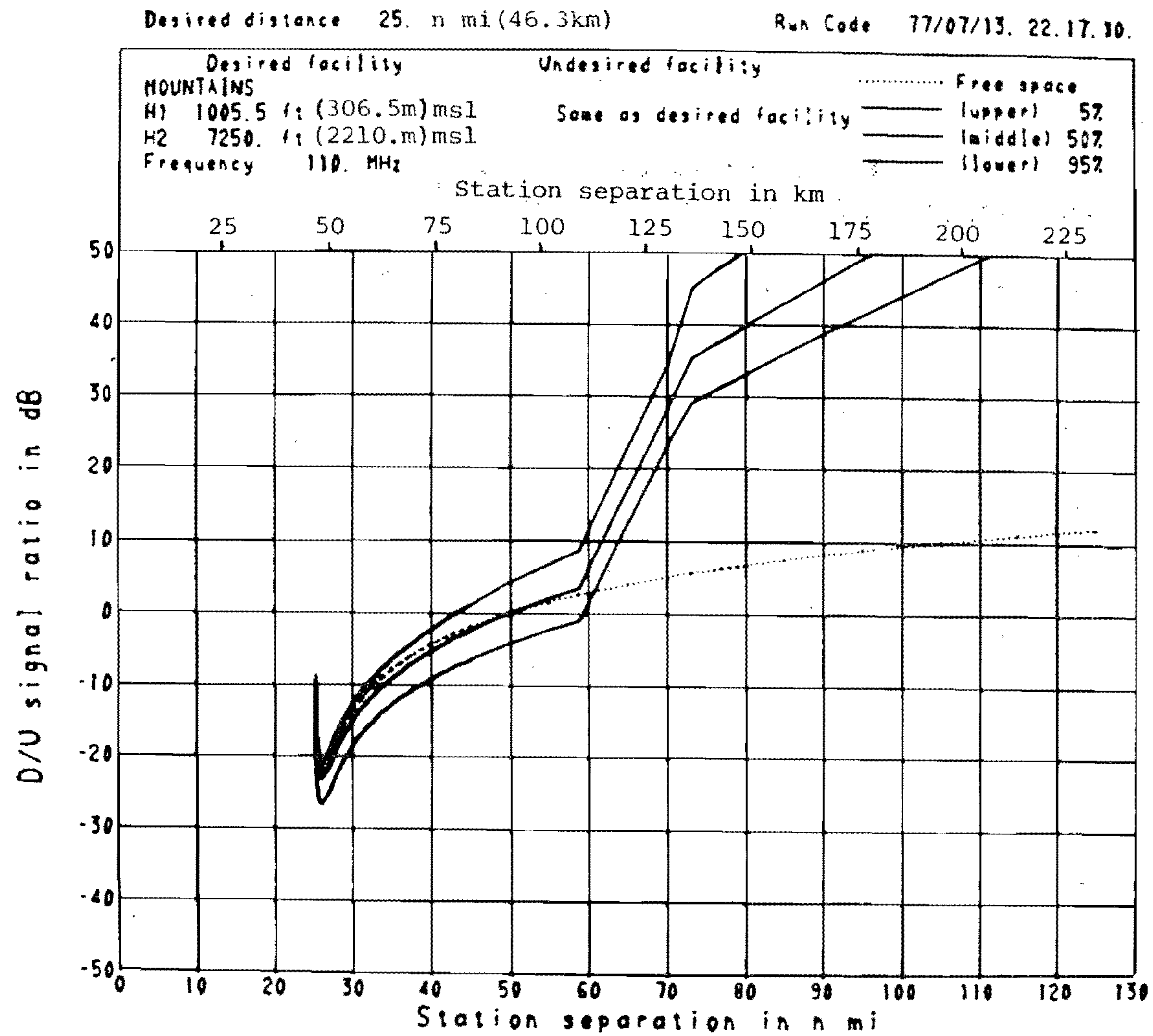

Figure A40. Signal ratio-S, ILS, mountains. Calculations were made for the parameters of figure A27 except with a Δh for mountains (740 ft, 226 m). Horizon parameters were calculated from Δh.

