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LEVEL

(12)

**AN ATLAS OF
BASIC TRANSMISSION LOSS
FOR 0.125 TO 15.5 GHZ**

M. E. Johnson and G.D. Gierhart

U.S. DEPARTMENT OF COMMERCE
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
BOULDER, COLORADO 80303



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16. Abstract This report provides an atlas of air/ground and air/air basic transmission loss predictions made with the IF-77 (ITS-FAA-1977) propagation model. Sets of predictions are provided for each of six frequencies; i.e., 0.125, 0.3, 1.2, 5.1, 9.4, and 15.5 GHz. Each set contains curves for 90 antenna height combinations where one antenna height varies from 3 to 30,000 m, and the other varies from 300 to 30,000 m. Each height combination is repeated for three time availabilities: 0.05, 0.5, and 0.95. Hence, 1620 transmission loss versus distance curves are provided. The maximum distance used is 1800 km. Propagation factors and application considerations are discussed. Example problems are used to illustrate the various application methods provided.			
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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	cm	m	km	in	ft	mi	nmi
cm	1	0.01	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}
mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	cm ²	m ²	km ²	in ²	ft ²	mi ²	nmi 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}
mi ²	2.59×10^{10}	2.59×10^6	2.590	4.01×10^9	2.79×10^7	1	0.7548
nmi 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 ³	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 ³	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

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

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

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT BRANCH

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This objective is achieved through the following services:

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- 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 Air-space System.
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AN ATLAS OF BASIC TRANSMISSION LOSS FOR 0.125 TO 15.5 GHz

M. E. Johnson and G. D. Gierhart¹

1. INTRODUCTION

Increasing air traffic density and fast, high-flying jets have made reliable navigation and communication systems for aircraft more important than ever before [9]². Radio frequencies available for the development of new systems and the expansion of present ones to meet future demands are limited partly by international agreements. Efficient use of these frequencies is therefore imperative to satisfy these demands without increasing the hazards of air travel.

Potential radio frequency interference problems must be recognized and dealt with effectively. Information contained in this report will resolve many such problems. Curves are included that may be used to estimate gross transmission characteristics of electromagnetic radiation at frequencies ranging from 0.125 to 15.5 GHz for antenna elevations applicable to air/ground and air/air transmissions.

Propagation of radio frequency energy at VHF/UHF/SHF is affected by the troposphere, specifically by variations in the refractive index of the atmosphere. The terrain along and in the vicinity of the great-circle path between transmitter and receiver also plays an important part. A 1977 propagation model (IF-77) developed by the Institute for Telecommunications (ITS) for the Federal Aviation Administration (FAA) that includes allowances for terrain and atmospheric effects was used to develop the basic transmission loss curves for this report, and it is discussed in Section 2. Similar curves were previously developed [4, 5], but the IF-77 model is an improvement over the methods used previously and new predictions are appropriate. In particular, previous curves were for a time availability of 0.5 (median) only, and those provided here apply to time availabilities of 0.05, 0.5, or 0.95.

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

Transmission loss [17, Sec. 2] is the ratio, expressed in decibels, of power radiated to the power that would be available at the receiving antenna terminals if there were no circuit losses except those associated with the radiation resistance of the receiving antenna. When both antennas are considered isotropic and loss-free, transmission loss is referred to as a basic transmission loss. Long-term median values of basic transmission loss are considered equivalent to the median level of hourly medians when there are many hourly medians.

Basic transmission loss, L_b , versus distance curves with time availabilities, q , of 0.05, 0.5, and 0.95 are given in Section 3. The L_b (0.05) curves may be used to estimate L_b values for an undesired interfering transmitter that are exceeded during 95% (100%-5%) of the time. Median (50%) propagation conditions may be estimated with the L_b (0.5) curves. Curves of L_b (0.95) may be used to estimate the service range for a desired transmitter at which service would be available for 95% of the time in the absence of interference. A discussion of application consideration, complete with illustrative examples, is provided in Section 4.

Except where otherwise indicated, all equations provided here are dimensionally consistent; e.g., all lengths in a particular equation are expressed in the same units. Calculations are made in the computer programs with all lengths expressed in kilometers. Braces are used around parameter dimensions when particular units are called for or when a potential dimension difficulty exists. A list of symbols is provided in the Appendix.

2. BASIC TRANSMISSION LOSS CALCULATIONS

During 1960-1973, the transmission loss prediction methods developed at the National Bureau of Standards [17] were extended and incorporated into an air/ground propagation model. This 1973 model (ITS-FAA-1973 or IF-73) was developed by ITS for the FAA [6] and has since evolved into the IF-77 model, which is applicable to air/ground, air/air, ground/satellite, and air/satellite paths [7, 10, 11]. It can also be used for ground/ground paths that are line-of-sight, smooth earth, or have a common horizon. These methods are based on a considerable amount of experimental data, and extensive comparisons of predictions with data have been made [12, 14].

In performing these calculations with IF-77, a smooth (terrain parameter $\Delta h=0$) earth with an effective earth-radius factor k of $4/3$ (surface refractivity $N_s=301$ N-units) was used along with compensation for the excessive ray bending associated with the $4/3$ model at high altitudes. Constants for average ground, horizontal polarization, isotropic antennas, and long-term power fading statistics for a continental temperate climate were also used. Although these parameters may be considered either reasonable or near worst-case for many applications, the curves should be used with caution if conditions differ drastically from those assumed.

For example, use of surface roughness, vertical polarization and nonisotropic antenna patterns could result in less signal level variability because of a lower reflection coefficient for the earth's surface. Thus, the assumed parameters would often be expected to provide worst-case values. However, the smooth earth curves may not provide worst-case condition situations that involve irregular terrain.

With the exception of a region "near" the radio horizon, values of median basic transmission loss for "within-the-horizon" paths were obtained by adding the attenuation due to atmospheric absorption (in decibels) to the transmission loss corresponding to free-space conditions. Within the region just inside the radio horizon, values of the transmission loss were calculated using geometric optics, to account for the phasor addition of the direct ray and a ray reflected from the surface of the earth. Segments of curves resulting from these two methods were joined to form a curve that shows median basic transmission loss as increasing monotonically with distance. Transition between the line-of-sight and diffraction regions was made using a straight line to connect a diffraction value at the radio horizon with a point just inside the line-of-sight region where the ray optics formulation is valid [6, Sec. A.4.2; 7, Sec. 7].

As indicated above, the two-ray interference model was not used exclusively for within-the-horizon median calculations, because the lobing structure obtained from it for short paths is highly dependent on surface characteristics (roughness as well as electrical constants), atmospheric conditions (the effective earth radius is variable in time), and antenna characteristics (polarization, orientation, and gain pattern). Such curves would often be more misleading than useful; i.e., the detailed structure of the lobing is highly dependent

on parameters that are difficult to determine with sufficient precision. However, the lobing structure is given statistical consideration in the calculation of variability.

For time availabilities other than 0.5 (median), the basic transmission loss, L_b , curves do not always increase monotonically with distance. This occurs because variability changes with distance can sometimes overcome the median level changes. Variability includes contributions from both hourly-median or long-term power fading and within-the-hour or short-term phase interference fading. Both surface reflection and tropospheric multipath are included in the short-term fading formulation used. However, surface reflection (i.e., lobing statistics) is not allowed to contribute to short-term variability in the region just inside the radio horizon (i.e., horizon side of horizon lobe). This results in a decrease in short-term variability in the horizon lobe region which can show up as a decrease in L_b (0.95) values. A decrease in short-term variability near the radio horizon has been observed in experimental air/ground propagation data [1].

3. TRANSMISSION LOSS VERSUS DISTANCE CURVES

Figures 1 through 84 at the end of this section show L_b versus distance for frequencies of 0.125, 0.3, 1.2, 5.1, 9.4, and 15.5 GHz; terminal 1 antenna elevations, H_1 , of 3, 10, 15, 30, 150, 300, 500, 1000, 5000, 10 000, 15 000, 20 000, 25 000, and 30 000 m; and terminal 2 antenna heights, H_2 , that range from 300 to 30 000 m using the values just given for H_1 . These figures are cataloged by increasing H_1 within each frequency group. Copies of large size graphs are available from the sponsoring agency upon written request (see p. i).

Each figure contains those curves for which H_2 values are equal to or greater than H_1 . Each figure consists of three curve sets where the upper, middle, and lower sets provide $L_b(0.05)$, $L_b(0.5)$, and $L_b(0.95)$, respectively. These correspond to time availabilities, q , of 0.05, 0.5, and 0.95. For example, $L_b(0.95) = 200$ dB, means that the basic transmission loss would be 200 dB or less during 95% of the time, and $L_b(0.5) = 190$ dB means that the median basic transmission loss is 190 dB.

A free space, L_{bf} , curve is included for each set, and it was calculated using the H_1 of the set and $H_2=30,000$ m. At zero distance it is the difference in antenna heights that determines L_{bf} so the L_{bf} curves shown are for the highest L_{bf} height combination. However, for path distances somewhat greater than the altitude difference, L_{bf} values are nearly identical.

The IF-77 propagation model (Sec. 2) used to calculate these curves includes allowances for a large number of factors that affect propagation (e.g., long-term power fading, surface reflection multipath, tropospheric multipath, etc.) and blends calculations made for the line-of-sight, diffraction, and scatter regions together in transition regions. These complications and the use of simple linear interpolation to obtain curves from the points actually calculated result in curves that are occasionally bumpy and have some discontinuities. For the most part, these are minor, but some are severe enough to encourage manual smoothing of the computer generated plots. Since such smoothing would tend to obscure places where problems with the IF-77 may exist and would require extensive drafting, it was not done. Comments concerning some of these bumps have been added to Figure 68.

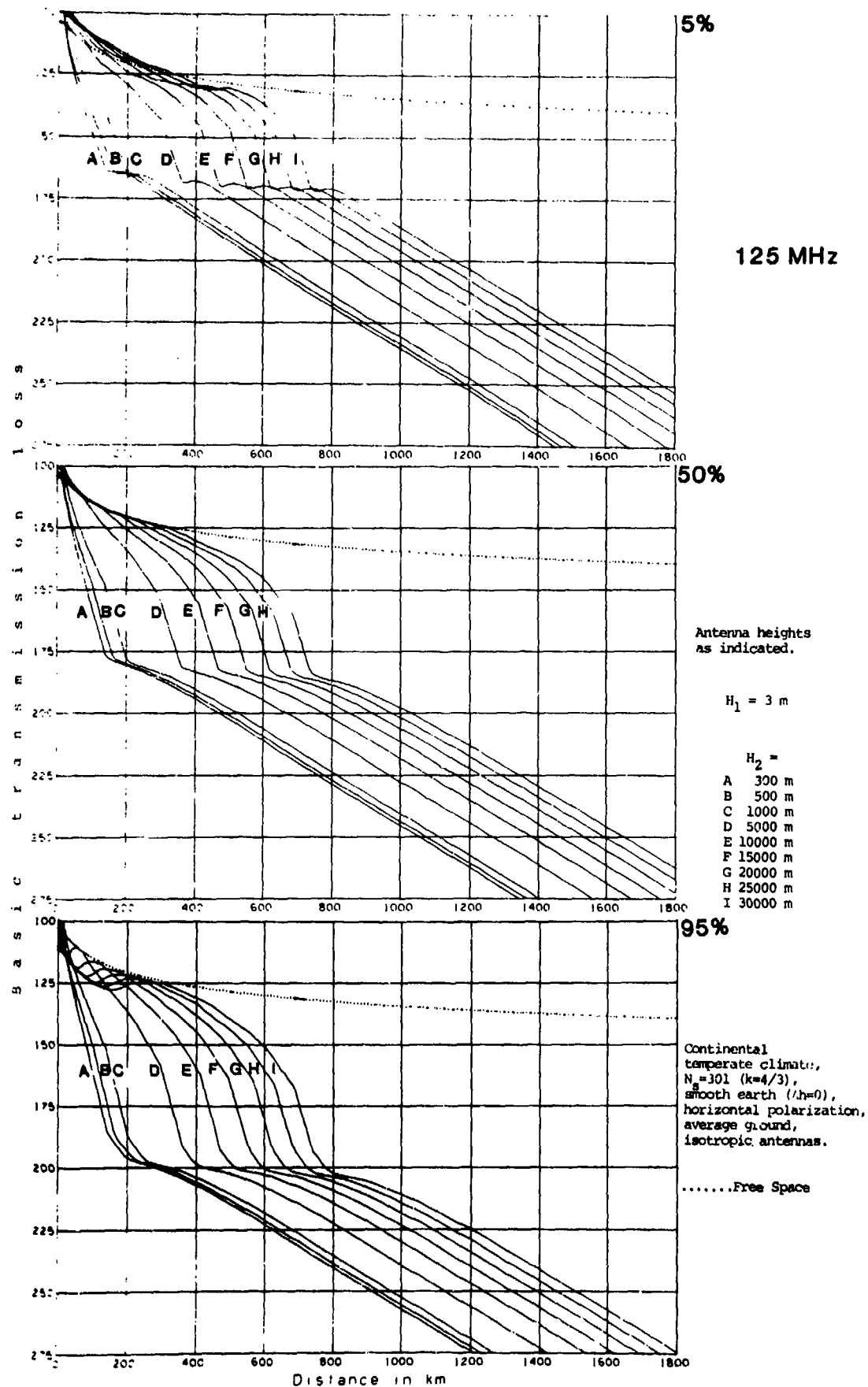


Figure 1. Basic transmission loss versus distance; $F = 125 \text{ MHz}$, $H_1 = 3 \text{ m}$.

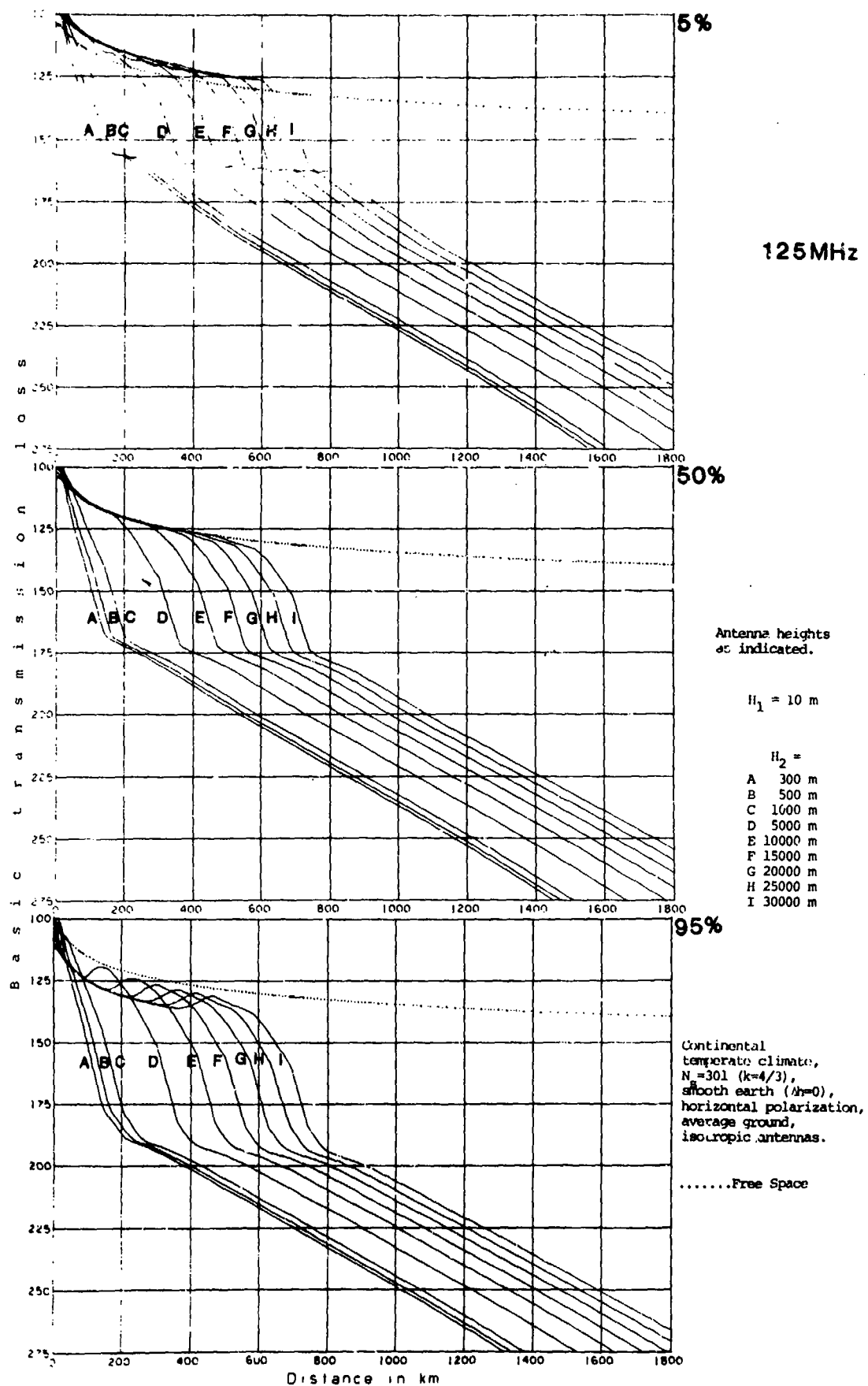


Figure 2. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 10$ m.

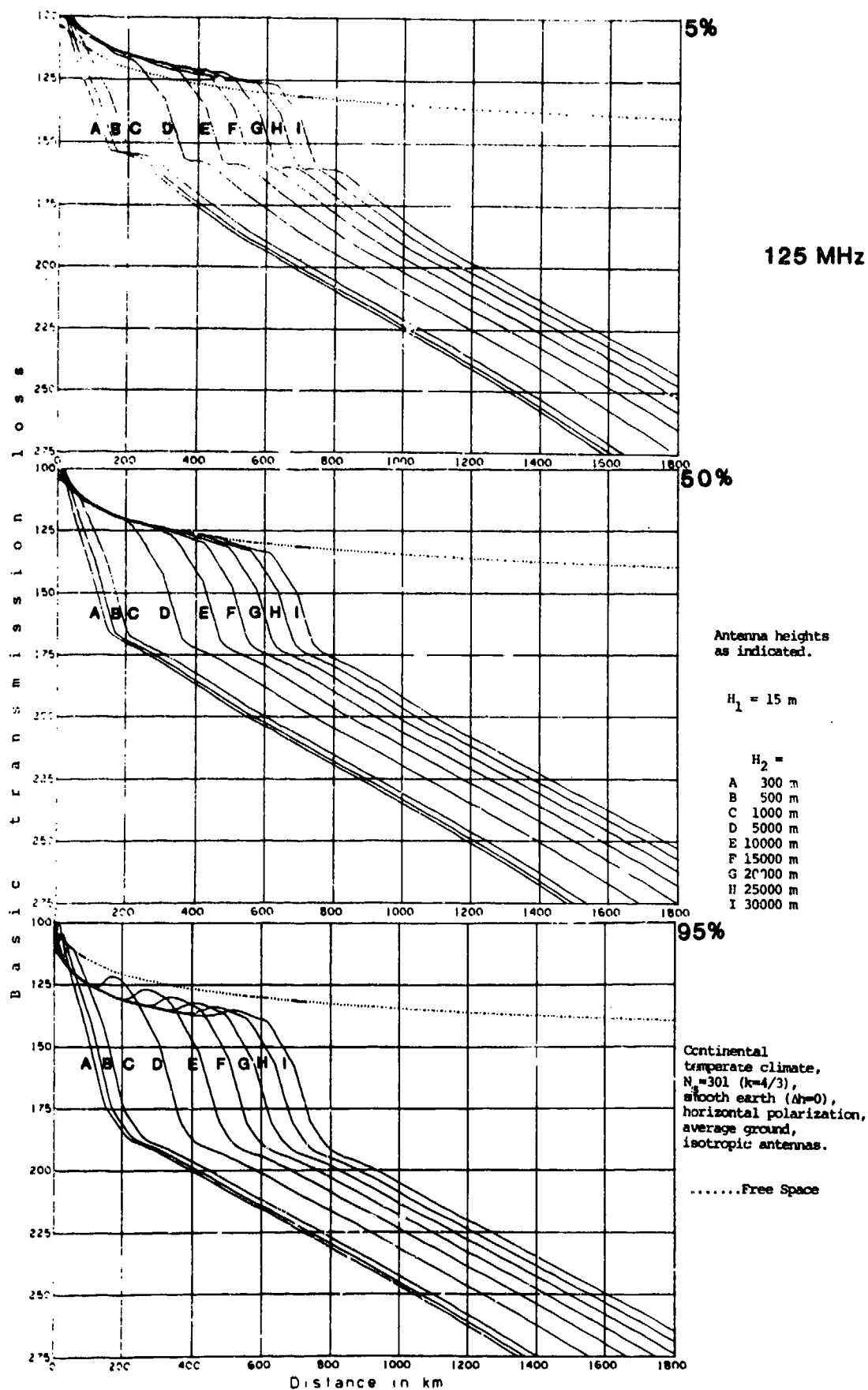


Figure 3. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 15$ m.

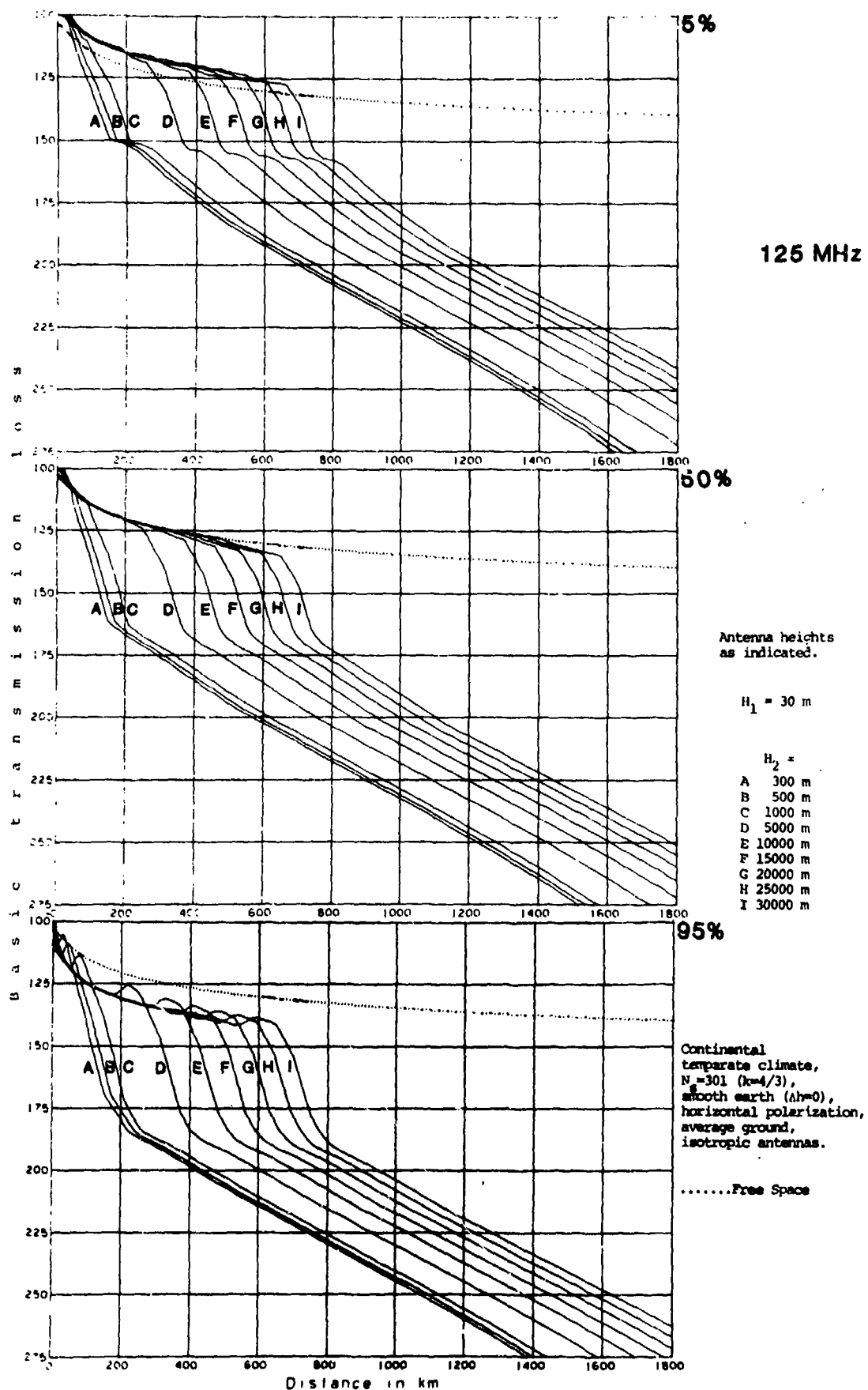


Figure 4. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 30$ m.

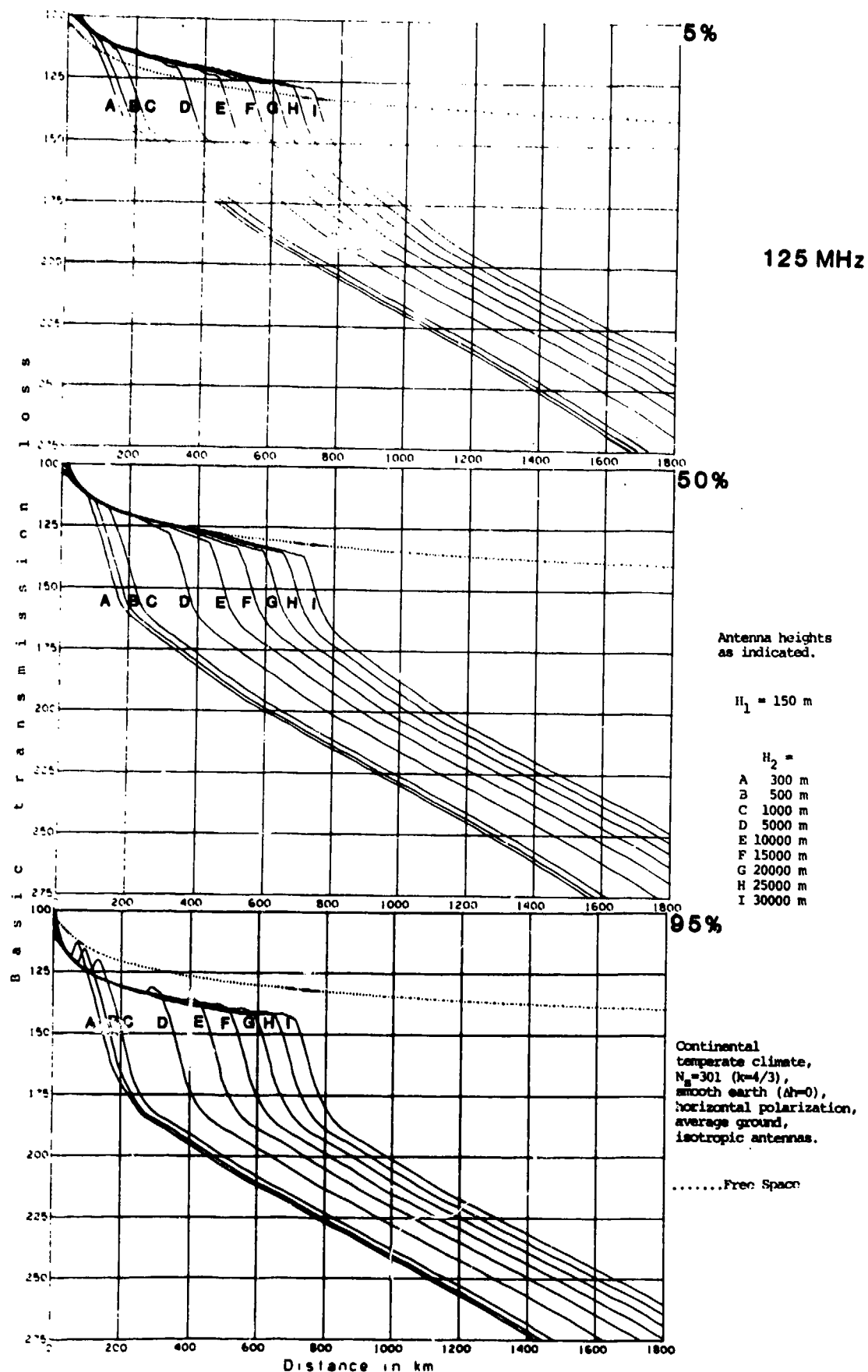
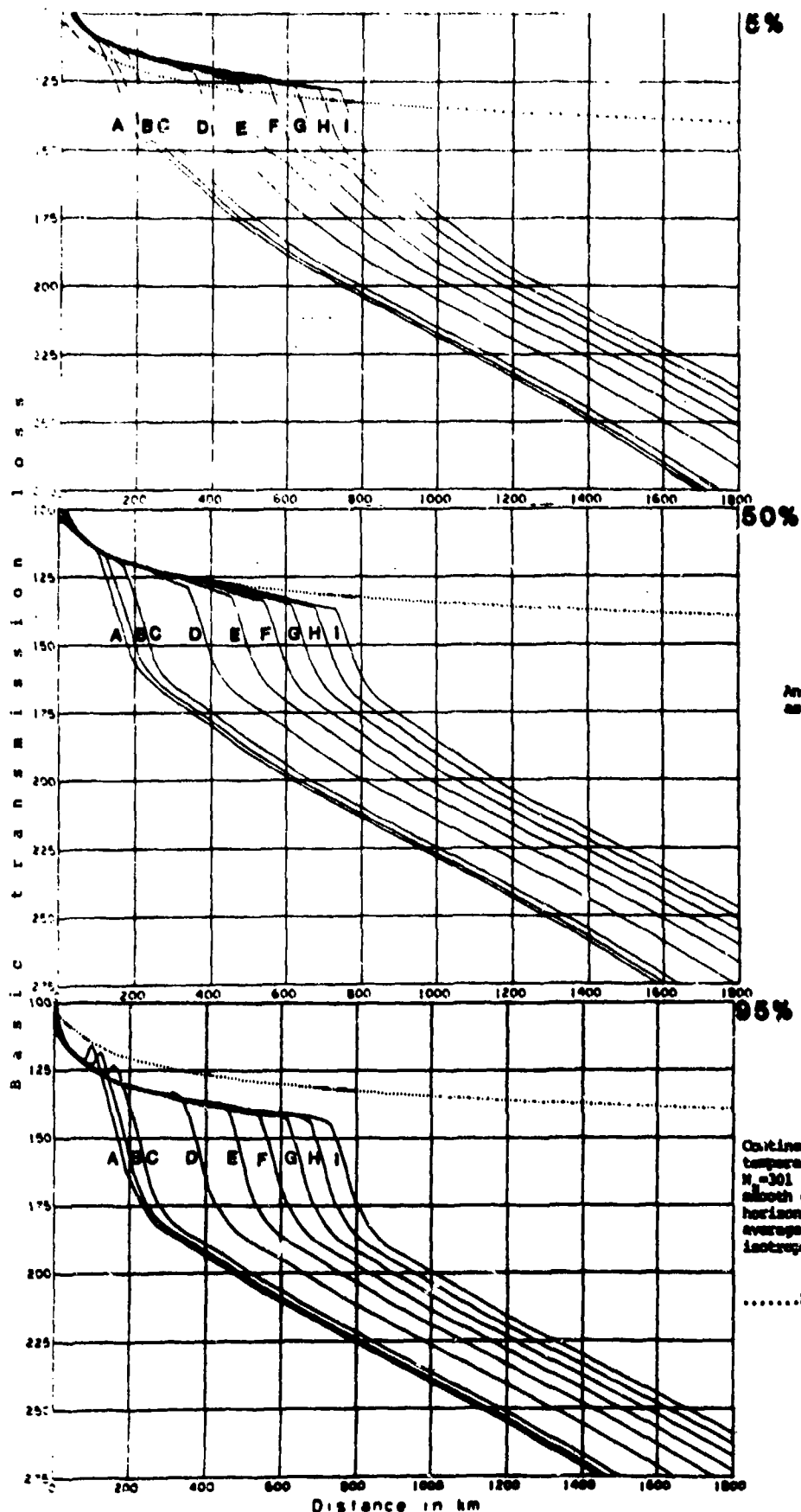


Figure 5. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 150$ m.



Antenna heights
as indicated.

$H_1 = 300$ m

$H_2 =$

A 300 m
B 500 m
C 1000 m
D 5000 m
E 10000 m
F 15000 m
G 20000 m
H 25000 m
I 30000 m

Continental
temperate climate,
 $M = 301$ ($n = 4/3$),
smooth earth ($g = 0$),
horizontal polarization,
average ground,
isotropic antennas.

.....Free Space

Figure 6. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 300$ m.

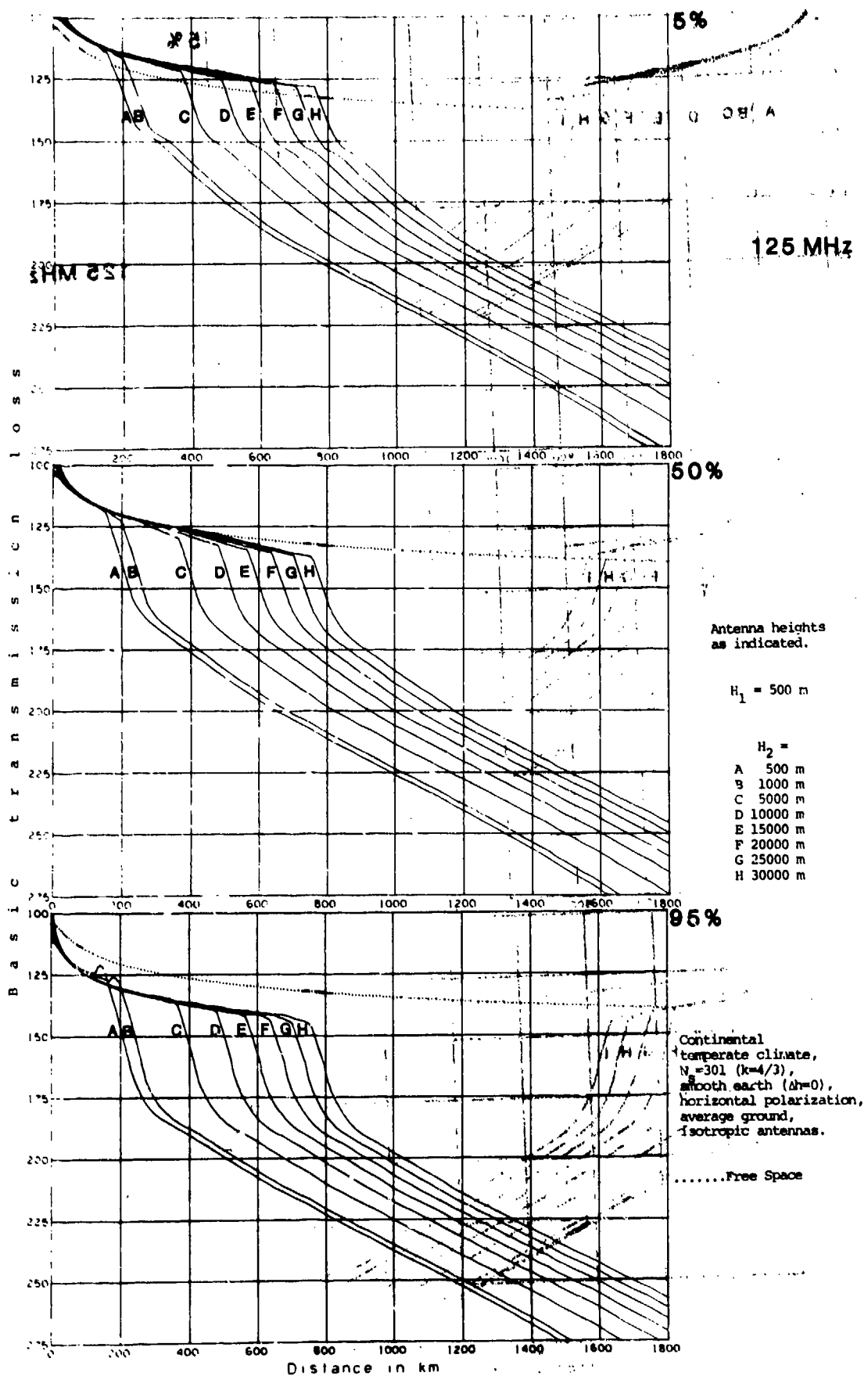


Figure 7. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 500$ m.

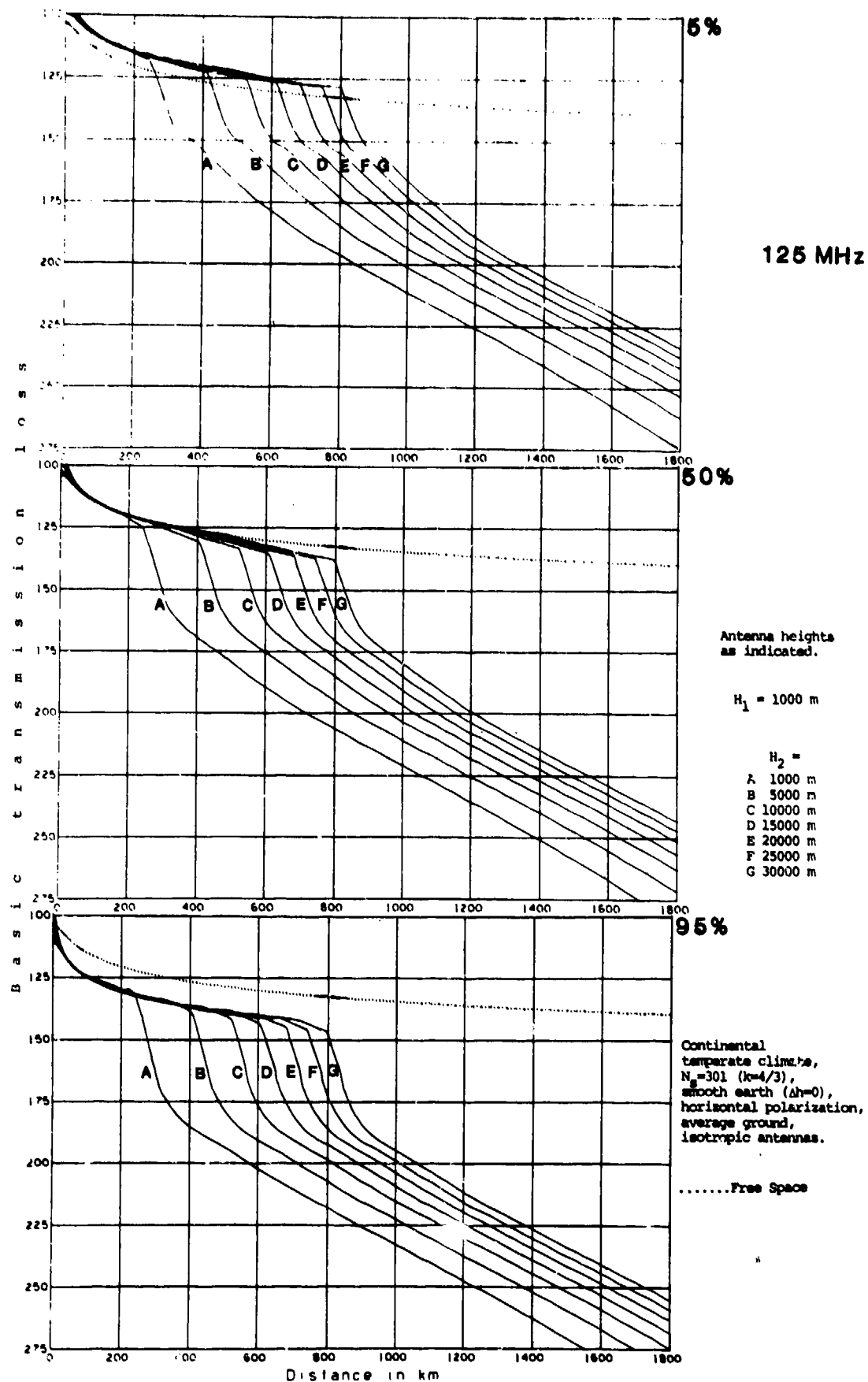


Figure 8. Basic transmission loss versus distance; $F = 125 \text{ MHz}$, $H_1 = 1000 \text{ m}$.

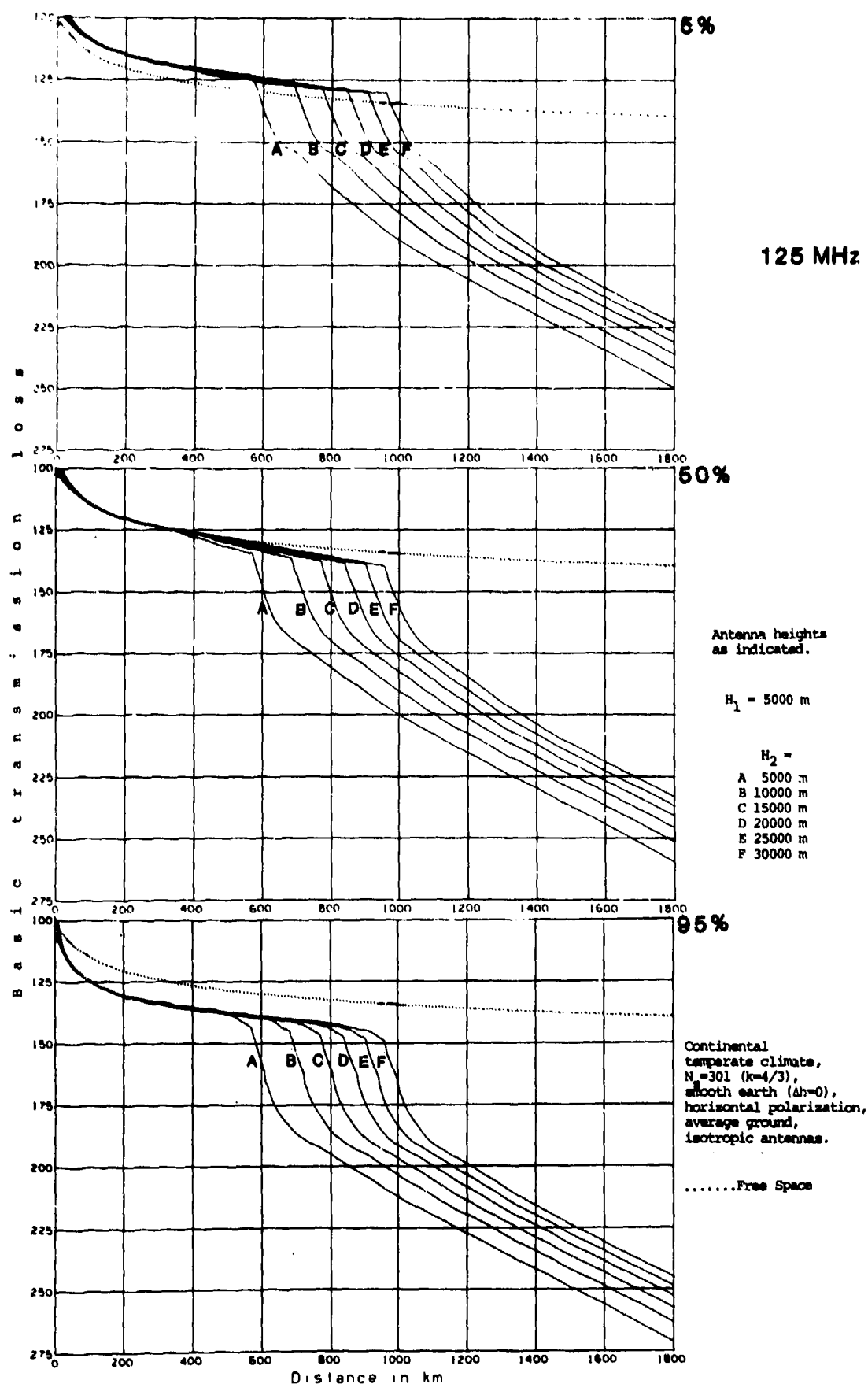


Figure 9. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 5000$ m.

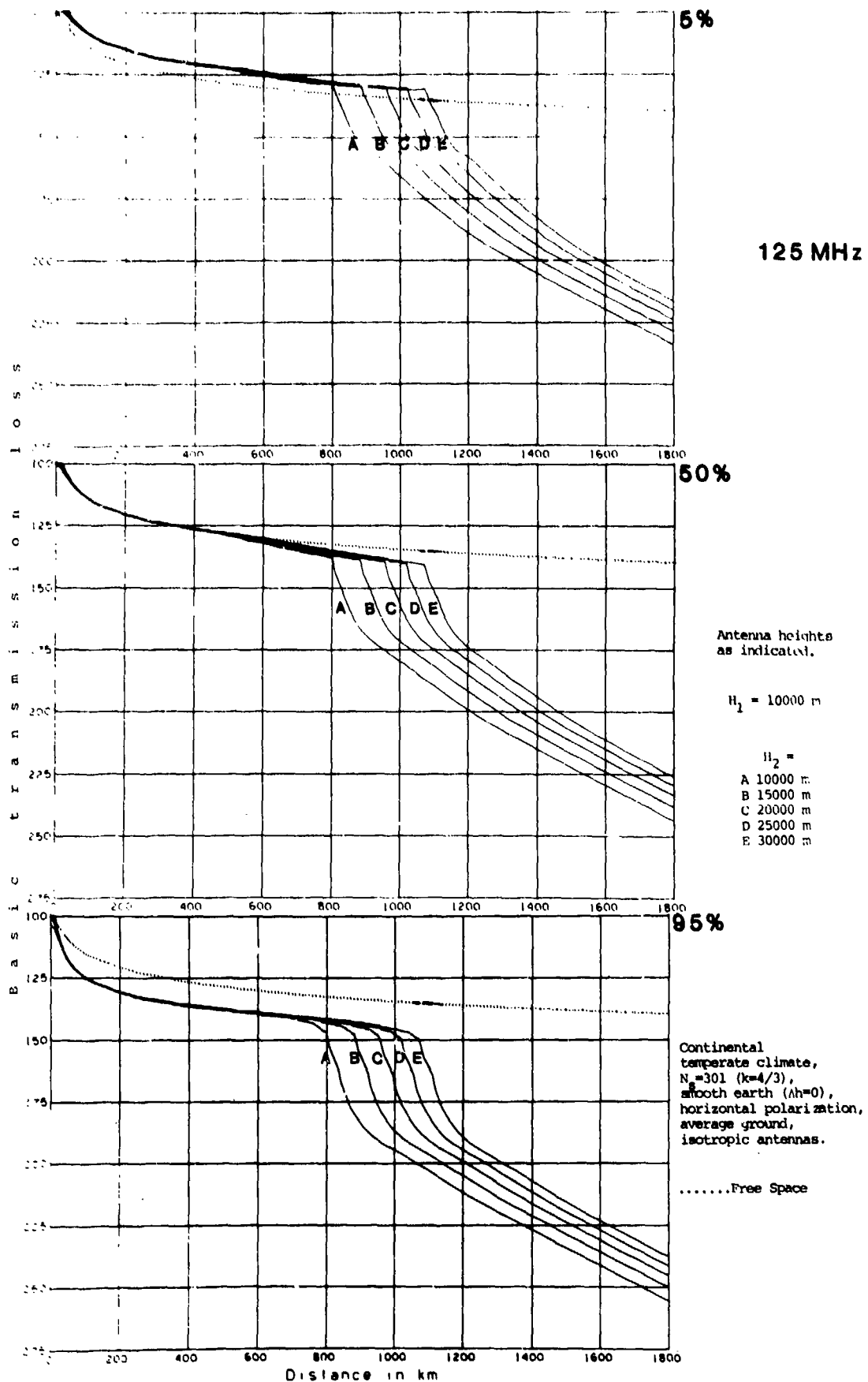


Figure 10. Basic transmission loss versus distance; $F = 125 \text{ MHz}$, $H_1 = 10\,000 \text{ m}$.