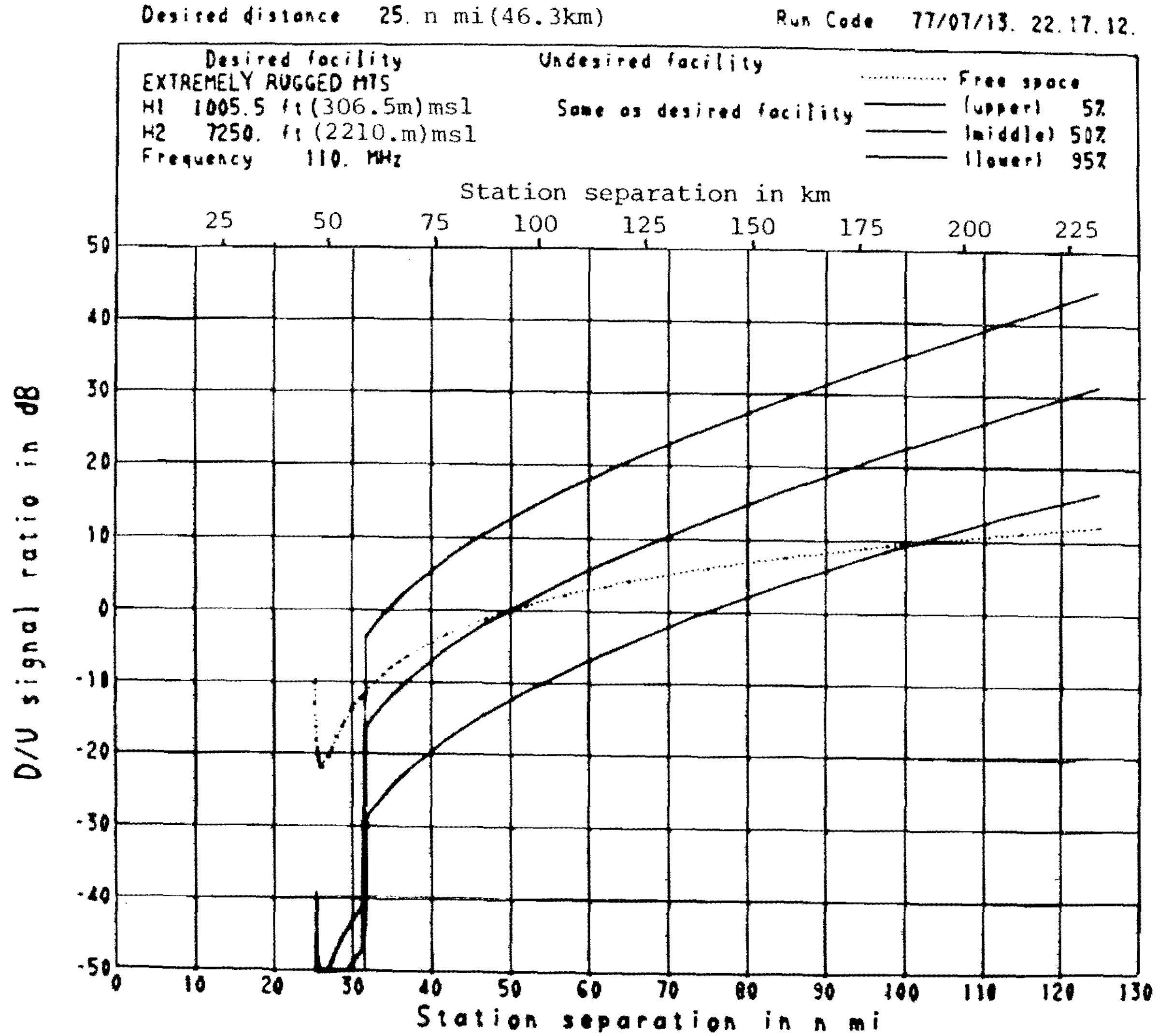

Figure A41. Signal ratio-S, ILS, extremely rugged mountains. Calculations were made for the parameters of figure A27 except with a Δh for extremely rugged mountains (2,625 ft; 800 m). Horizon parameters were calculated from Δh.

which decreases the desired signal level, and

(d) the exclusive use of Δh to describe terrain could easily result in station separations that are not appropriate for specific paths. Actual horizon information should be used whenever it is available.