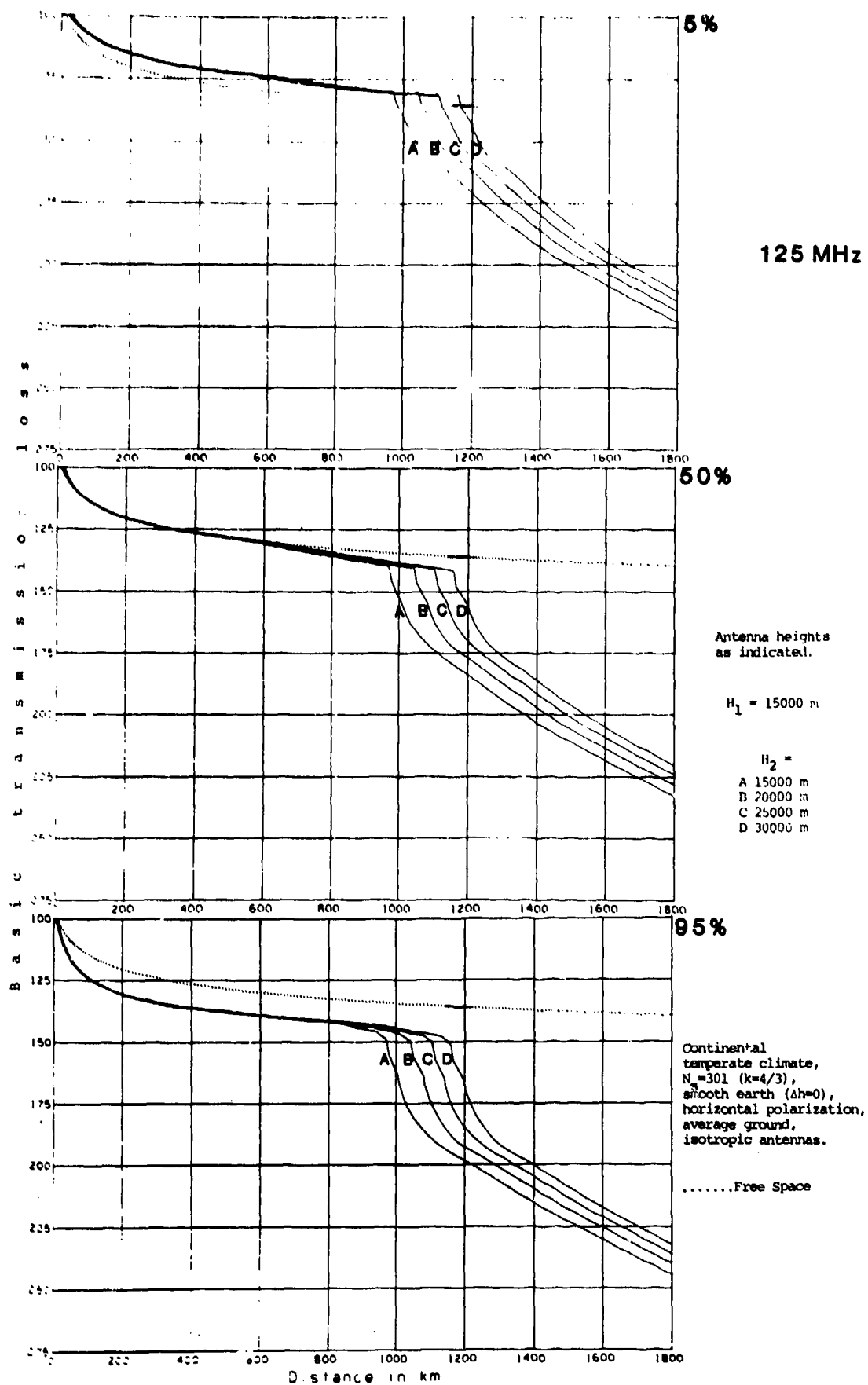


Figure 11. Basic transmission loss versus distance: $f = 125$ MHz, $H_1 = 15000$ m.

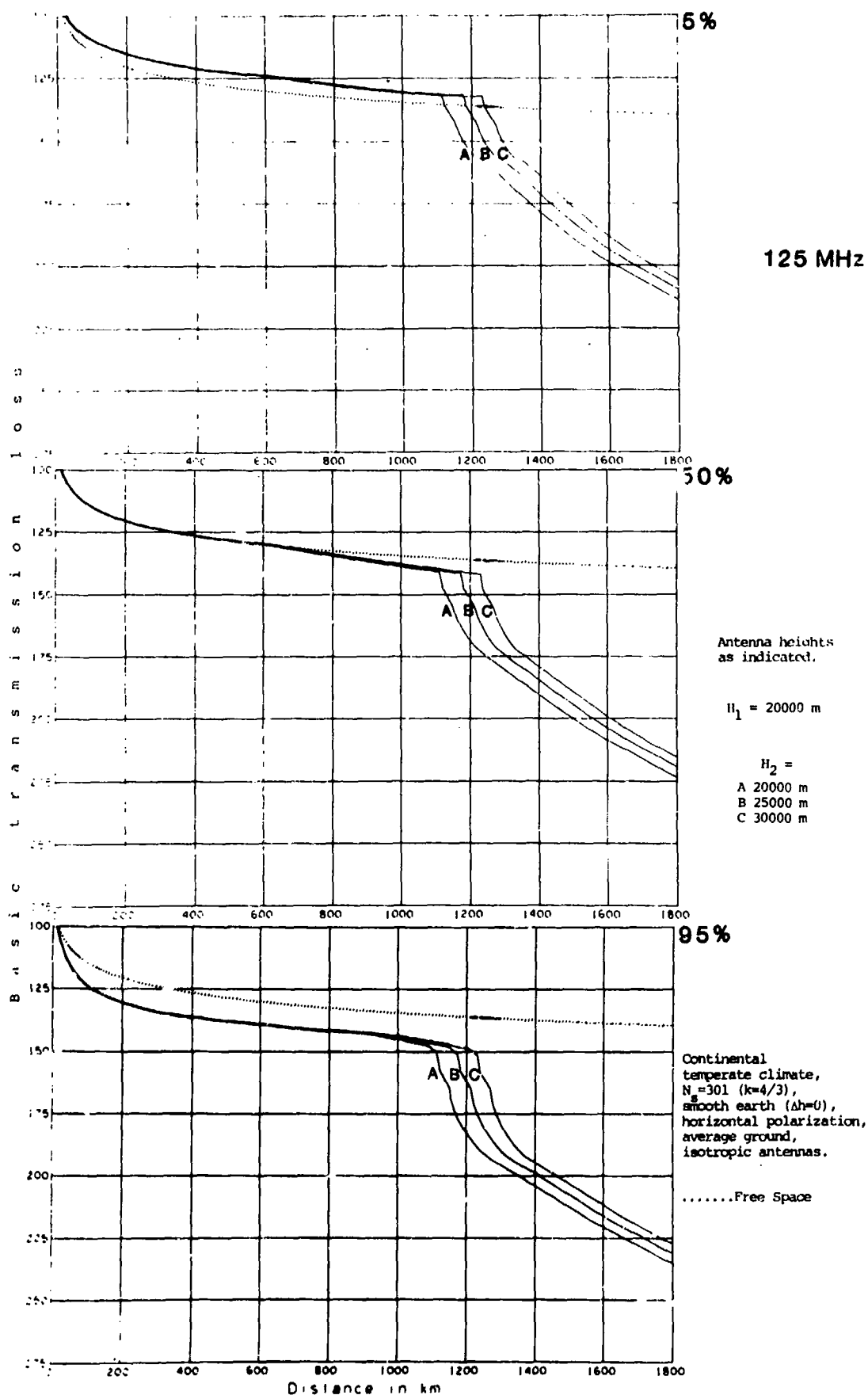


Figure 12. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 20\,000$ m.

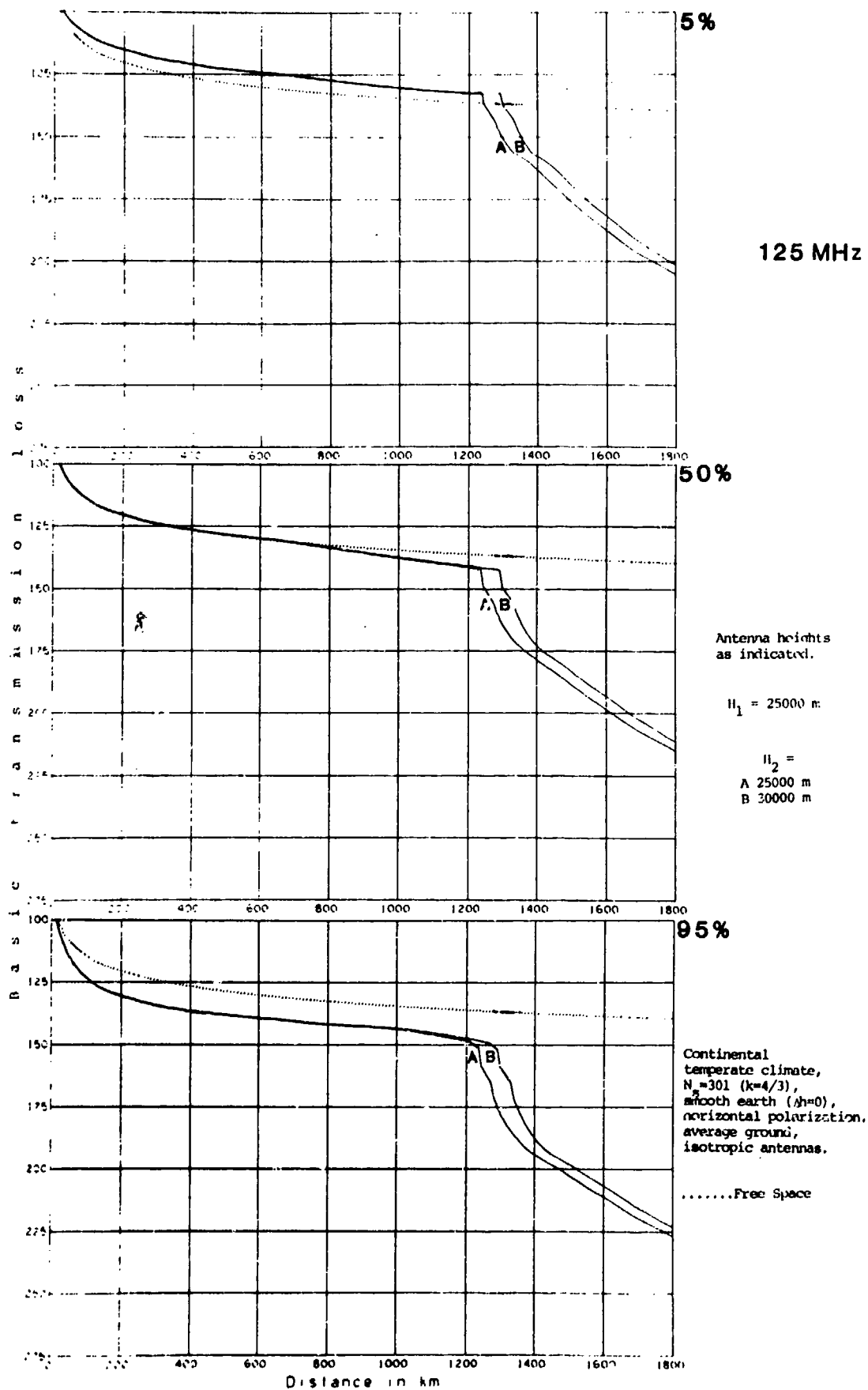


Figure 13. Basic transmission loss versus distance; $F = 125$ MHz, $H_1 = 25000$ m.

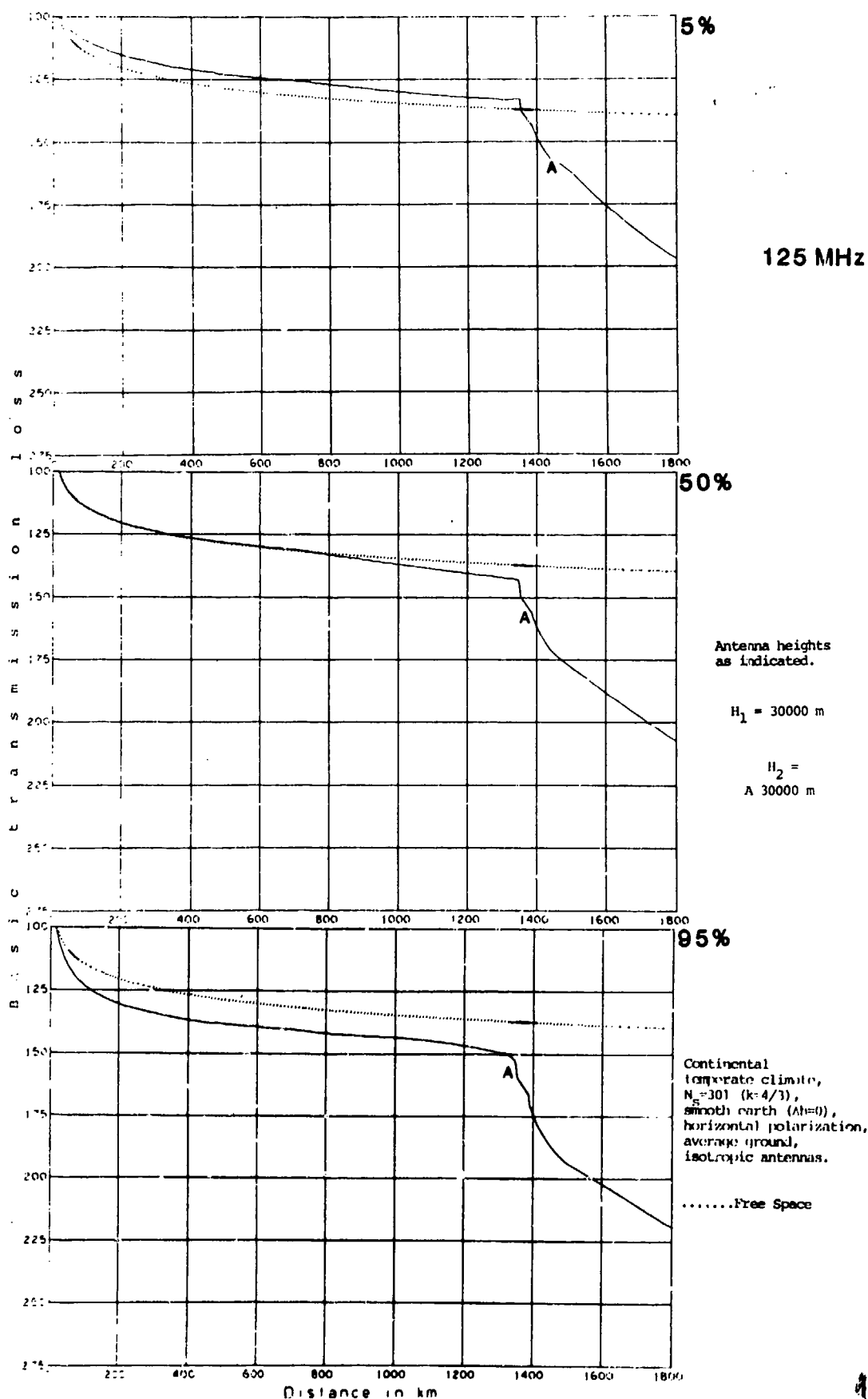


Figure 14. Basic transmission loss versus distance: $f = 125$ MHz, $H_1 = 30\,000$ m.

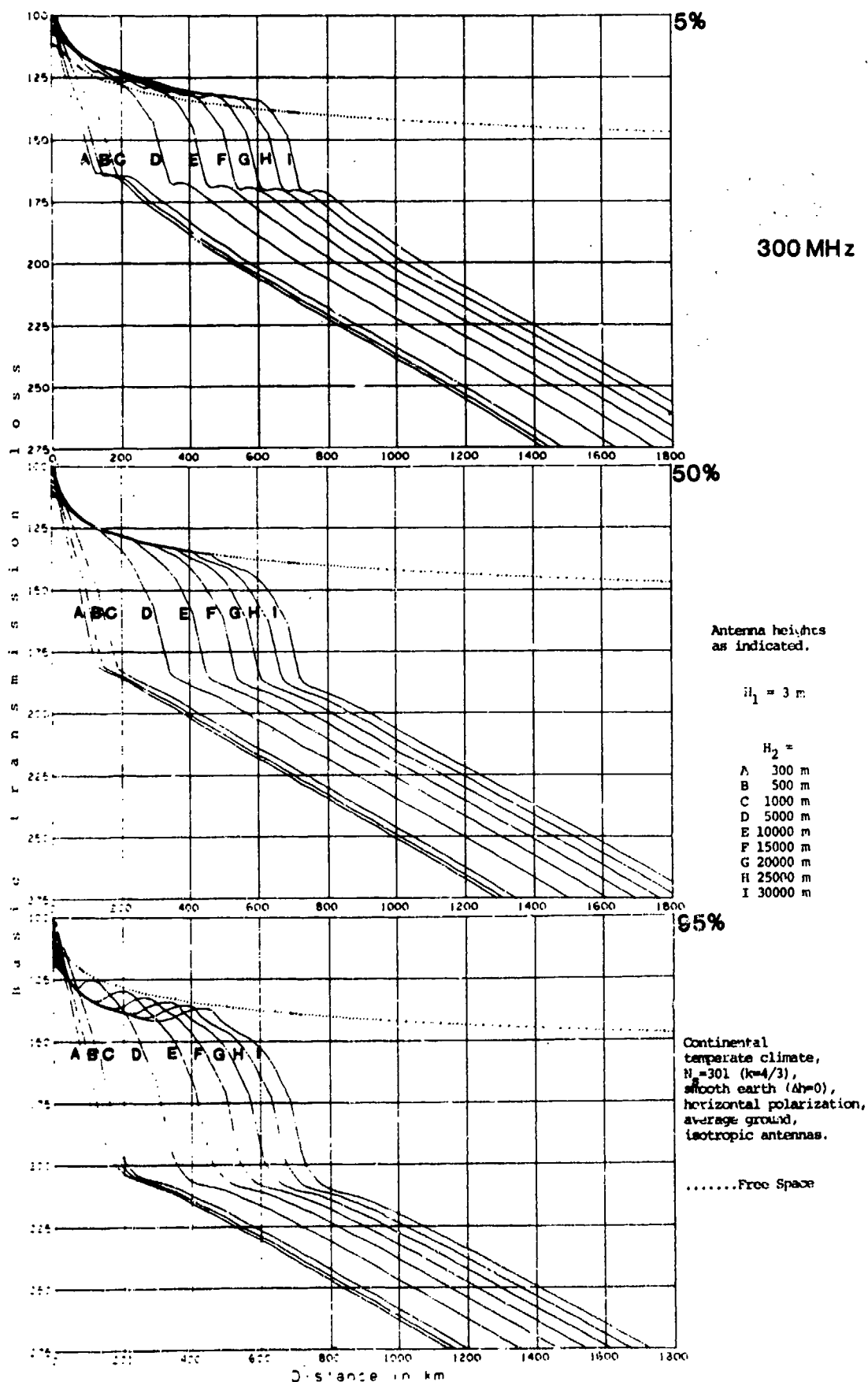


Figure 15. Basic transmission loss versus distance; $F = 300 \text{ MHz}$, $H_1 = 3 \text{ m}$.

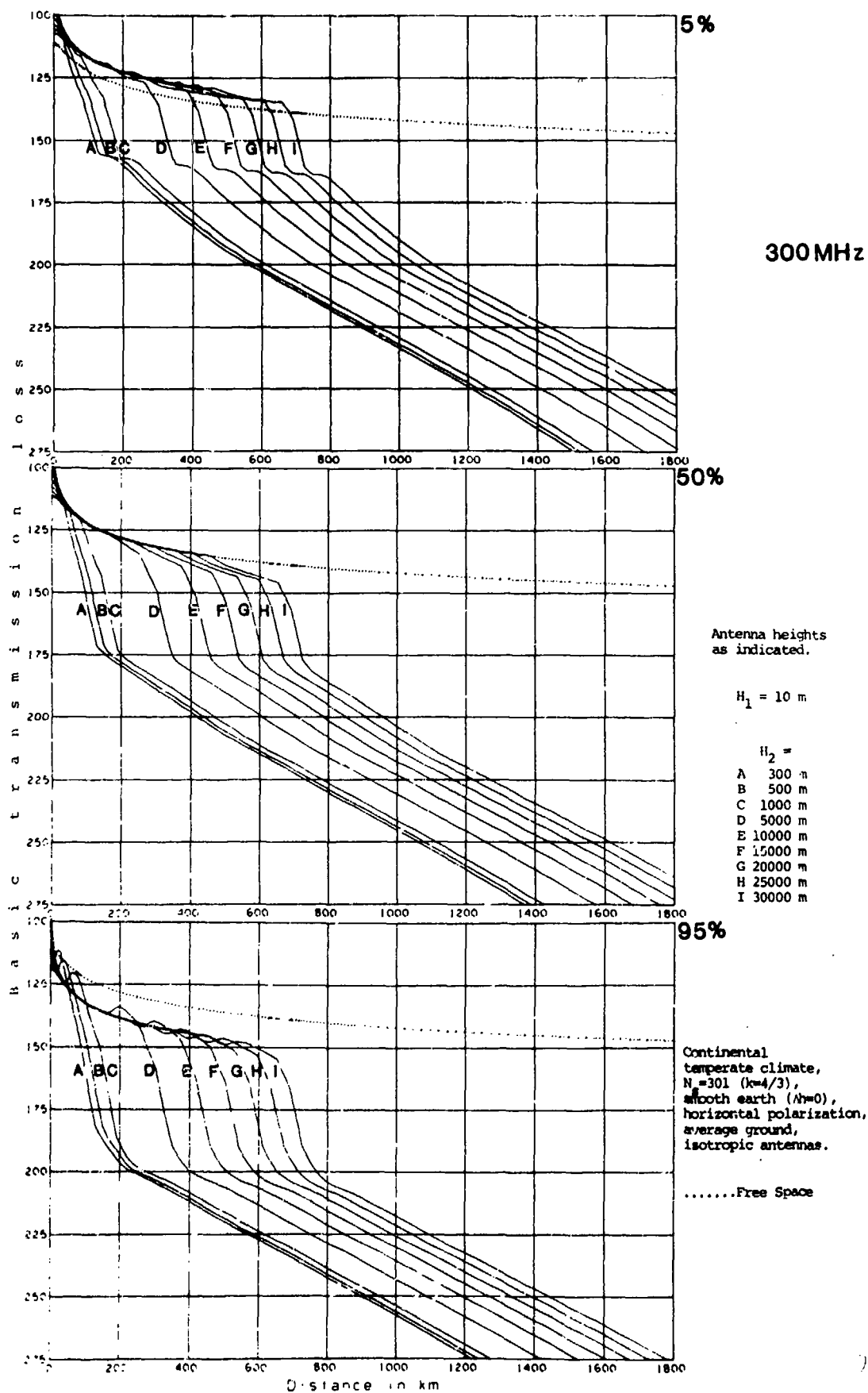


Figure 16. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 10$ m.