ILS, Separation, Terrain Profile

Problem A9: For geometry similar to the equal site elevation portion of figure A26 and the equipment parameters of figure A27, determine the station separation required to obtain a 23 dB desired-to-undesired localizer signal ratio at the aircraft with a time availability of 95 percent when terrain parameters are determined using (a) topographic maps and (b) the Electromagnetic Compatibility Analysis Center (ECAC) terrain file. Sites should be selected to have equal elevations as shown by topographic maps, and the terrain between them should be "severe".

Solution: Locations at Seattle (47°15'00"N, 122°22'47"W) and Portland (45°33'22"N, 122°30'25"W) were selected for the desired and undesired facilities, respectively. These locations were selected based on the problem requirements for equal site elevations and severe terrain from paths for which topographic profile data are available on computer cards [39, fig. 2.22]. It is unlikely that these particular locations would ever actually be selected as localizer sites.

In calculating the desired signal level at the aircraft, only terrain characteristics associated with the desired facility are used, and beyond the facility horizon obstacle the terrain is taken as smooth with an elevation equal to the effective reflecting surface elevation for the desired facility. Similar considerations are involved in the calculations of the undesired signal level. Hence, actual terrain between the facility horizon obstacles is not involved in station separation calculations since only terrain between each facility and its horizon obstacle is utilized to determine key terrain characteristics.

Figures A42 and A43 were developed for this problem, and the required station separations obtained from them are given below along with site and horizon parameters for the two sets of terrain data used:

Parameters*	Terrain Data From: Topographic Maps	Terrain Data From: ECAC Terrain File
Required station separation [n mi (km)]	72 (133)	75 (139)
Figure	A42	A43
Desired Facility (Seattle)		
Effective reflection surface elevation [ft (m)]	19.7 (6)	98.4 (30)
Horizon distance [n mi (km)]	2.6 (4.9)	31.56 (58.44)
Horizon height [ft (m)]	325 (99)	3,199 (975)
Site elevation [ft (m)]	19.7 (6)	98.4 (30)
Terrain parameter [ft (m)]	394 (120)	692 (211)
Undesired Facility (Portland)		
Effective reflection surface elevation [ft (m)]	19.7 (6)	200 (61)
Horizon distance [n mi (km)]	34.6 (64.0)	34.67 (64.21)
Horizon height [ft (m)]	4,268 (1,301)	3,930 (1,198)
Site elevation [ft (m)]	19.7 (6)	200 (61)
Terrain parameter [ft (m)]	1,654 (504)	1,470 (448)

*A surface refractivity referred to mean sea level value of 279 N-units was used (see fig. 51). Equipment related parameters are as given in figure A27.

The larger required station separation for the ECAC terrain case is caused by the greater site elevation and lower horizon height associated with the undesired facility which increases the undesired signal level. Both required separations are at least 25% less than the actual great-circle site separation of 101.7 n mi (188.4 km).