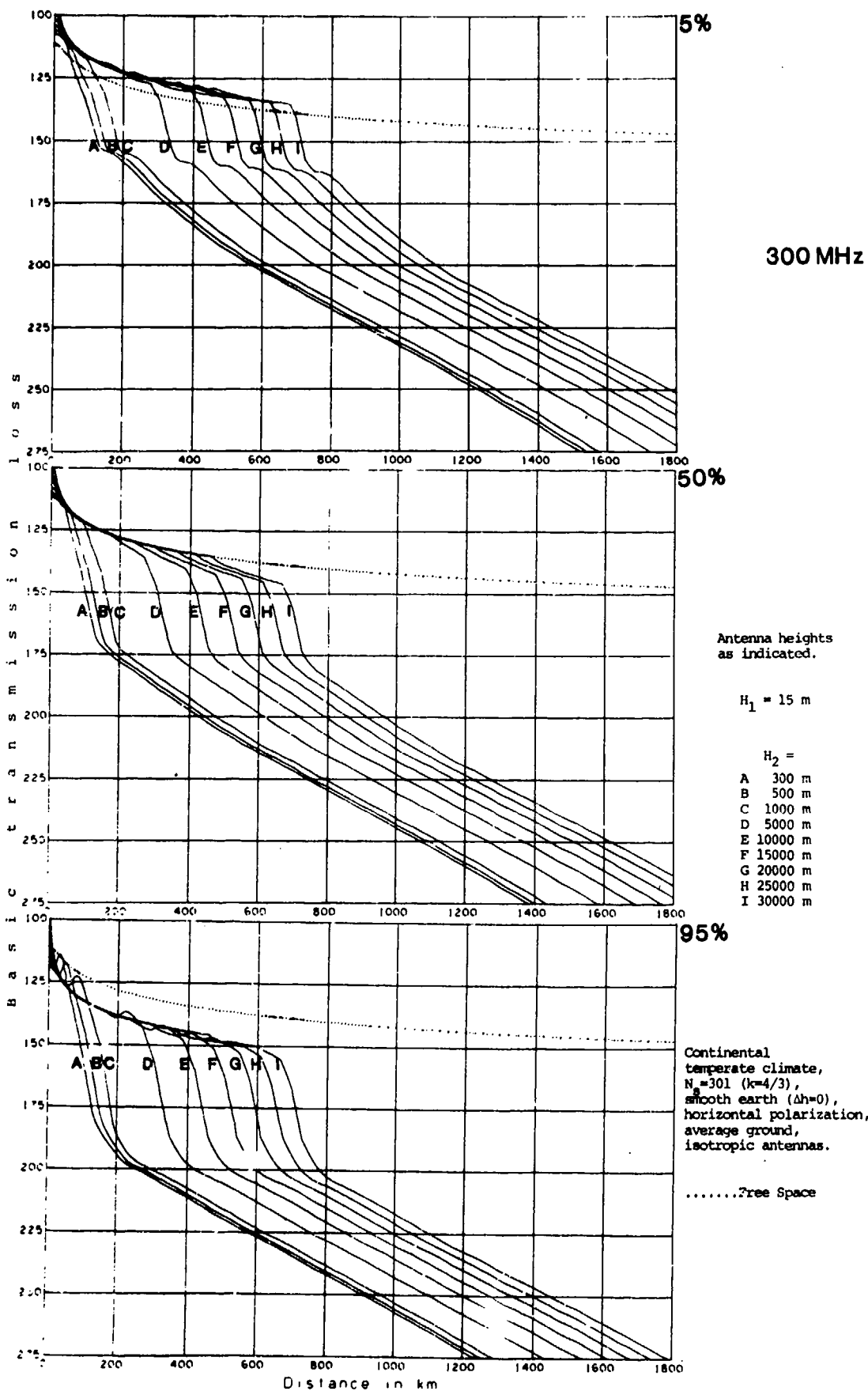


Figure 17. Basic transmission loss versus distance; $F = 300 \text{ MHz}$, $H_1 = 15 \text{ m}$.

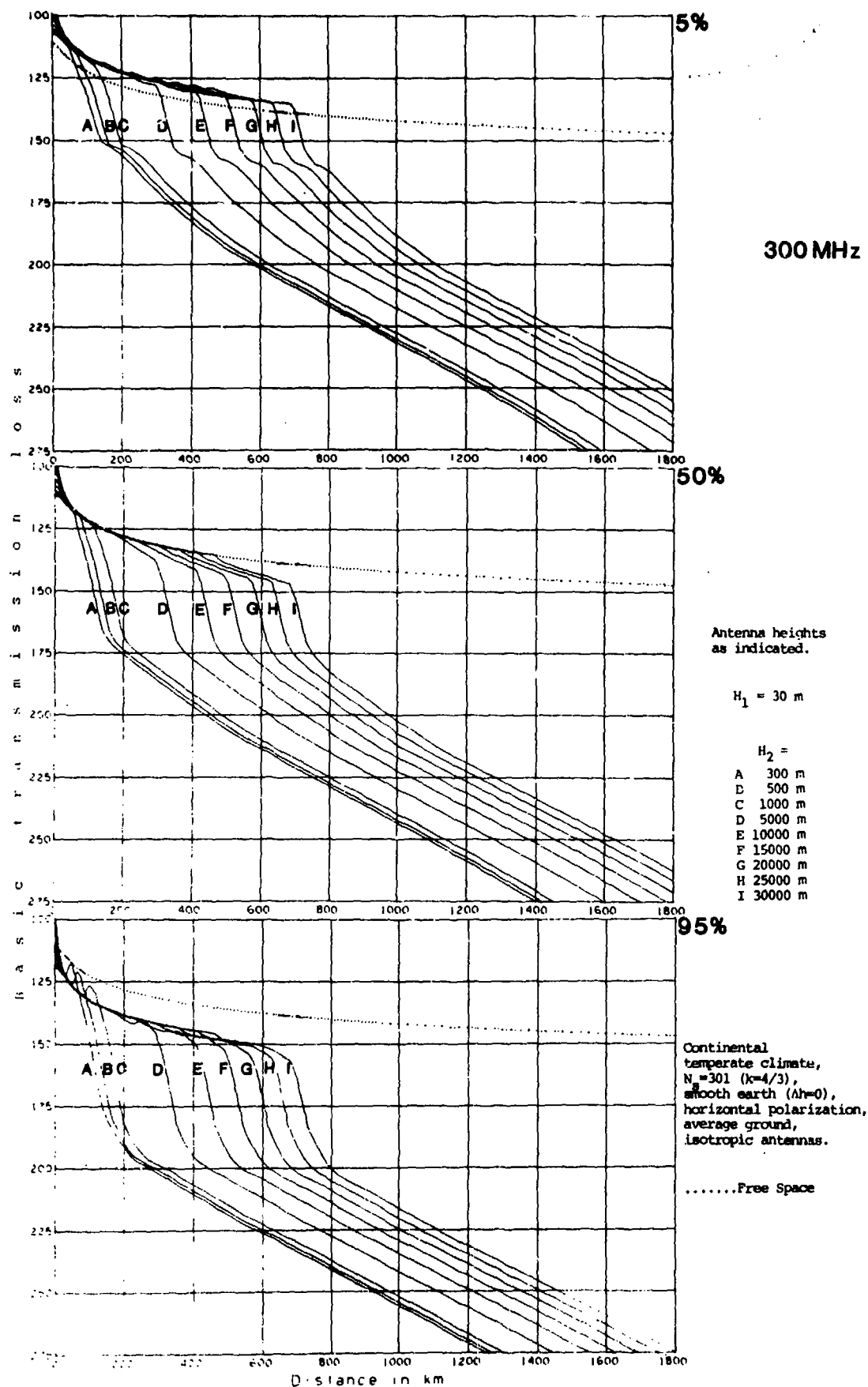


Figure 18. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 30$ m.

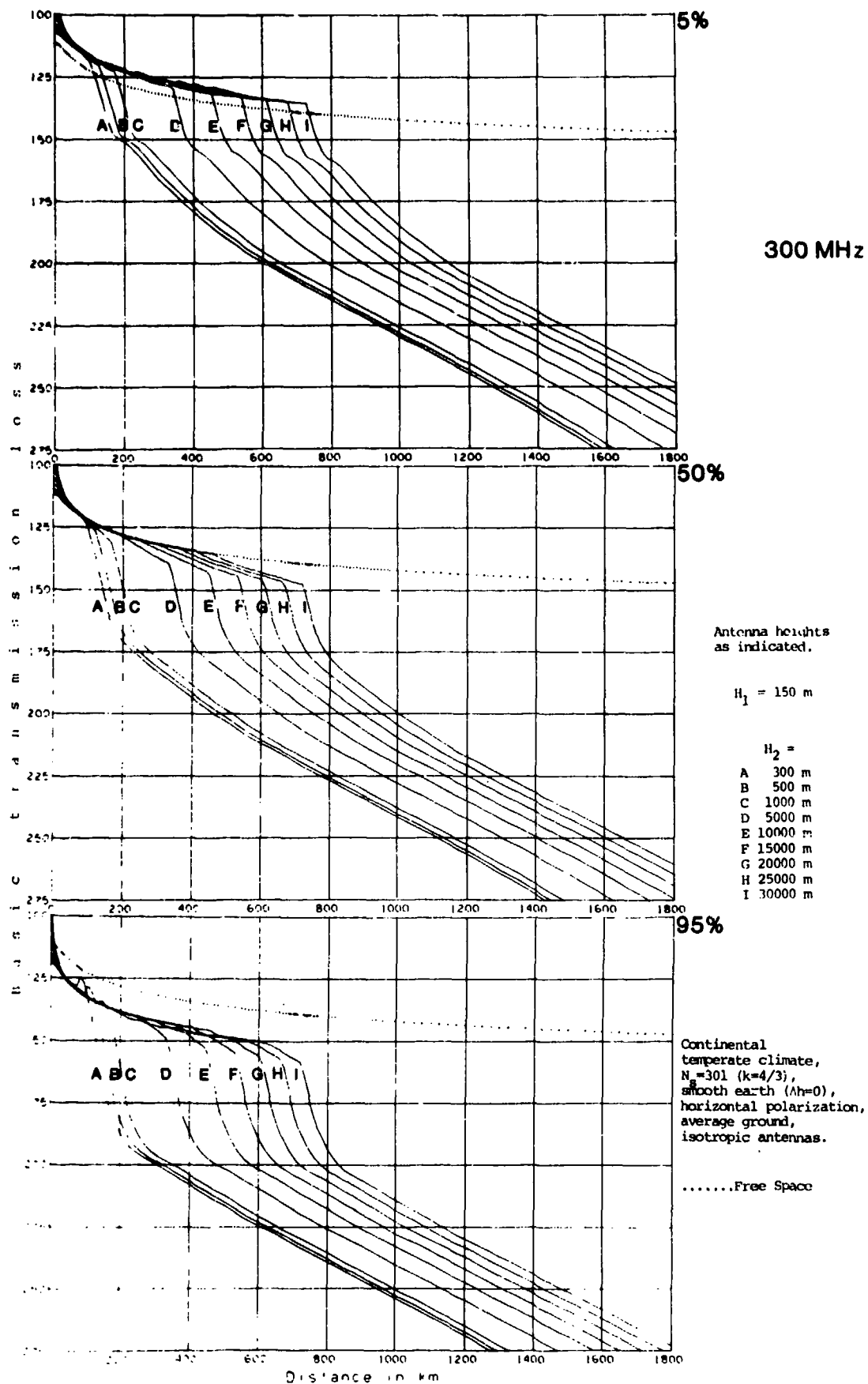


Figure 19. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 150$ m.

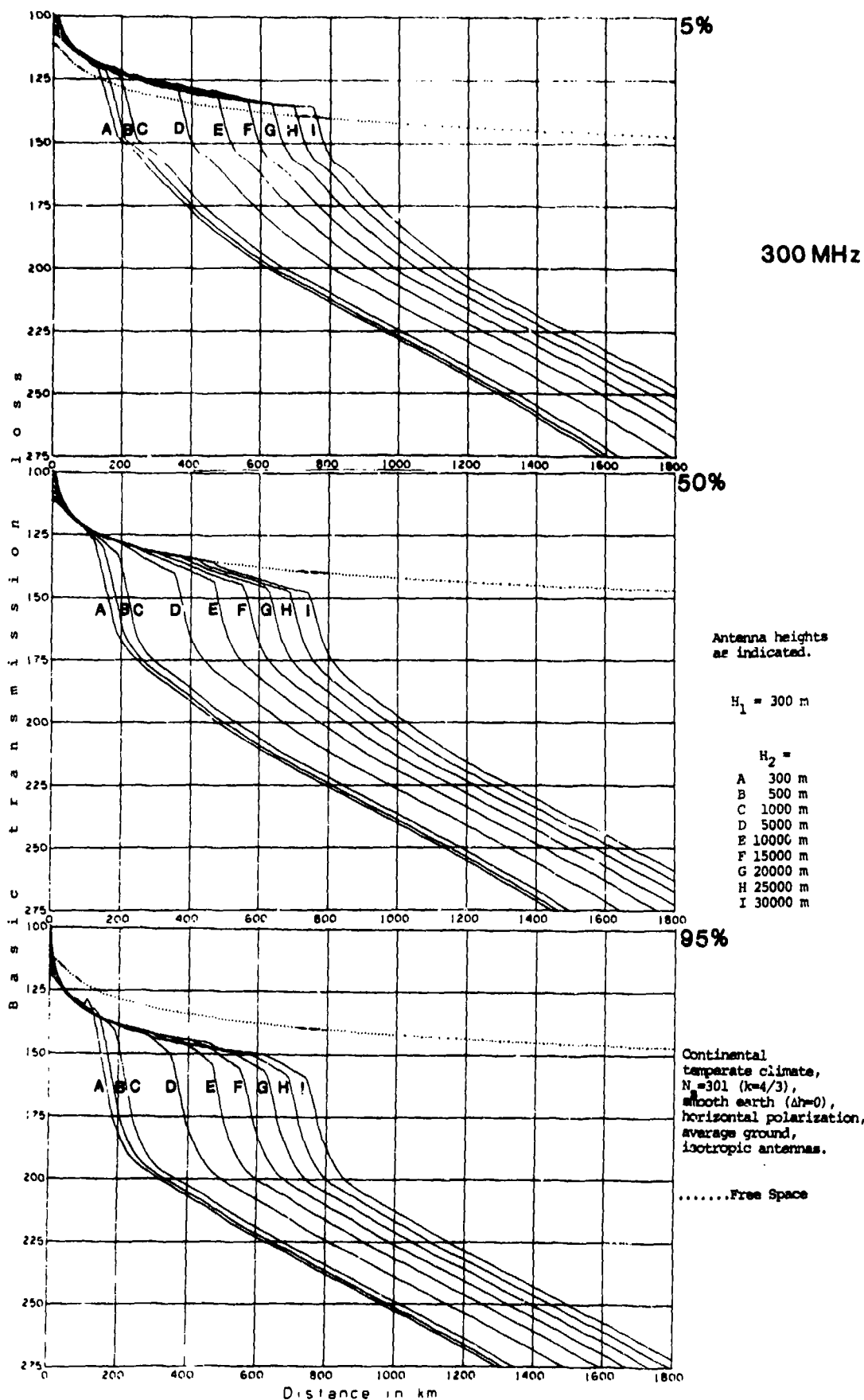


Figure 20. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 300$ m.

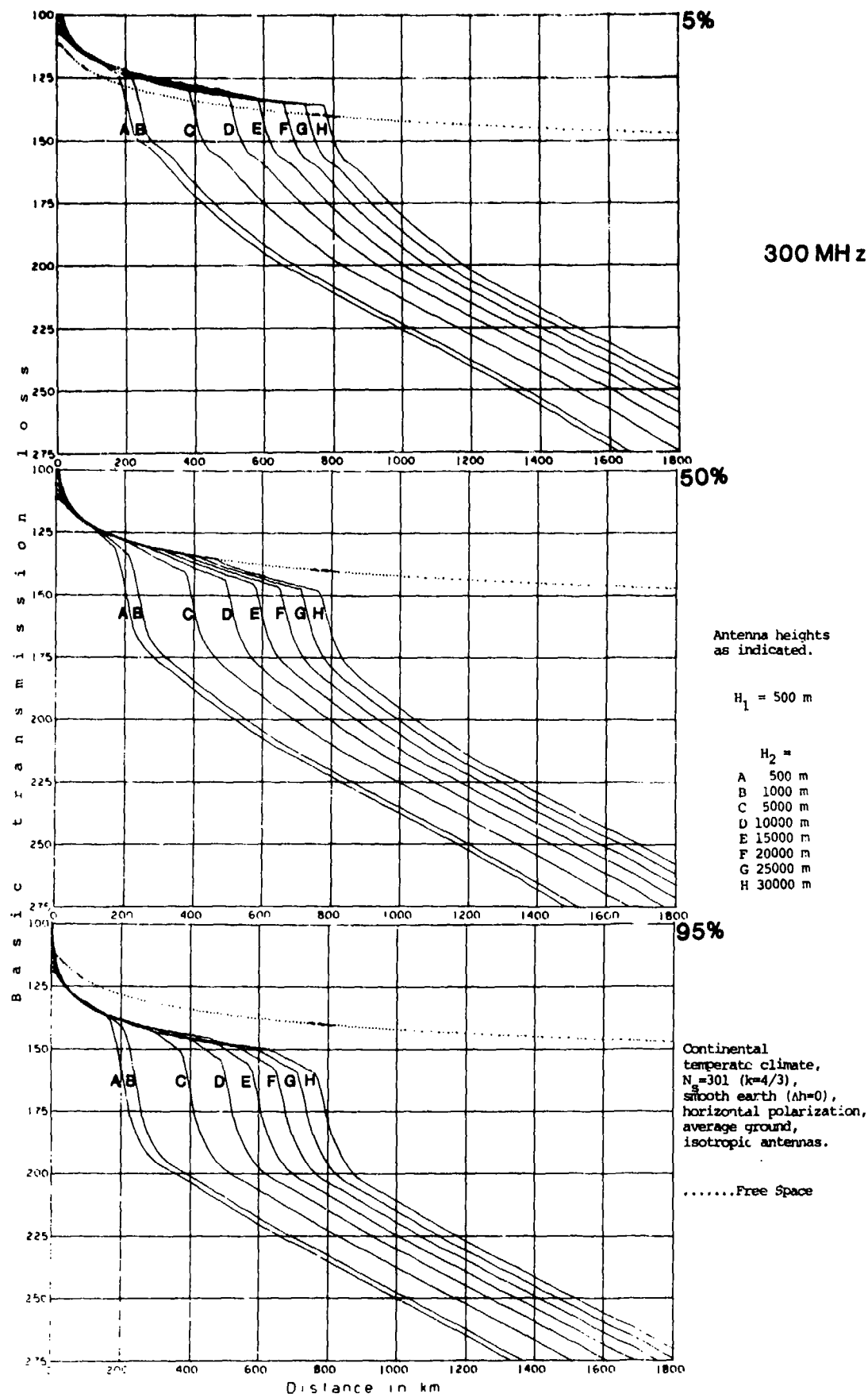


Figure 21. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 500$ m.

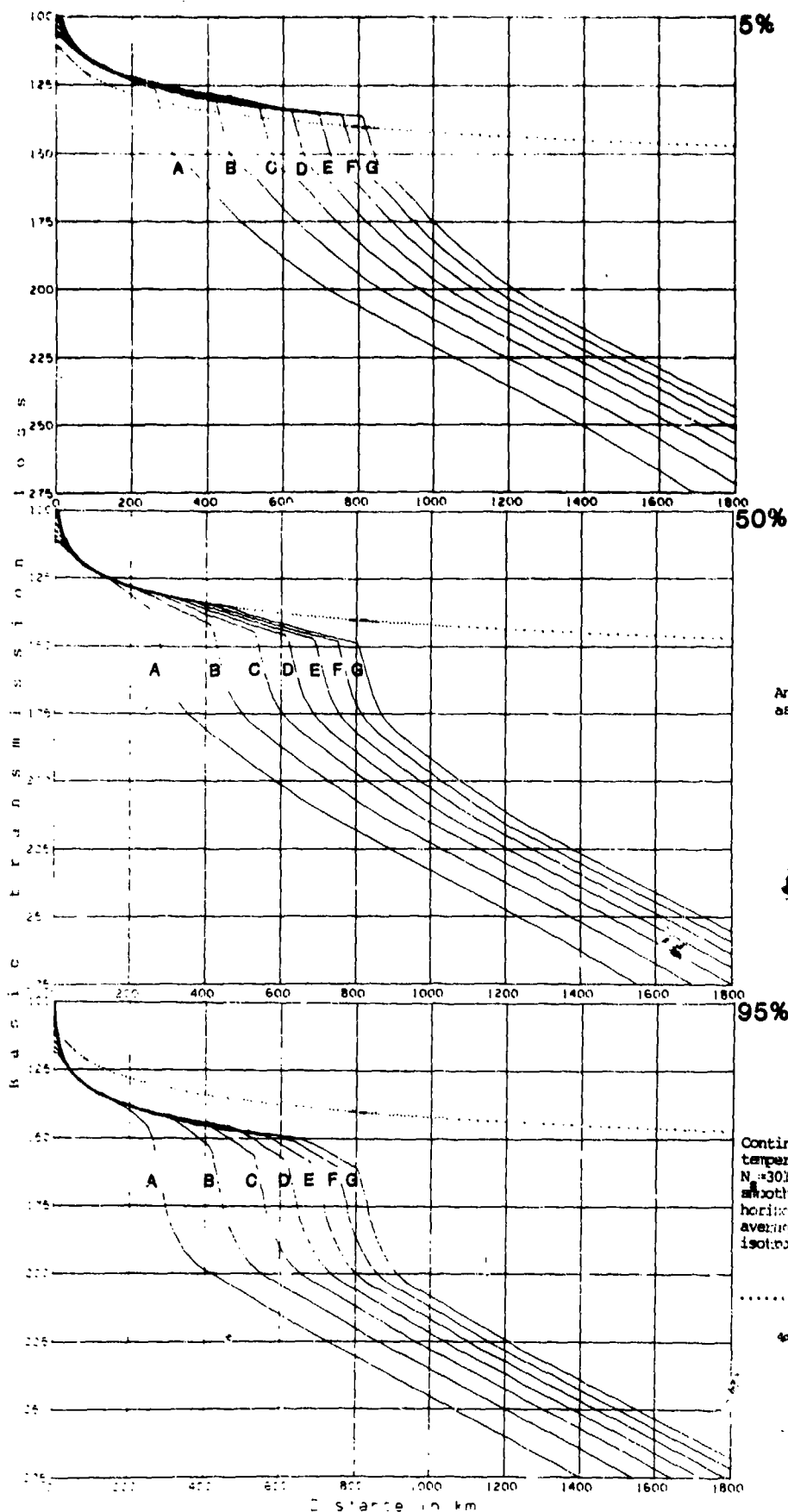


Figure 22. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 1000$ m.

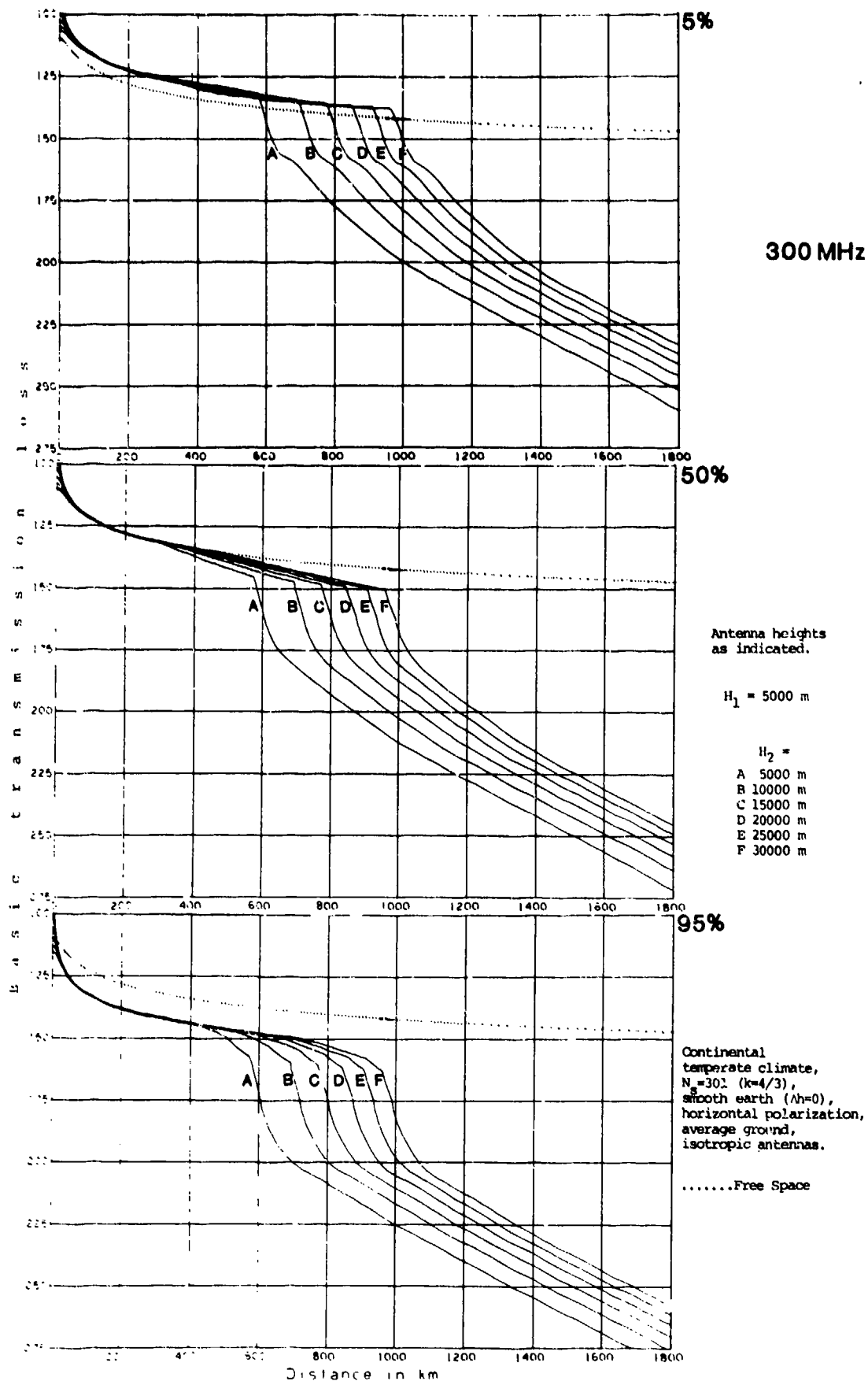


Figure 23. Basic transmission loss versus distance; $F = 300 \text{ MHz}$, $H_1 = 5000 \text{ m}$.