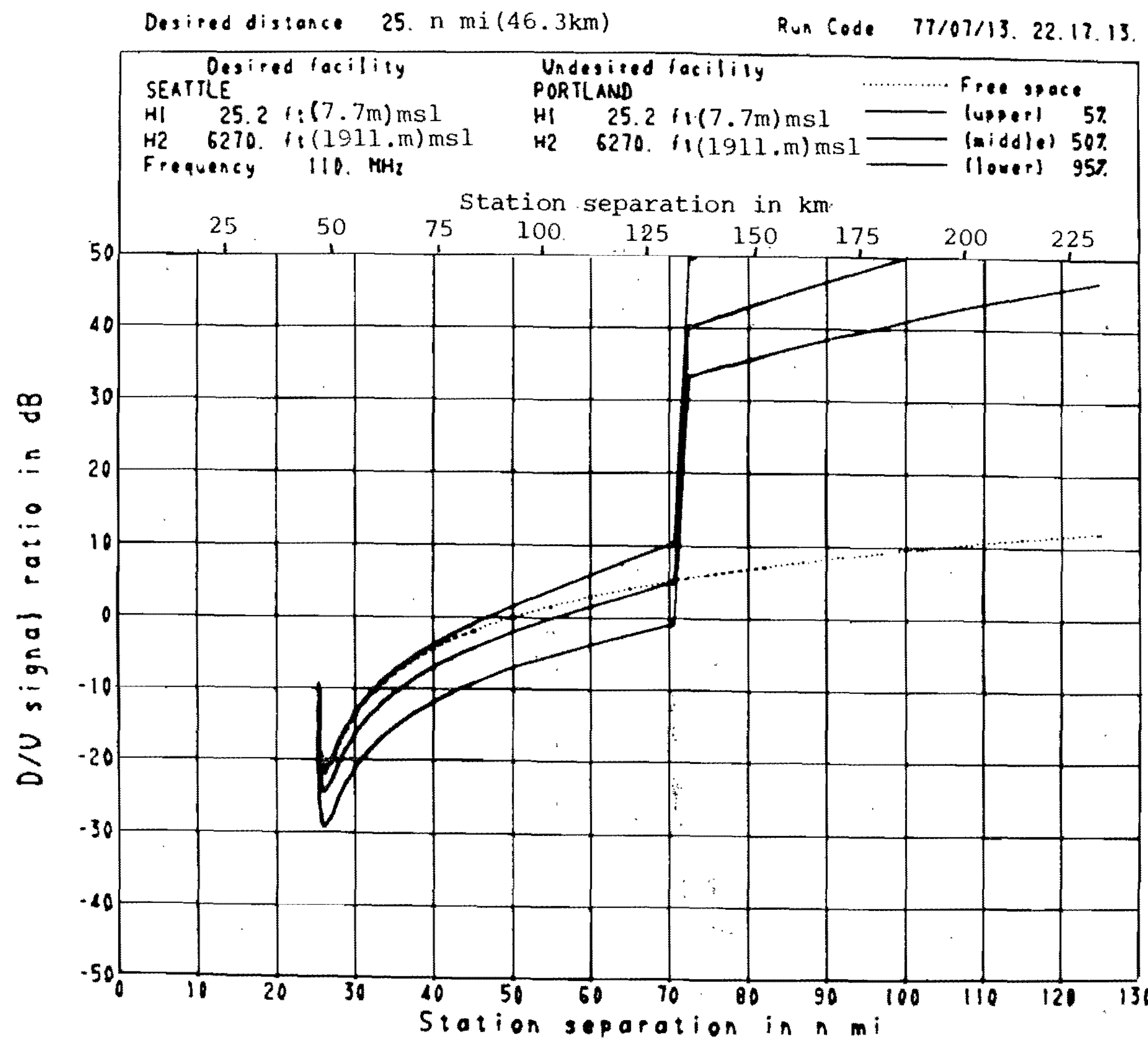

Figure A42. *Signal ratio-S, ILS, path parameters from topographic maps (see text). Equipment parameters are as given in figure A27. The sharp increase in D/U near 70 n mi (130 km) is in response to a sharp decrease in the undesired signal level that occurs as line of sight conditions are lost over the undesired facility to aircraft path (see figs. A37 through A41).*