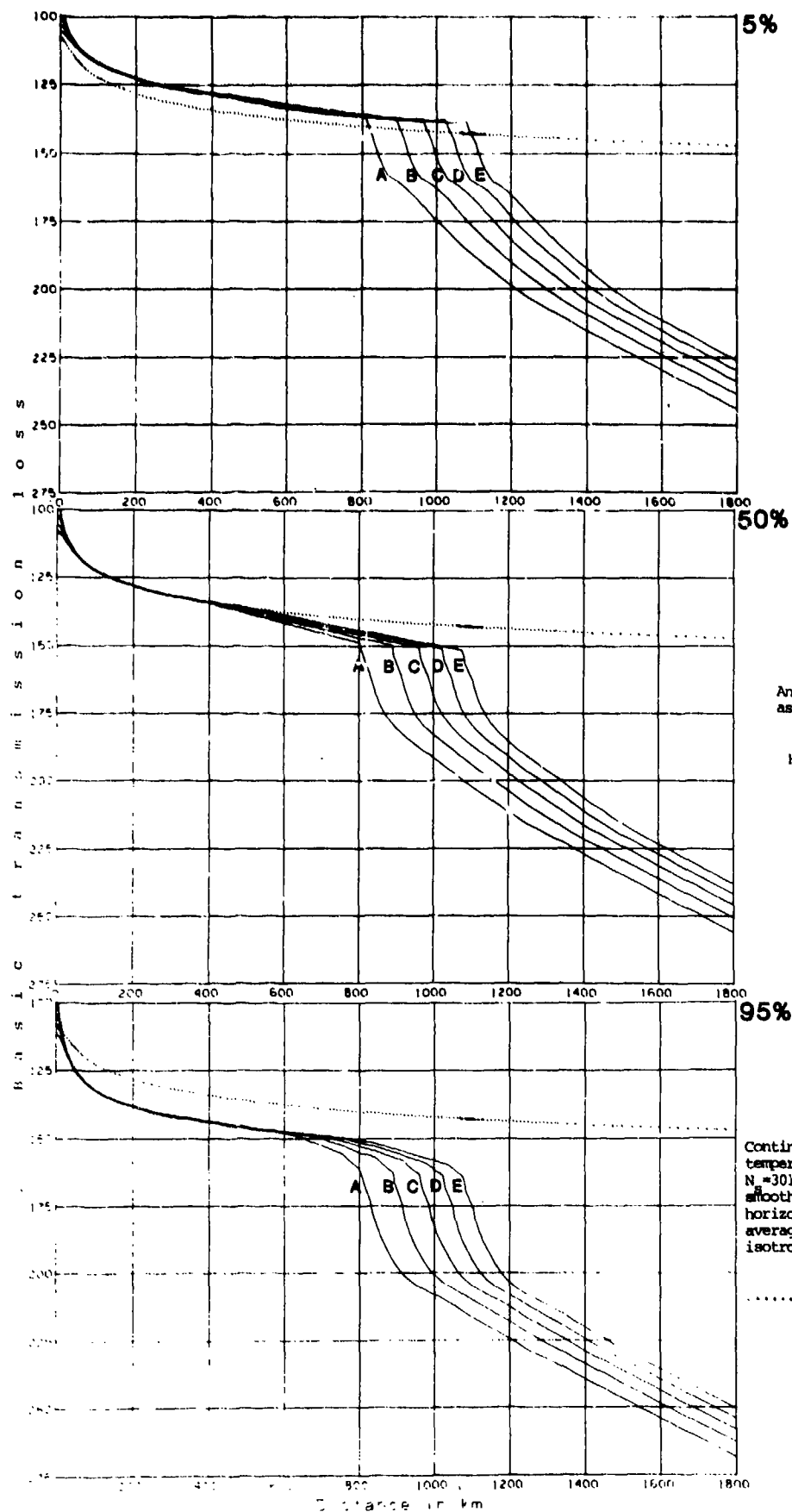


Figure 24. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 10\ 000$ m.

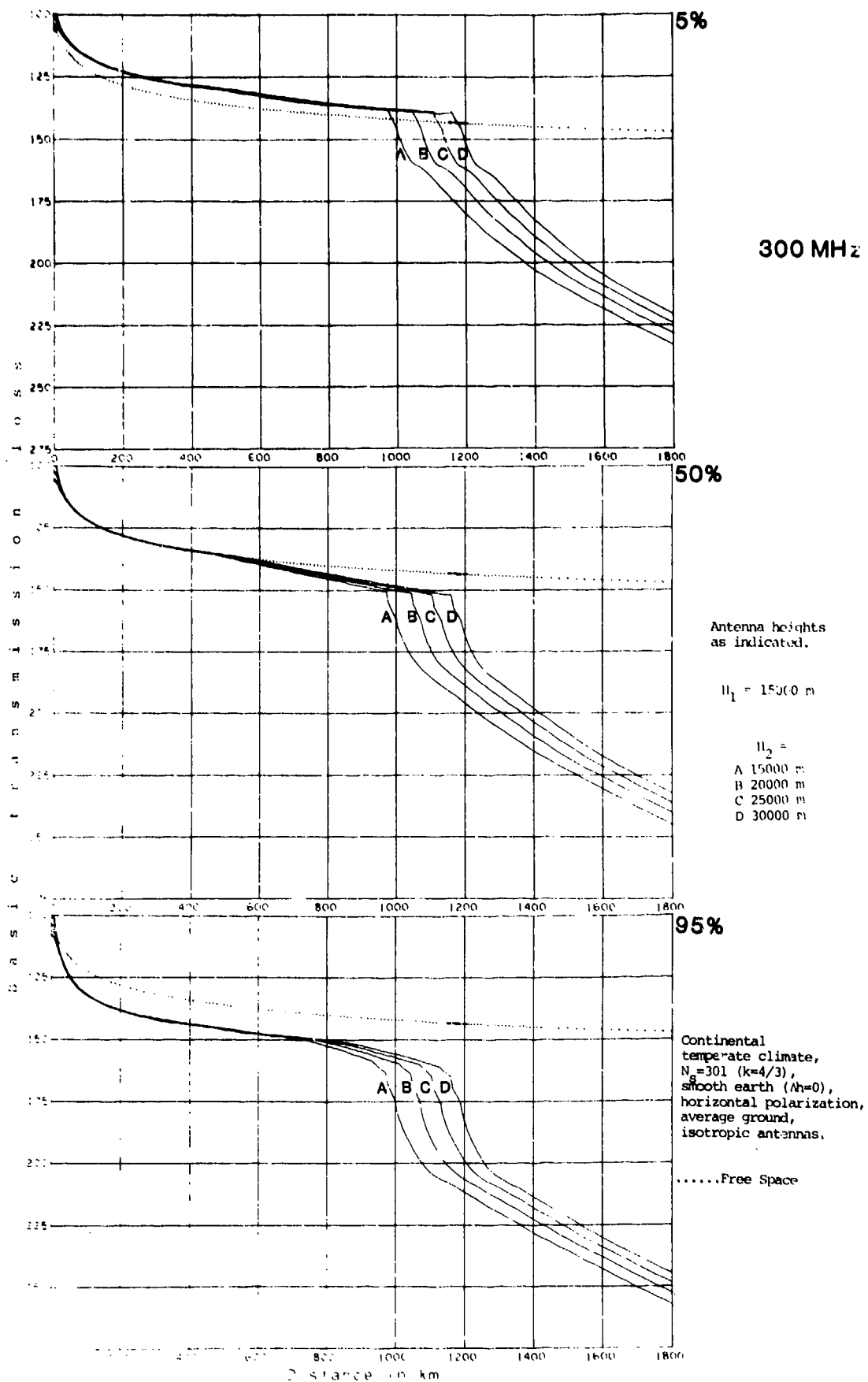


Figure 25. Basic transmission loss versus distance; $F = 300 \text{ MHz}$, $H_1 = 15000 \text{ m}$.

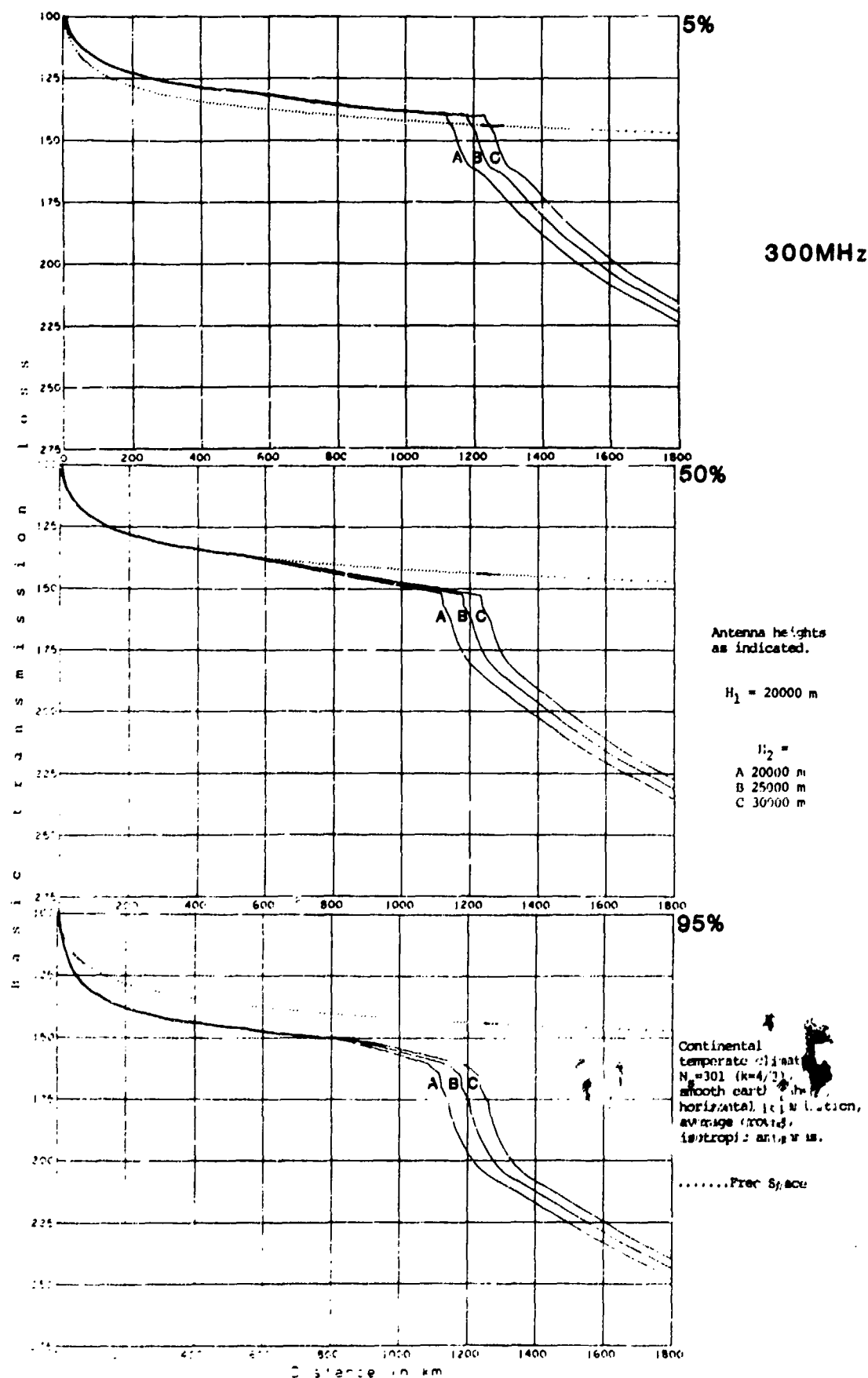


Figure 26. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 20000$ m.

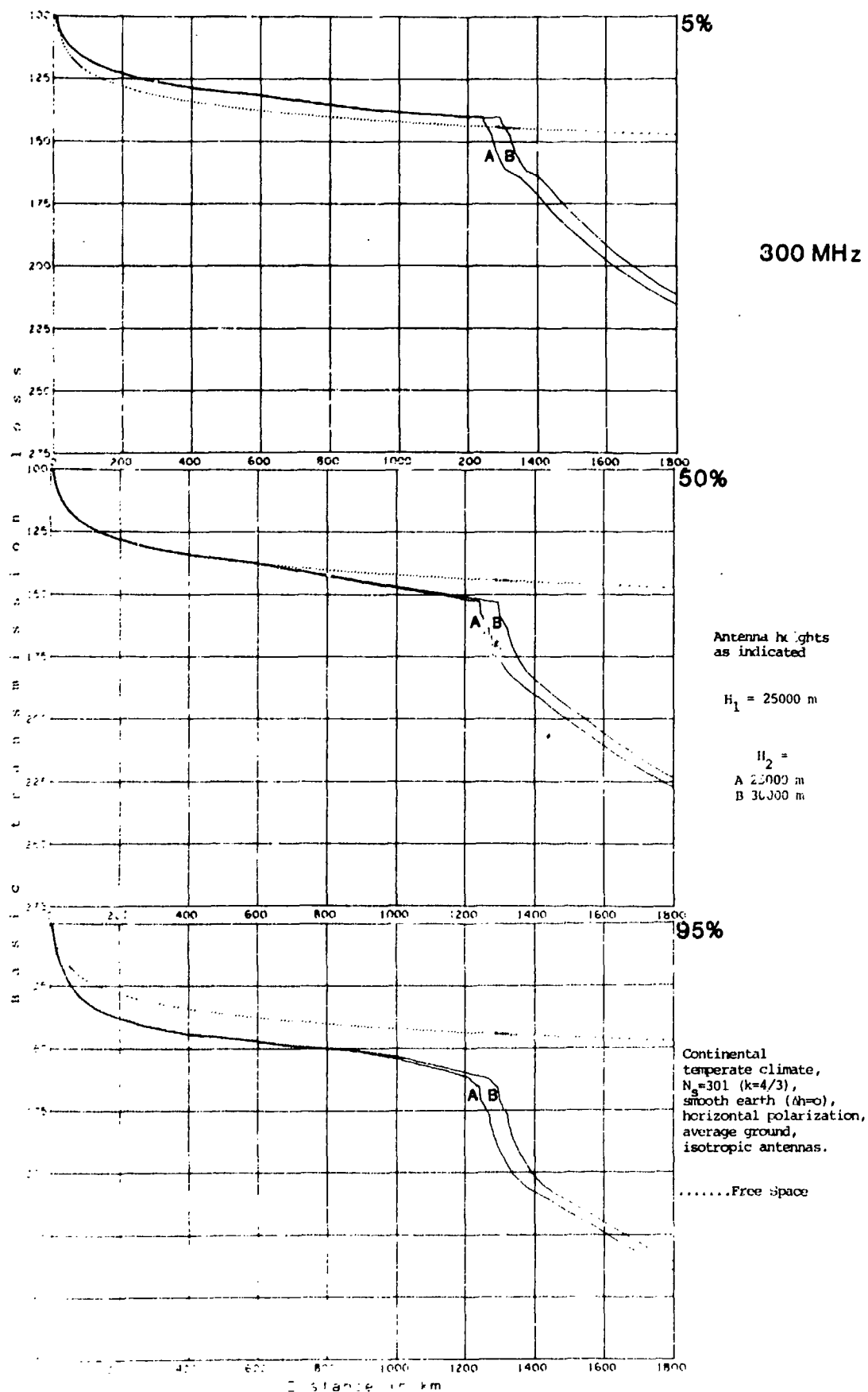


Figure 27. Basic transmission loss versus distance; $F = 300$ MHz, $H_1 = 25\ 000$ m.

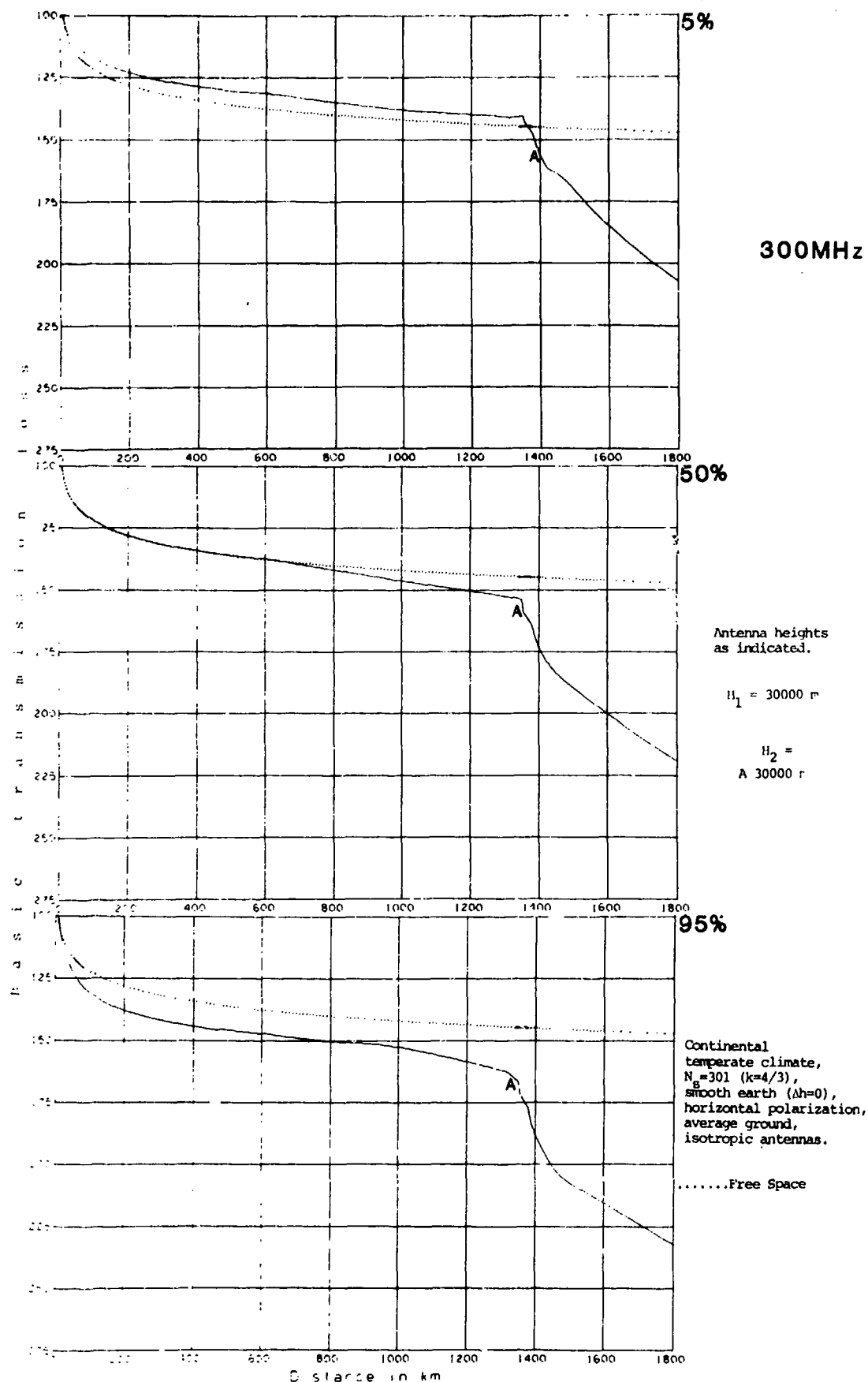


Figure 26. Basic transmission loss versus distance; $F = 300 \text{ MHz}$, $H_1 = 30\,000 \text{ m}$.

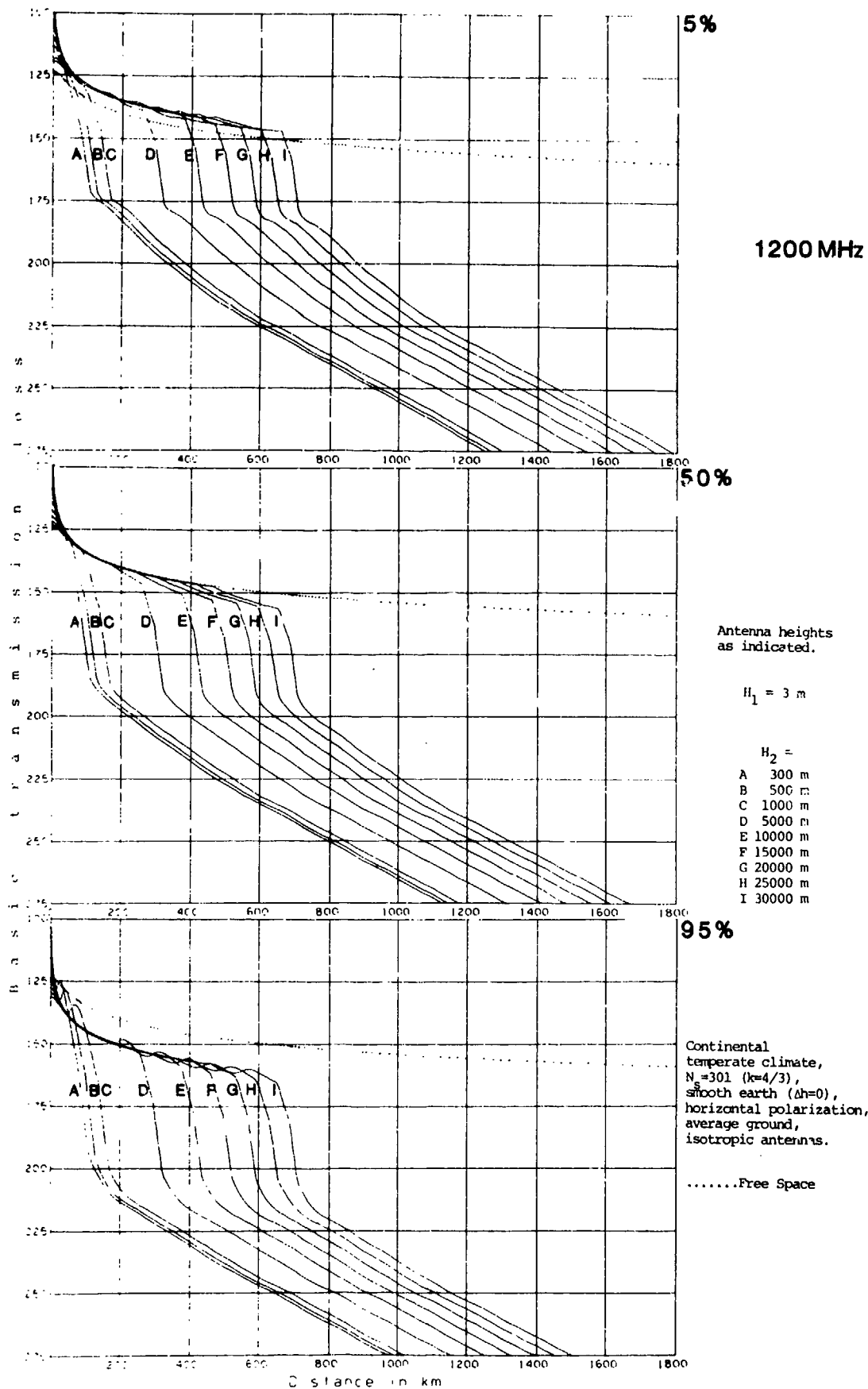


Figure 29. Basic transmission loss versus distance; $F = 1.2 \text{ GHz}$, $H_1 = 3 \text{ m}$.

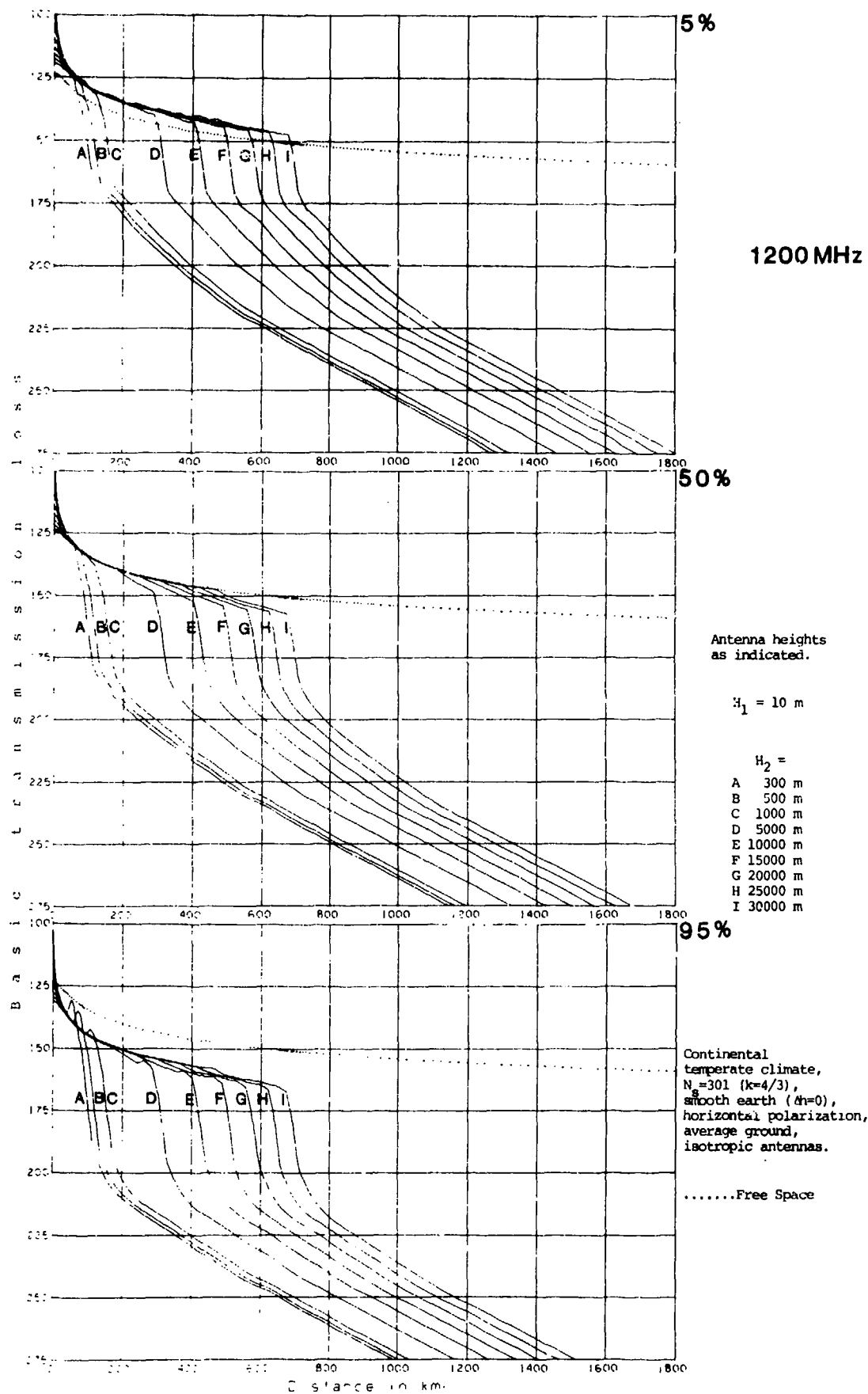


Figure 30. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 10$ m.

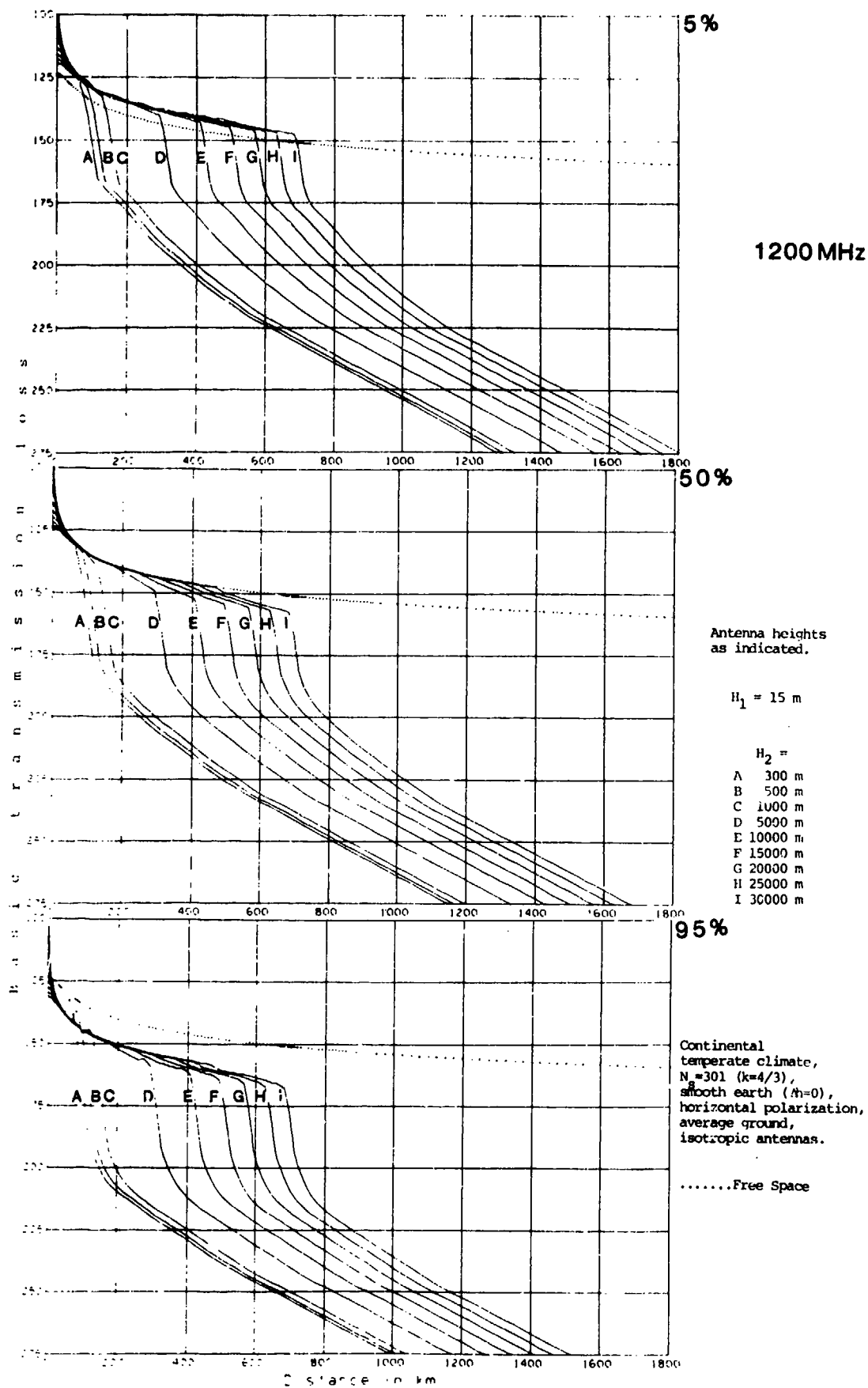


Figure 31. Basic transmission loss versus distance; $F = 1.2 \text{ GHz}$, $H_1 = 15 \text{ m}$.

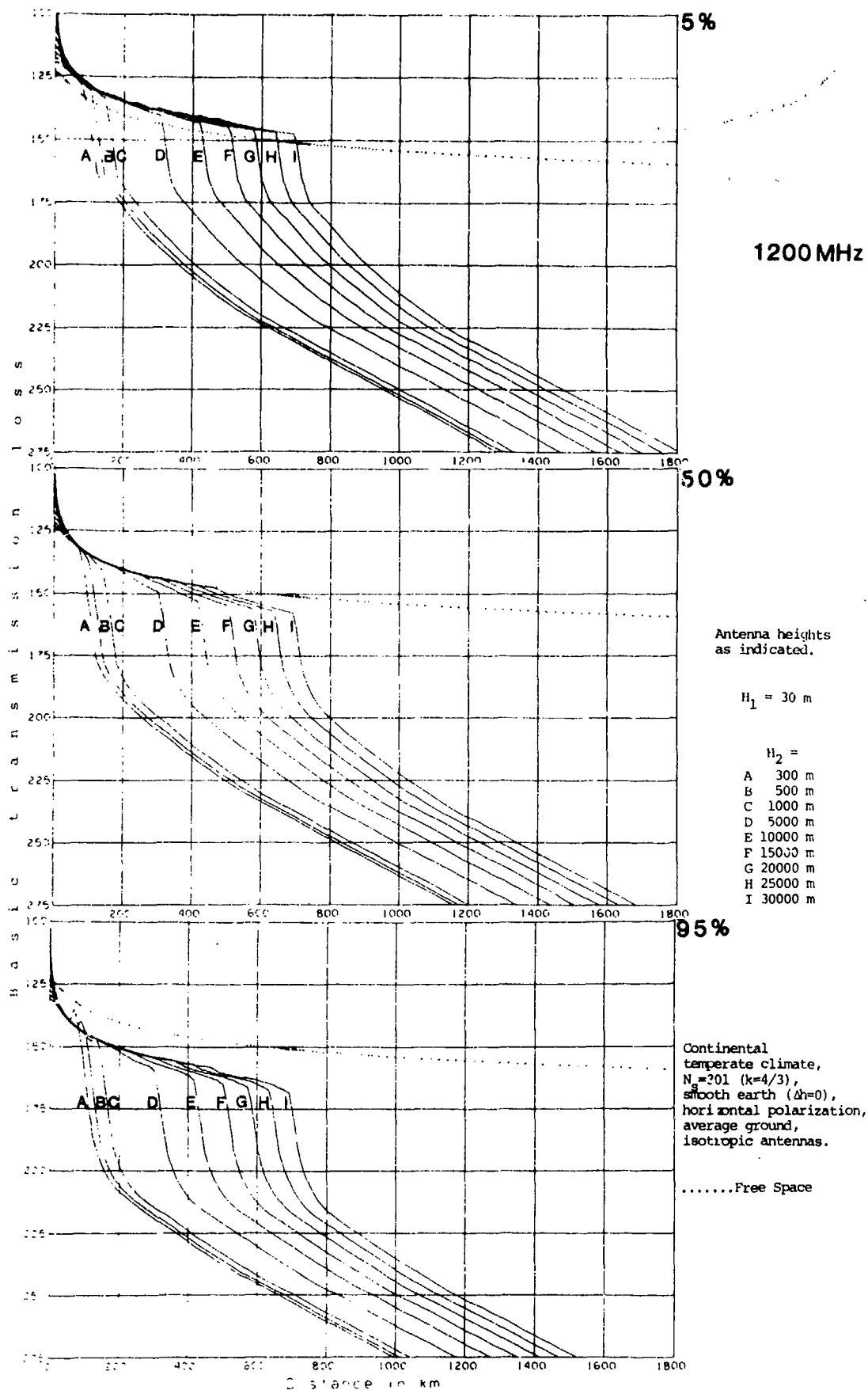


Figure 32. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 30$ m.

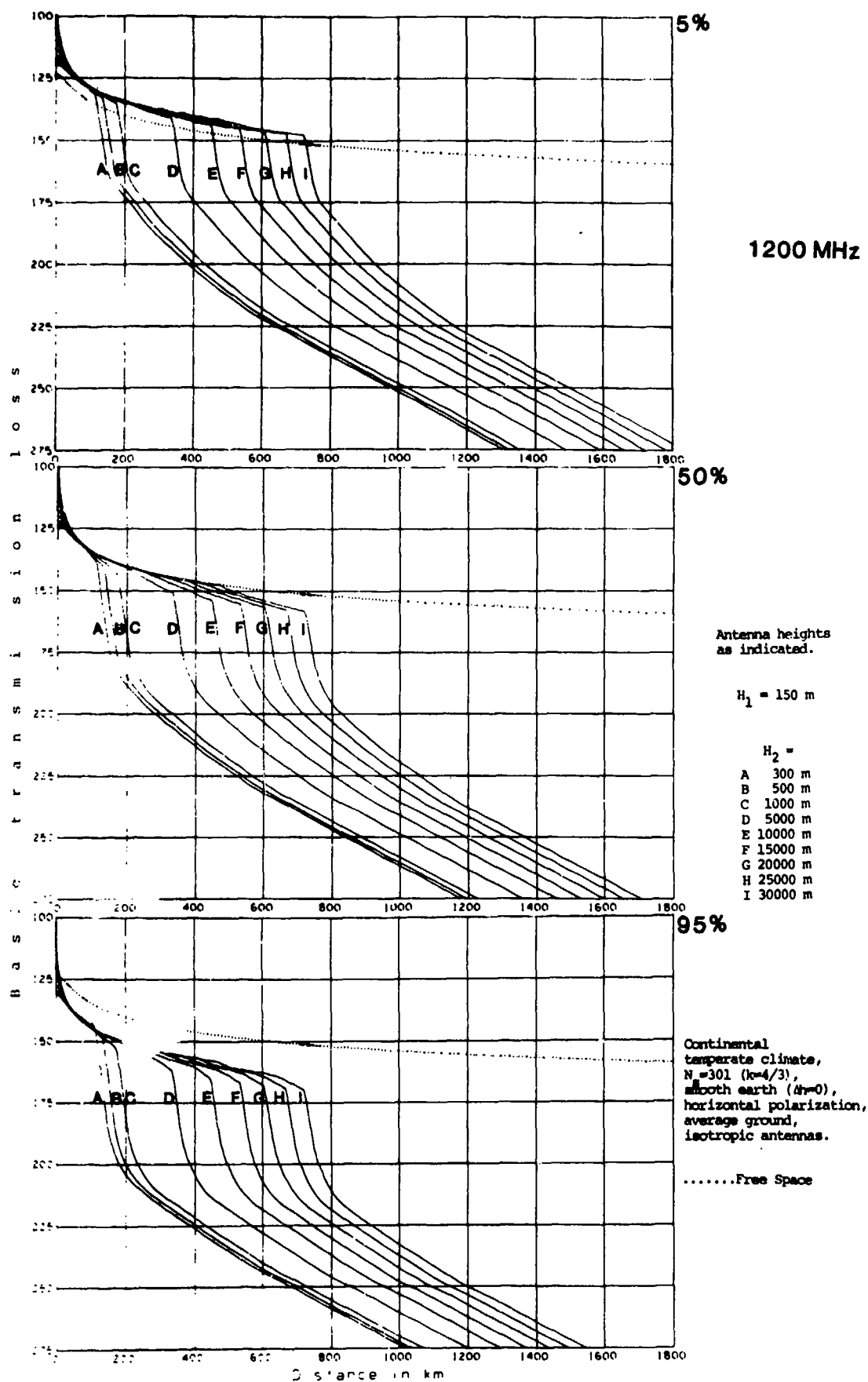


Figure 33. Basic transmission loss versus distance; $F = 1.2 \text{ GHz}$, $H_1 = 150 \text{ m}$.

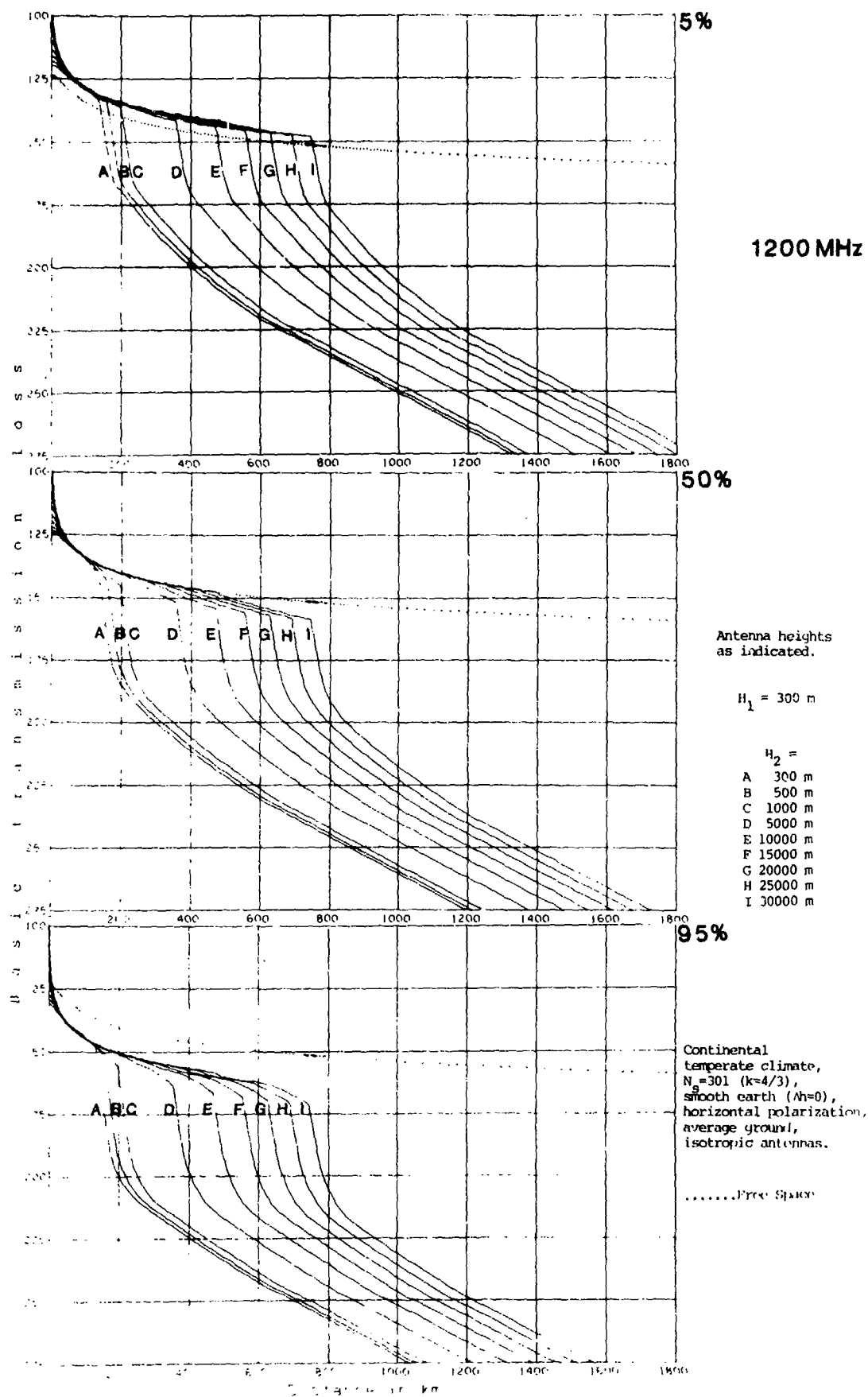


Figure 14. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 300$ m.

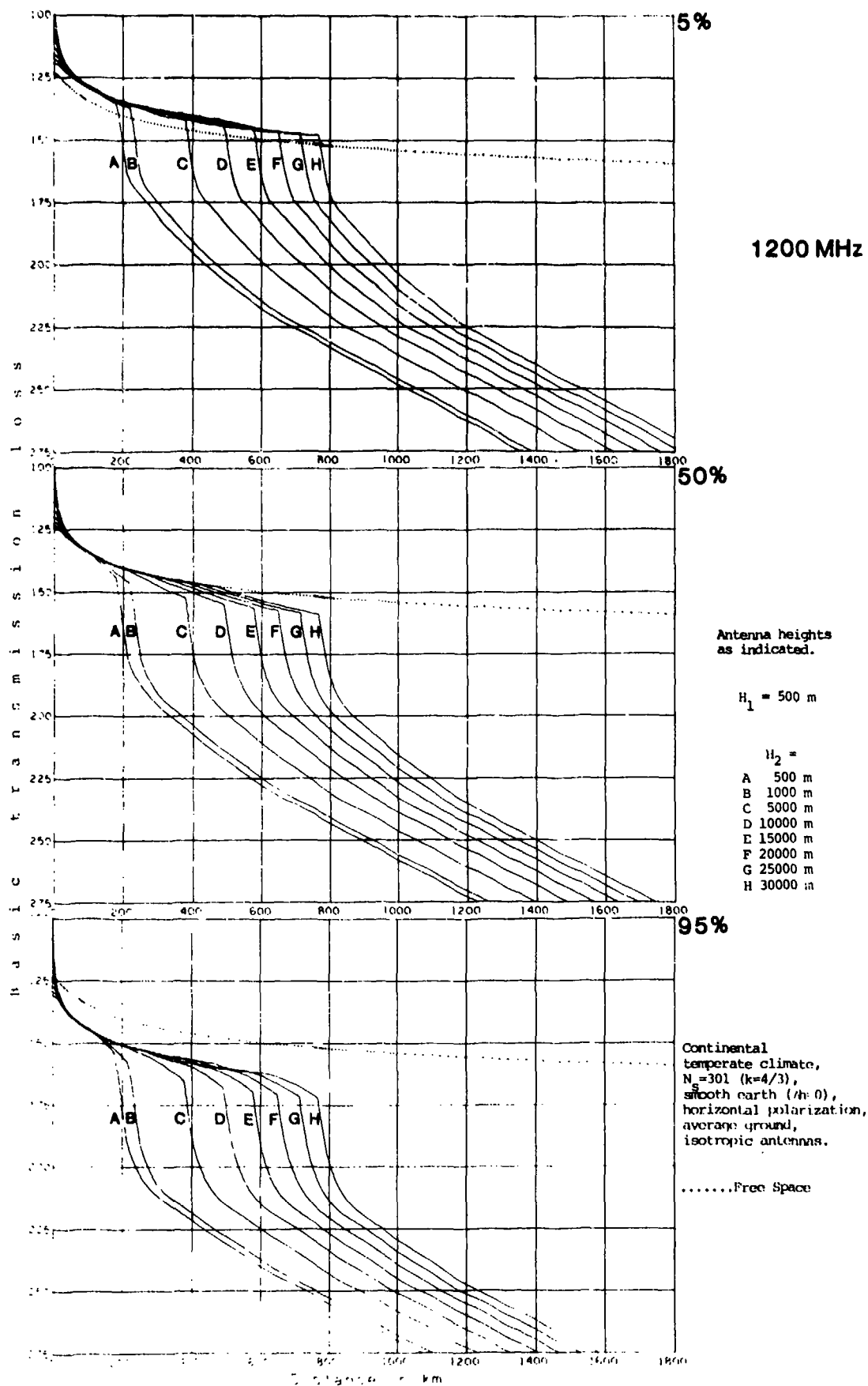


Figure 35. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 500$ m.