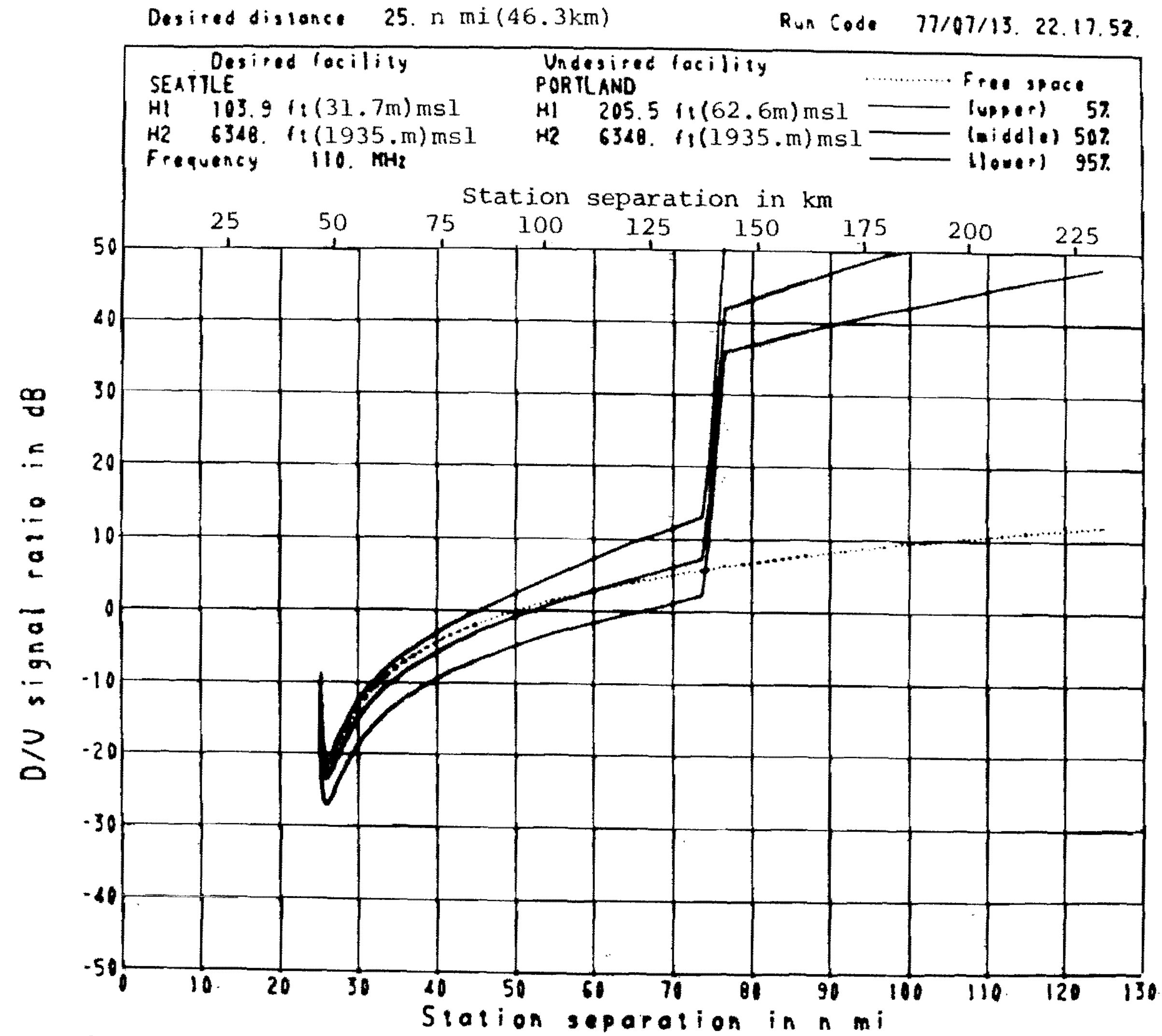

Figure A43. Signal ratio-S, ILS, horizon parameters from ECAC terrain file (see text). Equipment parameters are given in figure A27. The sharp increase in D/U near 74 n mi (137 km) is in response to a sharp decrease in the undesired signal level that occurs as line-of-sight conditions are lost over the undesired facility to aircraft path (see figs. A37 through A41).

APPENDIX B.

LIST OF SYMBOLS

This list includes most of the abbreviations, acronyms, and symbols used in this report. Many are similar to those previously used in other reports [24, 27, 37, 49]. The units given for symbols in this list are those required by or resulting from equations as given in this report. Except where otherwise indicated, equations are dimensionally consistant so that appropriate units can be selected by the user.

In the following list, the English alphabet precedes the Greek alphabet, letters precede numbers, and lower-case letters precede upper-case letters. Miscellaneous symbols and notations are given after the alphabetical items.

a	Effective earth radius used in (A1).
a_a	An adjusted effective earth radius shown in figure 40 [24, (44)].
a_o	Earth radius (fig. 41).
APODS	A program name (table 1).
ARD	Aviation Research and Development.
ATADU	A program name (table 1).
ATC	Air Traffic Control.
ATLAS	A program name (table 1).
ATOA	A program name (table 1).
A_I	Effective receiving area [dB-sq m] of an isotropic antenna used in (1).
cm	Centimeters (10^{-2} m).
CCIR	International Radio Consultative Committee.
CDC 6600	Control Data Corporation's 6600 digital computer.

CRPL	Central Radio Propagation Laboratory.
d	Great-circle distance between facility and aircraft. For line-of-sight paths, it is calculated as indicated in figure 40. It is related to central angle by (7) and (8).
dB	Decibels, 10 log (dimensionless ratio of powers).
dBi	Antenna gain in decibels greater than isotropic.
dBW	Power in decibels greater than 1 watt.
dB-sq m	Effective area in decibels.
dB-W/sq m	Power density in decibels greater than 1 watt per square meter.
deg	Degrees.
d_D	Desired facility-to-aircraft distance shown in figure 42.
d_U	Undesired facility-to-aircraft distance shown in figure 42.
d_1	Facility to reflection point distance shown in figure 40 and plotted in figure 15.
d_2	Reflection point to aircraft distance shown in figure 40.
DD	Used for d_D (table 1).
Delta R	Path length difference (Δr) or extent by which the length of the reflected ray exceeds that of the direct ray (fig. 40) and calculated using (2).
DME	Distance Measuring Equipment.
DOC	United States Department of Commerce.
DOT	United States Department of Transportation.
DUDD	A program name (table 1).
DURATA	A program name (table 1).

$D_{A,B,C,D,E}$	Desired facility-to-aircraft distances shown in figure 43.
D/U	Desired-to-undesired signal ratio [dB] available at the output of an ideal (loss less) receiving antenna.
eqn.	Equation.
ECAC	Electromagnetic Compatibility Analysis Center.
EIRP	Equivalent isotropically radiated power [dBW] as defined by (11).
EIRPG	EIRP [dBW] increased by the main beam gain [dBi] of the receiving antenna as in (12).
ERP	Effective radiated power [dBW] as defined in the section 4.1 discussion on EIRP.
ESSA	Environmental Science Services Administration.
f	Frequency.
fss	Facility site surface (table 2).
ft	Feet.
f_d	Lobing frequency [Hz] with distance from (4).
f_f	Frequency fraction for half-bandwidth (fig. 15).
f_h	Lobing frequency [Hz] with height from (6).
f_ℓ	Lobing frequency [Hz] from (5).
FAA	Federal Aviation Administration.
FAR	Facility-to-aircraft ray.
FORTRAN	FORmula TRANslating system, a family of programming languages.
FTS	Federal Telephone System.
g	Normalized voltage antenna gain from (10).
GAIN	Sum [dBi] of transmitting and receiving antenna main beam gains.

GCPP Great-circle path plane.

GHz Gigahertz (10^9 Hz).

GOES Geostationary Operational Environmental Satellite.

GPO Government Printing Office.

G_R Gain [dBi] of the receiving antenna main beam for (12) or (13).

G_T Gain [dBi] of the transmitting antenna main beam for (11) or (13).

hr Hour.

HIPOD A program name (table 1).

Hz Hertz.

H1 Facility antenna height above fss or msl.

H2 Aircraft altitude above msl.

$H_{D,U}$ Height of desired or undesired facility antenna above its site surface. Used in (A1).

$H_{1,2}$ Antenna elevations above the reflecting surface shown in figure 40.

$H_{1/3}$ Significant wave height of table 6.

$H_{\Delta e}$ Magnitude of the difference in site elevations. Used in (A1).

in Inches.

IEEE Institute of Electrical and Electronic Engineers.

IF-73 ITS-FAA-1973 propagation model.

IF-77 ITS-FAA-1977 propagation model.