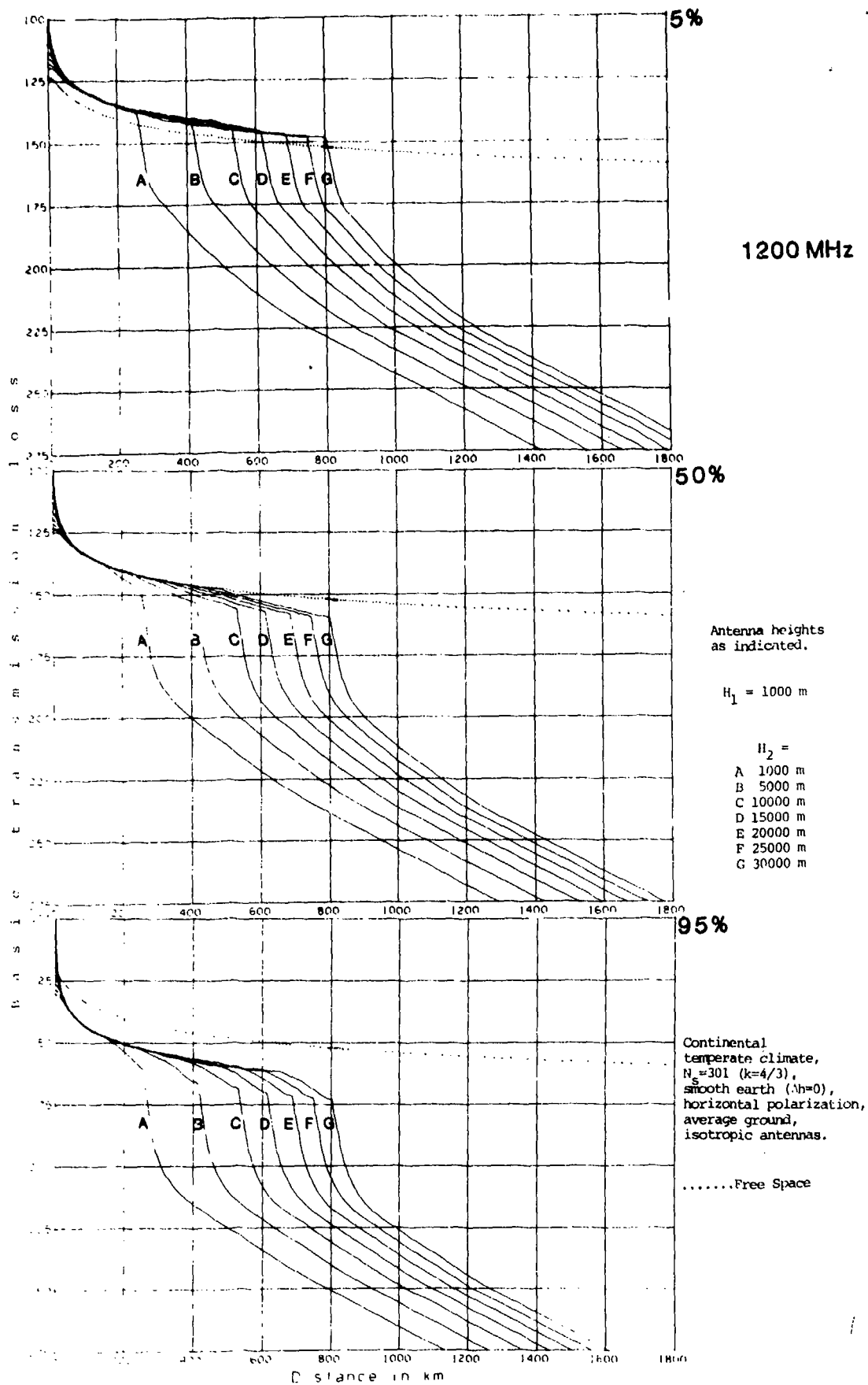


Figure 36. Basic transmission loss versus distance; $F = 1.2 \text{ GHz}$, $H_1 = 1000 \text{ m}$.

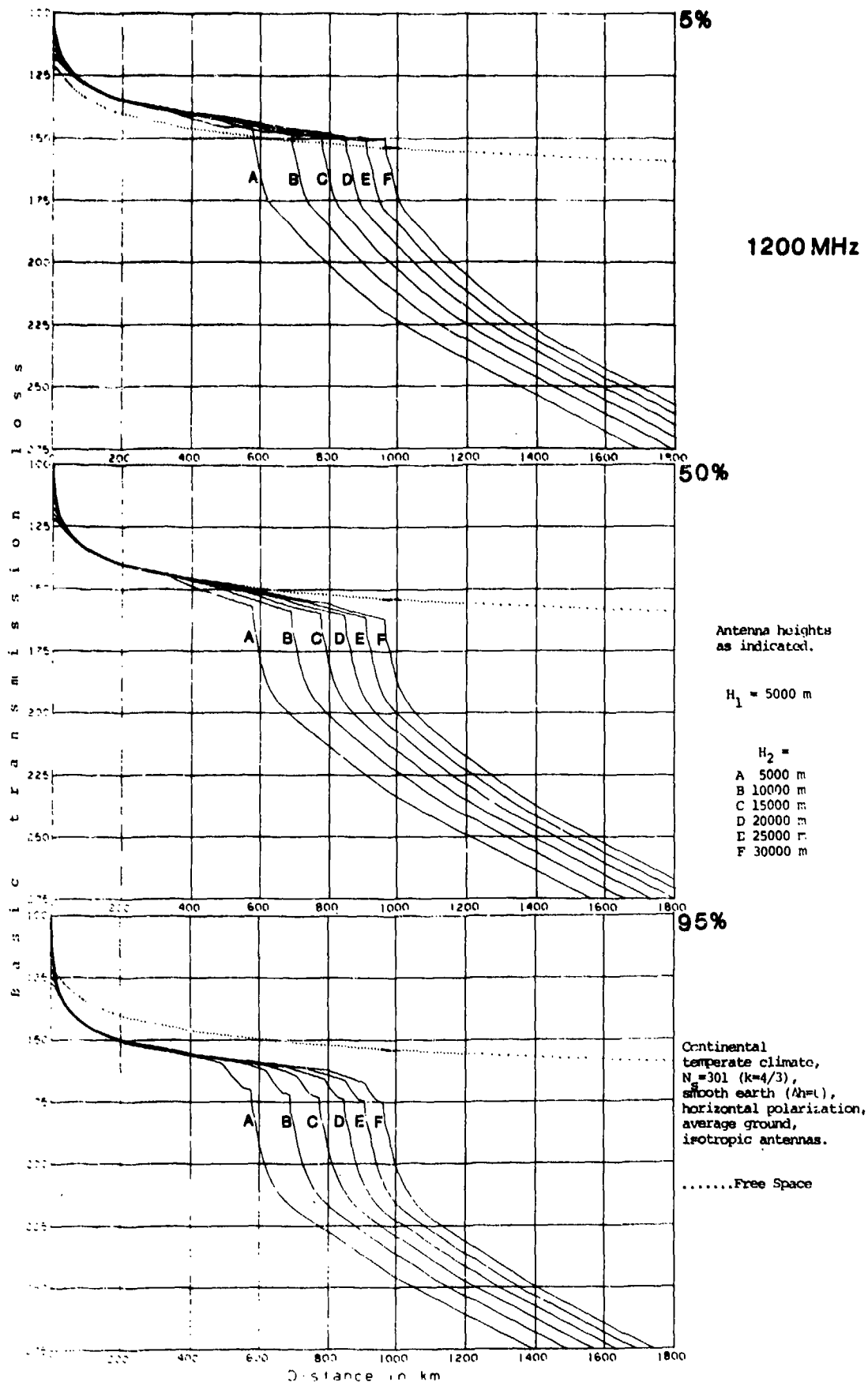


Figure 37. Basic transmission loss versus distance; $F = 1.2 \text{ GHz}$, $H_1 = 5000 \text{ m}$.

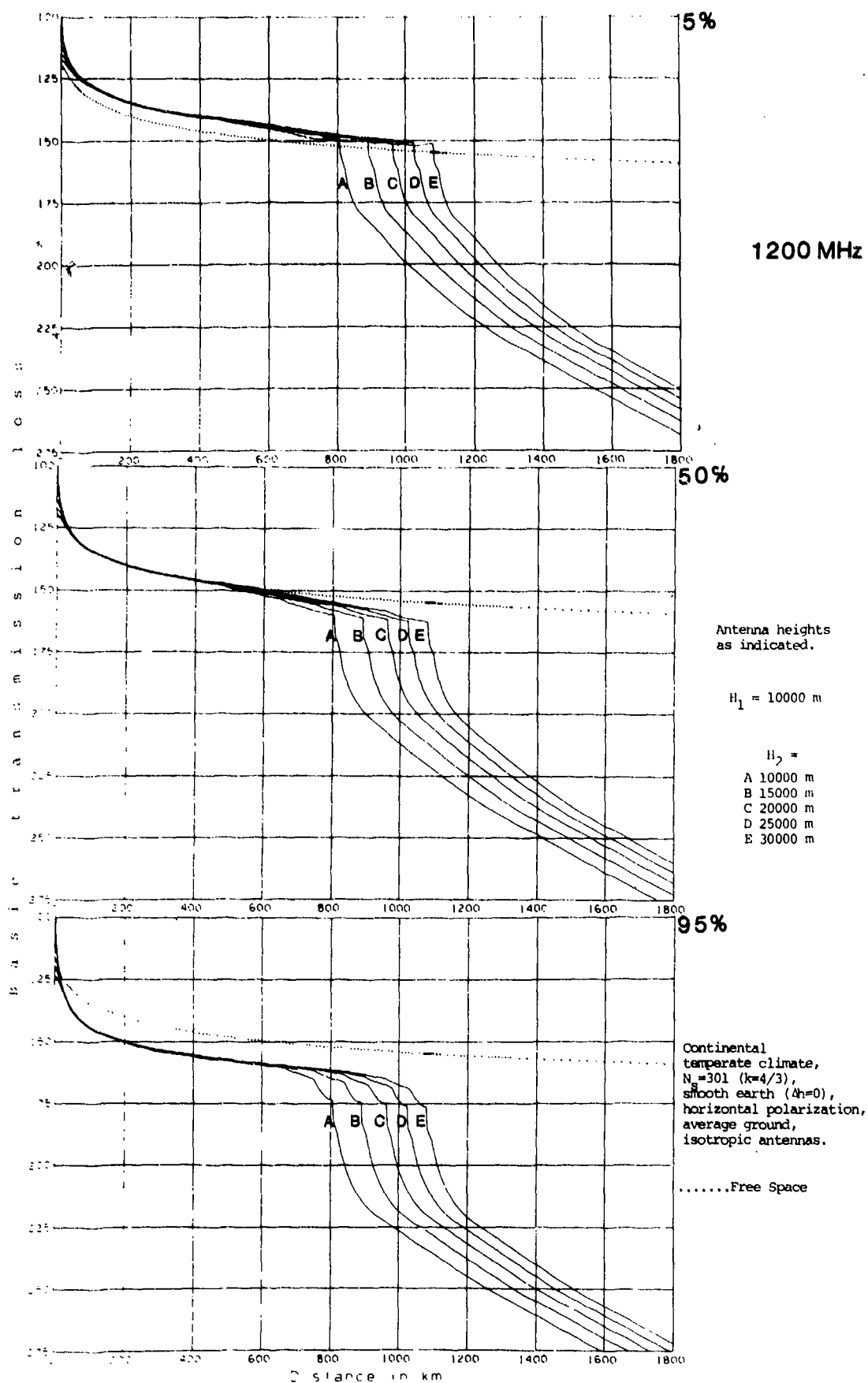


Figure 38. Basic transmission loss versus distance: $F = 1.2$ GHz, $H_1 = 10\ 000$ m.

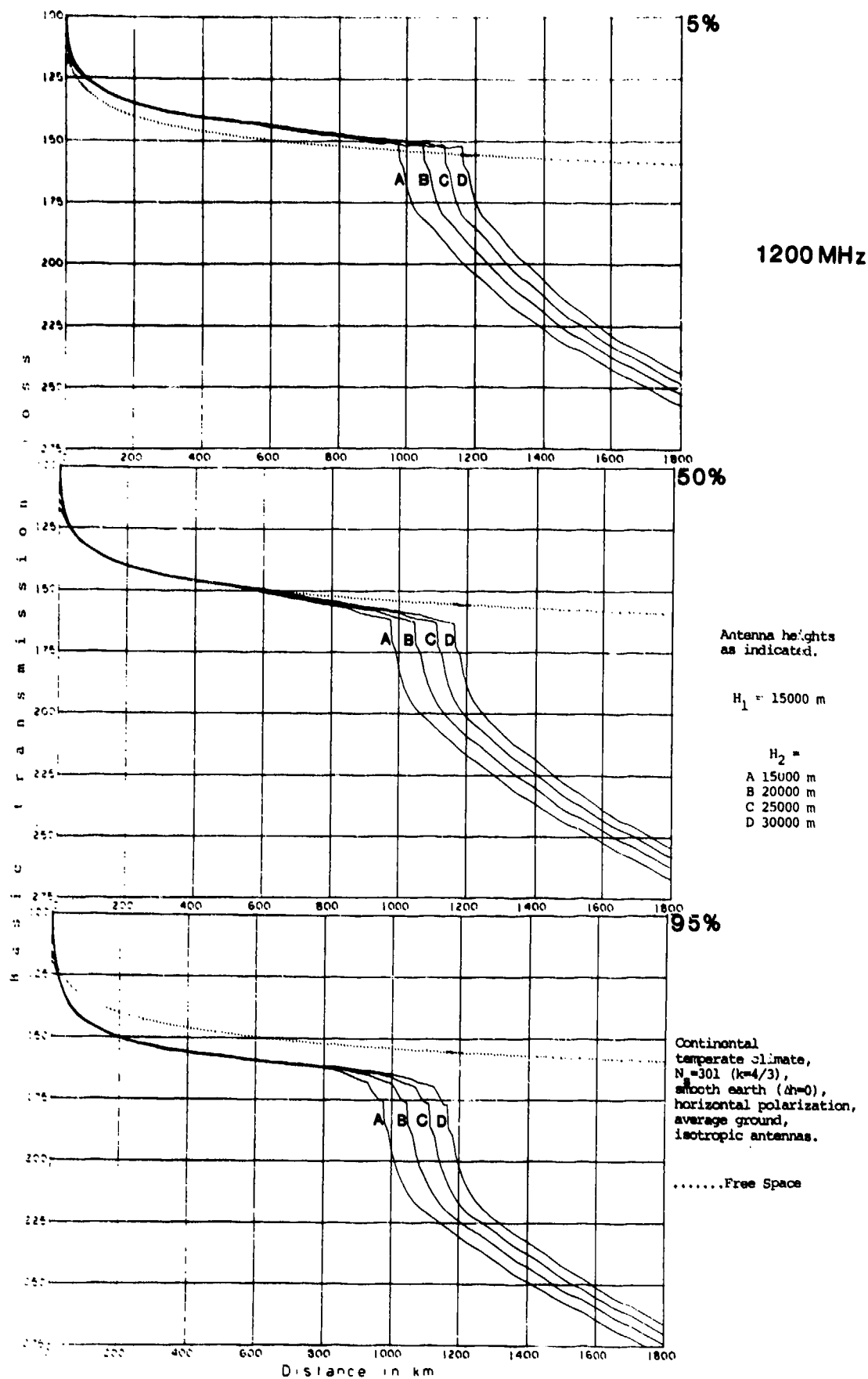


Figure 39. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 15000$ m.

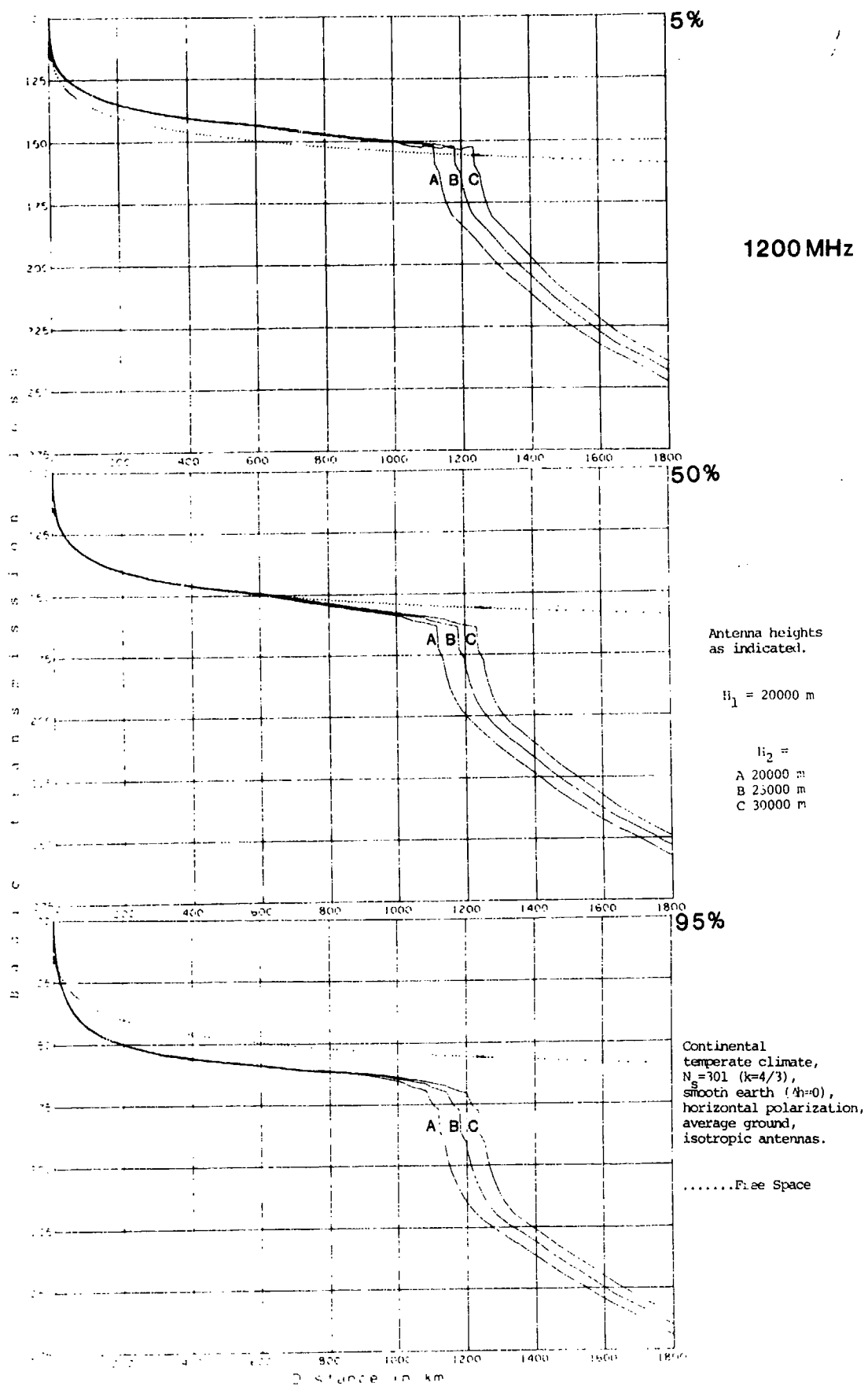


Figure 40. Basic transmission loss versus distance; $F = 1.2$ GHz, $h_1 = 20000$ m.

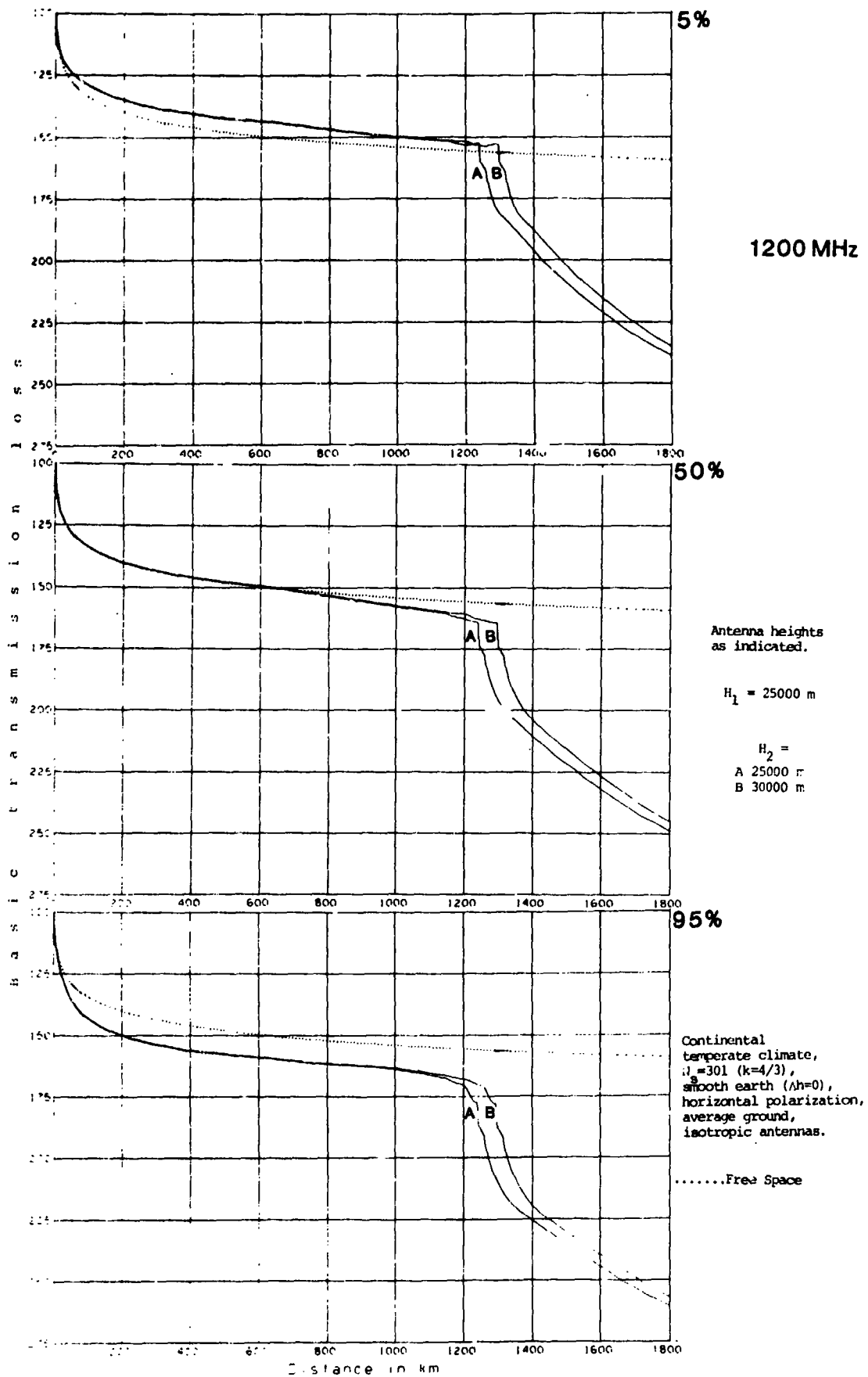


Figure 41. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 25\ 000$ m.

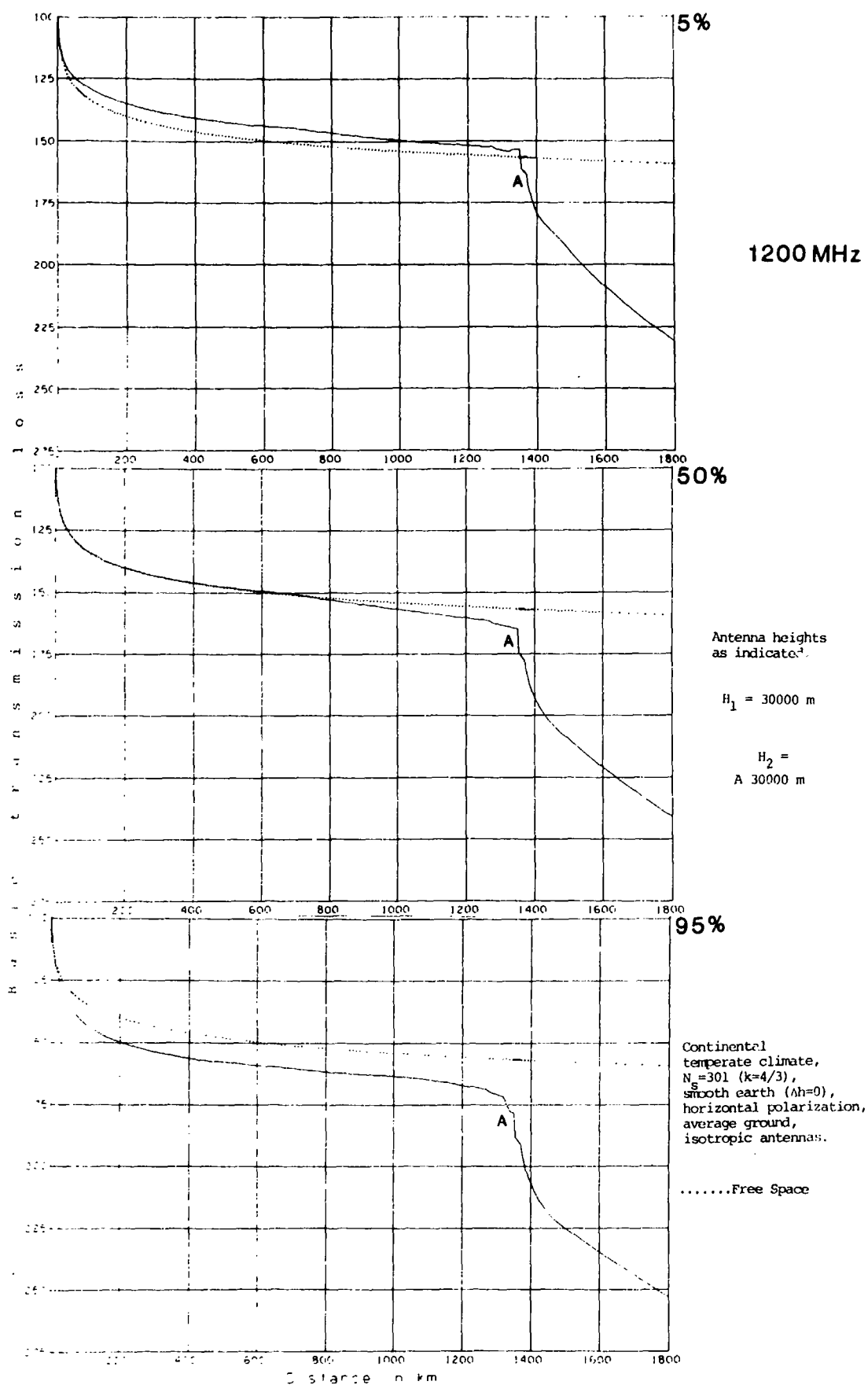


Figure 42. Basic transmission loss versus distance; $F = 1.2$ GHz, $H_1 = 30\,000$ m.