ILS Instrument Landing System.

ITS Institute for Telecommunication Sciences.

IRE Institute of Radio Engineers.

JTAC Joint Technical Advisory Committee.

kHz	Kilohertz (10^3 Hz).
km	Kilometer (10^3 m).
kts	Knots [n mi/hr].
log	Common (base 10) logarithm.
LOBING	A computer program (table 1).
$L_b(95\%)$	Basic transmission loss [dB] level <u>not</u> exceeded for 95% of the time.
m	Meters.
mhos	Unit of conductance or siemens.
min	Minutes.
mm	Millimeters (10^{-3} m).
msl	Mean sea level.
MHz	Megahertz (10^6 Hz).
n	A power used in the ionospheric scintillation frequency scaling factor discussion of section 4.1.
n mi	Nautical miles.
nsec	Nanoseconds (10^{-9} sec).
NBS	National Bureau of Standards.
NDLF	Normalized distance lobing frequency used in (4).
NHLF	Normalized height lobing frequency used in (6).
NOAA	National Oceanic and Atmospheric Administration.
NTIS	National Technical Information Service.
N_o	Minimum monthly mean surface refractivity (N-units) referred to mean sea level from figure 51 or 52.

N_s	Minimum monthly surface refractivity [N-units] (sec. 4.1, refractivity discussion).
N-units	Units of refractivity [4, sec. 1.3] corresponding to (refractive index -1) x 10^6.
Prob.	Problem.
P_I	Power available [dBW] at the output of an ideal (loss less) isotropic receiving antenna from (1).
P_{TR}	Total radiated power [dBW] used in (11).
rad	Radians.
rms	Root mean square.
r_o	Direct ray length shown in figure 40.
$r_{1,2}$	Segments of reflected ray path shown in figure 40 and components of r_{12}.
r_{12}	Reflected ray path length as shown in figure 40.
RTA-2	A TACAN facility antenna type.
sec	Seconds.
sq m	Square meters.
s mi	Statute miles.
S	Station separation shown in figures 42 and 43, and calculated from (9).
SHF	Super-High Frequency (3 to 30 GHz).
SRVLUM	A program name (table 1).
S_f	Facility separation shown in figures 42 and 43.
S_{min}	Minimum valid station separation calculated from (A1).
S_R	Power density at receiving antenna [dB-W/sq m] used in (1).

TACAN	TACtical Air Navigation, an air navigation aid used to provide aircraft with distance and bearing information.
THz	Terahertz (10^{12} Hz or 10^6 MHz).
TWIRL	A program name (table 1).
UHF	Ultra-High Frequency (300 to 3000 MHz).
VHF	Very High Frequency (30 to 300 MHz).
VOR	VHF Omni-Directional Range, an air navigation aid used to provide aircraft with bearing information.
V/V	Volts per volt.
V_d	Magnitude of aircraft radial velocity for (4).
V_h	Magnitude of aircraft vertical ascent rate for (6).
$\alpha_{A,B,D,D,E}$	Angles identified in figure 43.
Δh	Terrain parameter used to charcterize terrain, from table 7 or figure 53.
Δr	Path length difference for rays shown in figure 40 and calculated using (2).
Θ_d	Angle between direct ray and reflected ray at the facility as shown in figure 40.
Θ_e	Ray elevation angle used in (10).
Θ_{h1}	Direct ray elevation angle shown in figure 40.
Θ_{HP}	Half power beam-width of facility with JTAC antenna pattern, used in (10).
Θ_t	Beam tilt above horizontal of facility antenna, used in (10).
Θ_o	Central angle shown in figure 41 and used in (7) and (8).
σ_h	Root-mean-square deviation of surface excursions within the limits of the first Fresnel zone in the dominant reflecting plane from table 6.

λ	Wavelength.
τ	Time lag [nsec] of reflected ray with respect to the direct ray, from (3).
$\phi_{D,U}$	Angles defined in figure 43.
ψ	Grazing angle shown in figure 40.
$(\ldots)^\circ$	Degrees, e.g. 12°.
°C	Degrees celsius.

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