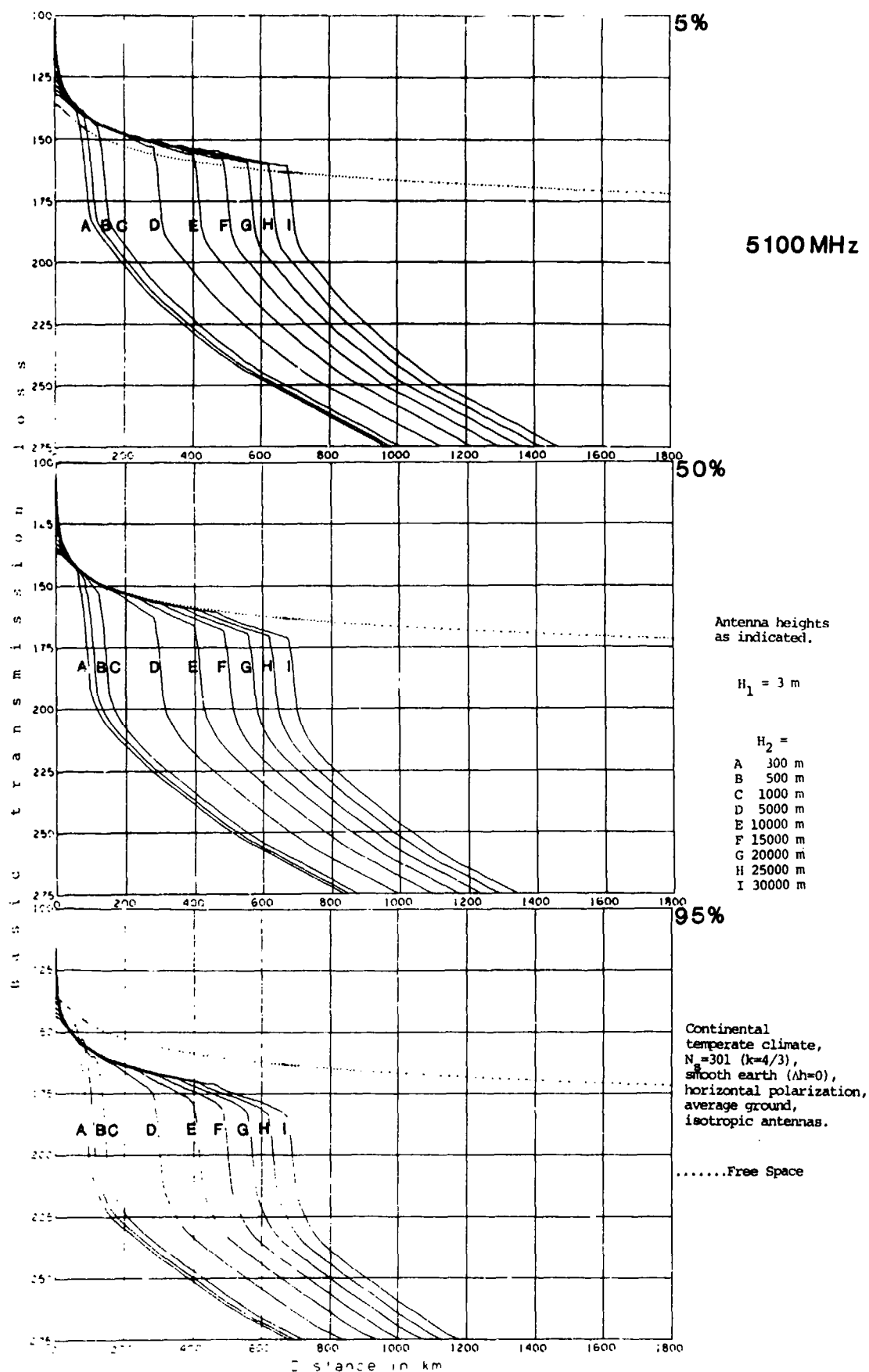
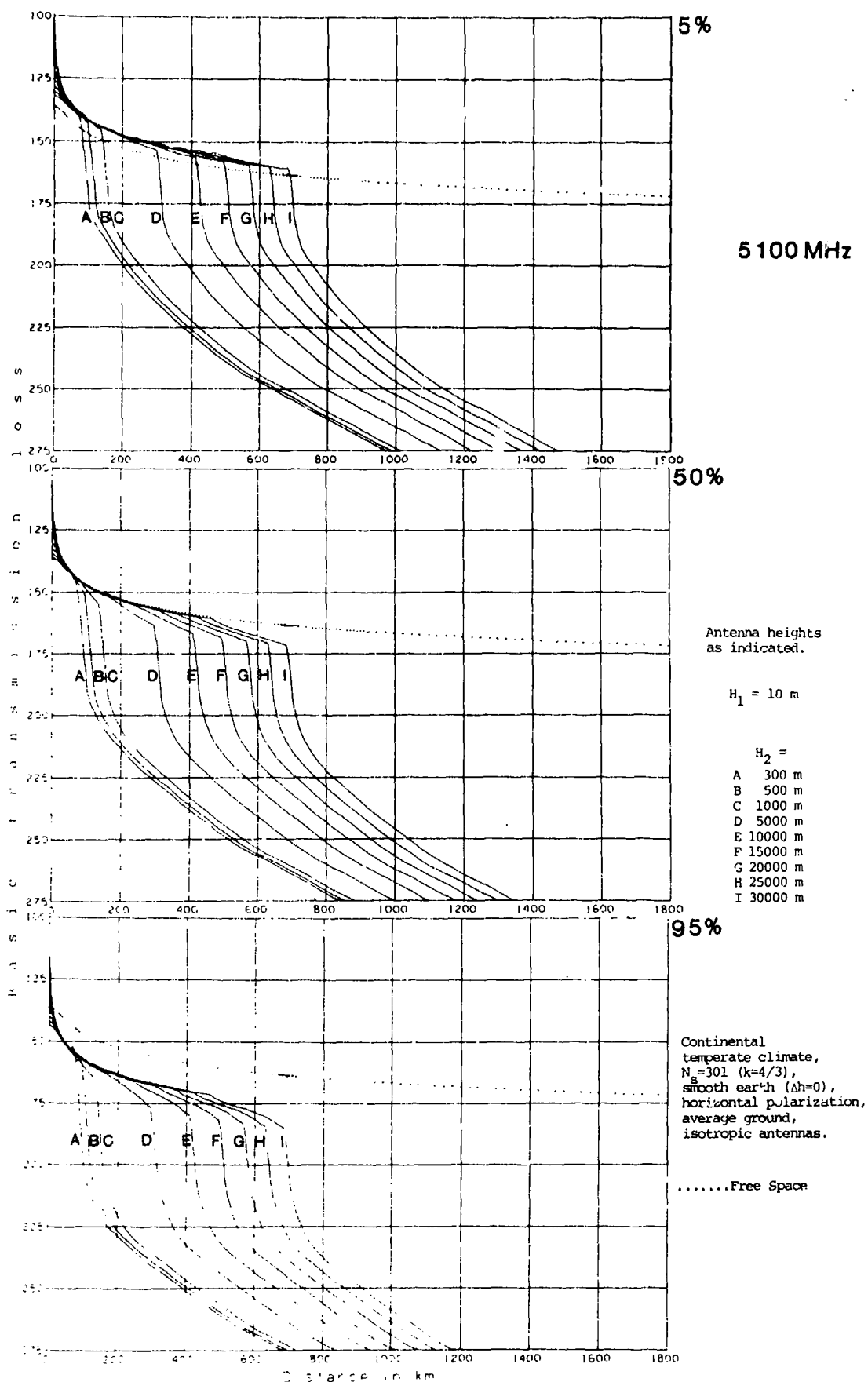


Figure 43. Basic transmission loss versus distance; $F = 5.1 \text{ GHz}$, $H_1 = 3 \text{ m}$.



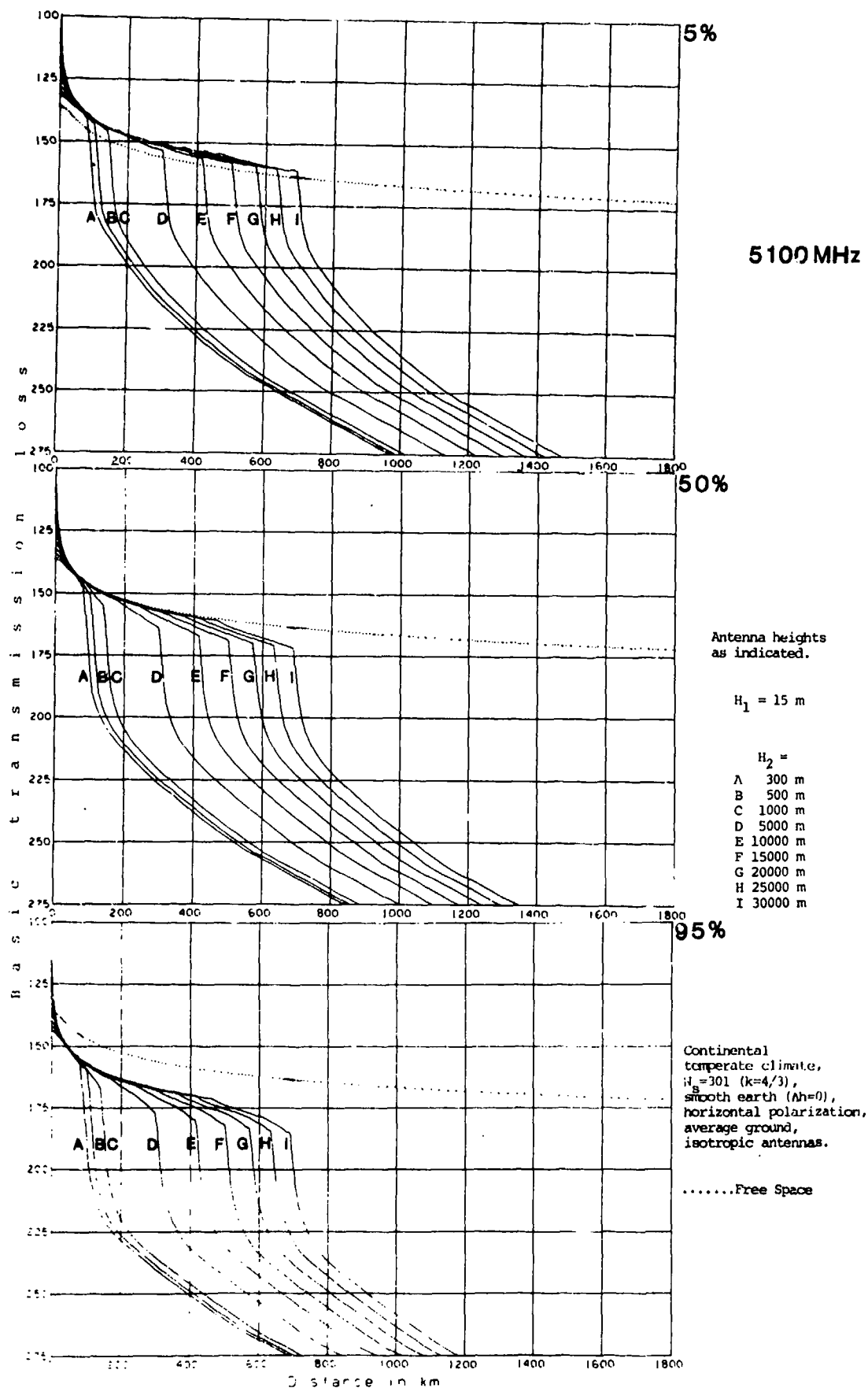


Figure 45. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 15$ m.

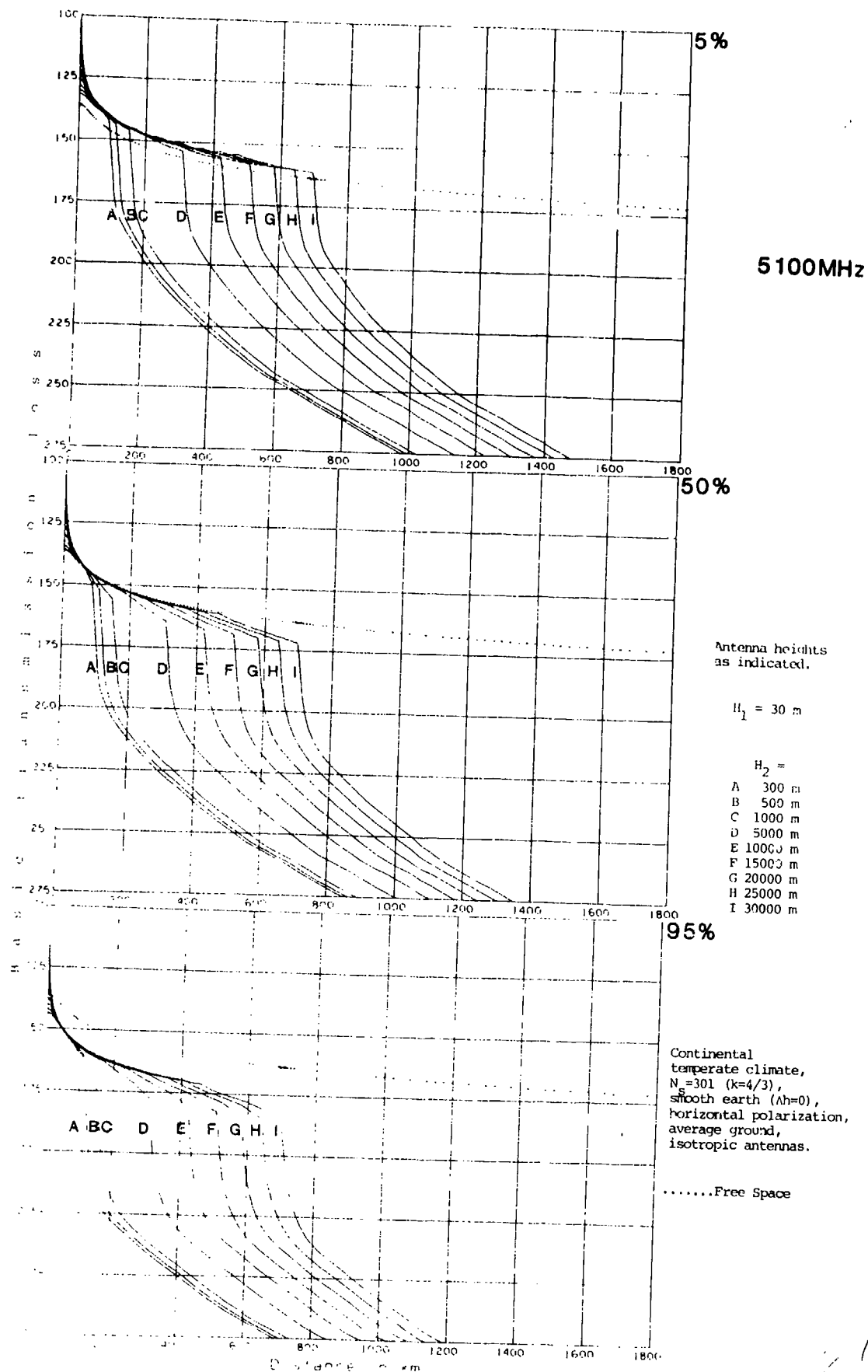


Figure 46. Basic transmission loss versus distance; $F = 5.1 \text{ GHz}$, $H_1 = 30 \text{ m}$.

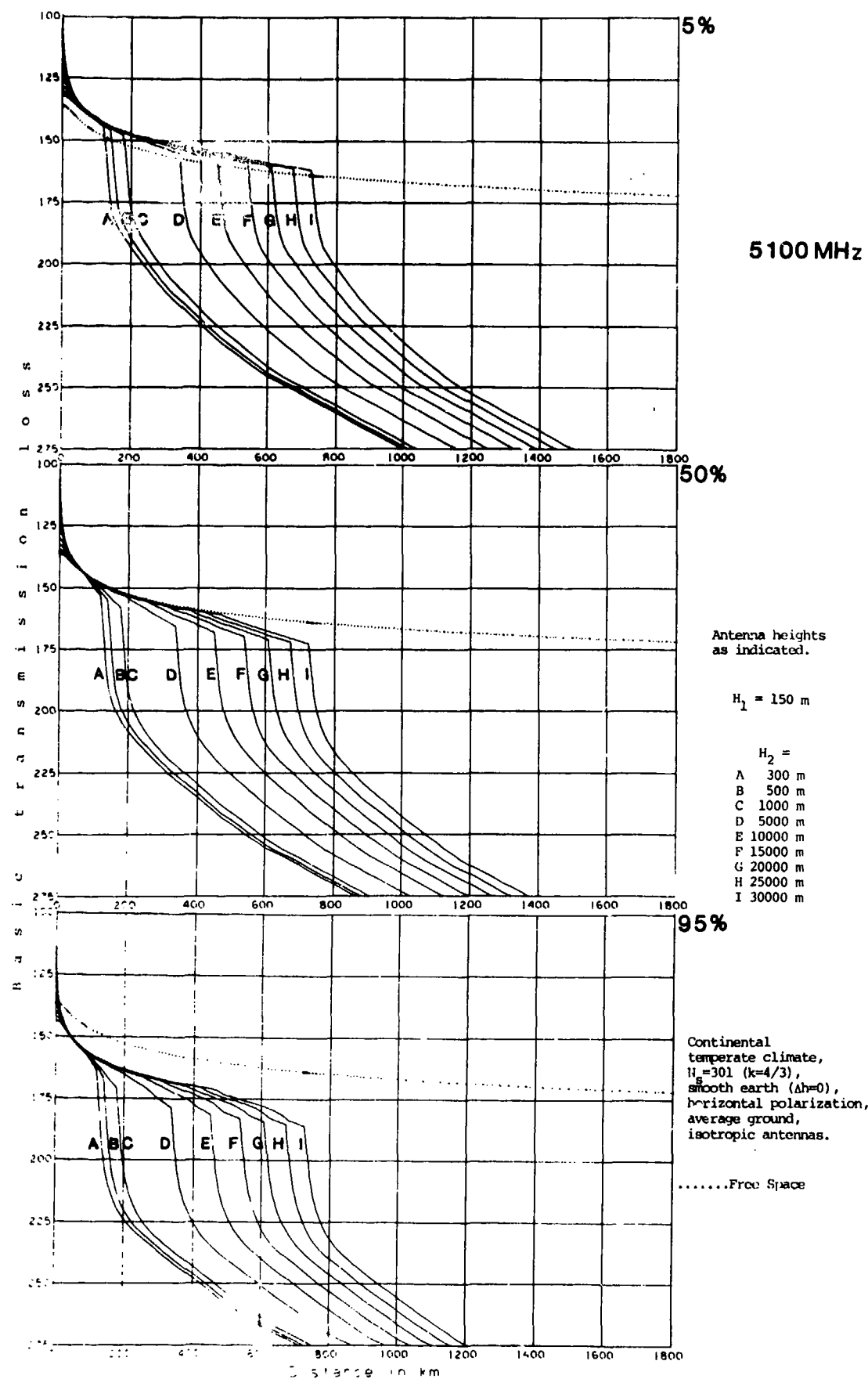


Figure 47. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 150$ m.

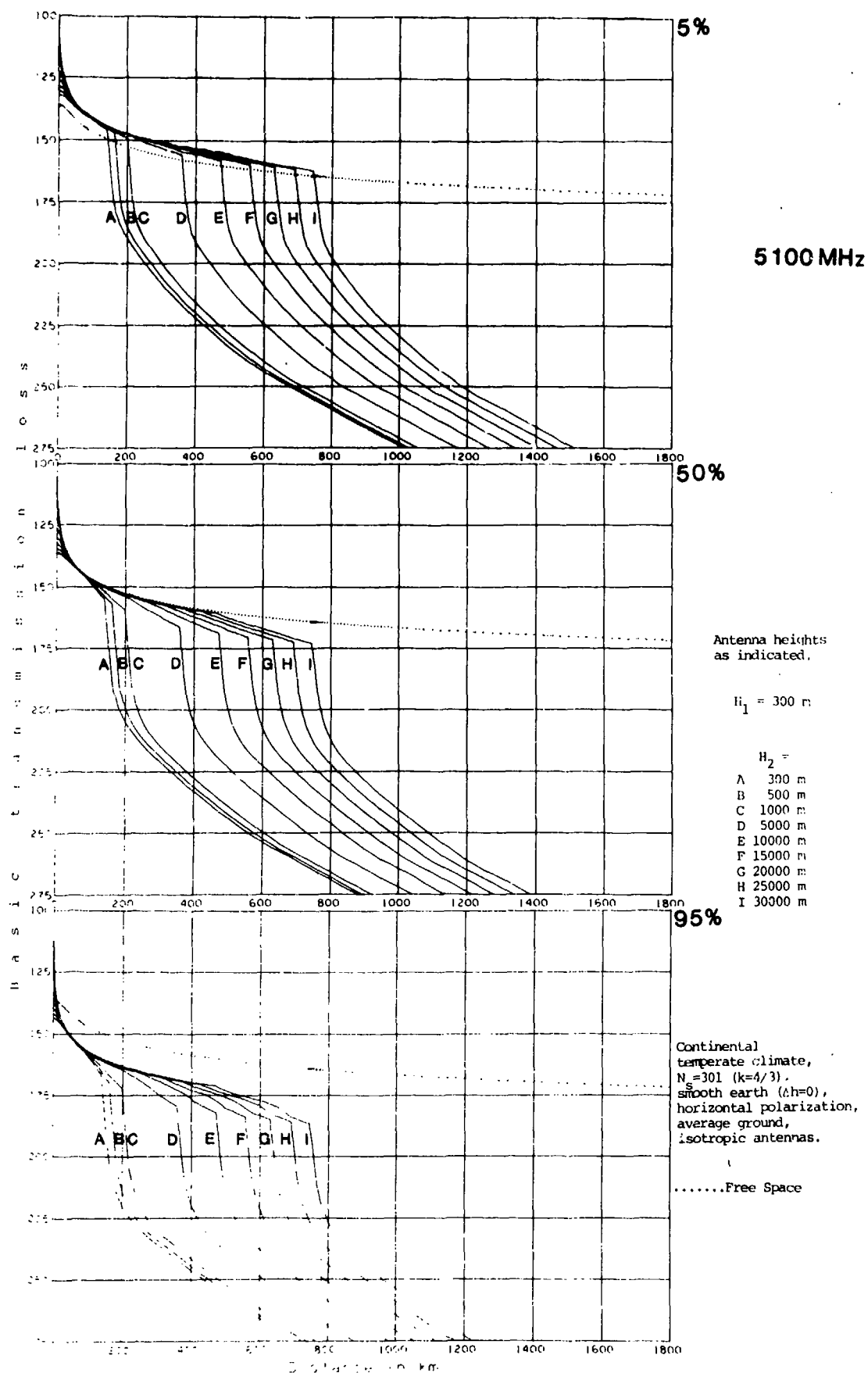


Figure 46. Basic transmission loss versus distance; $F = 5.1 \text{ GHz}$, $H_1 = 300 \text{ m}$.

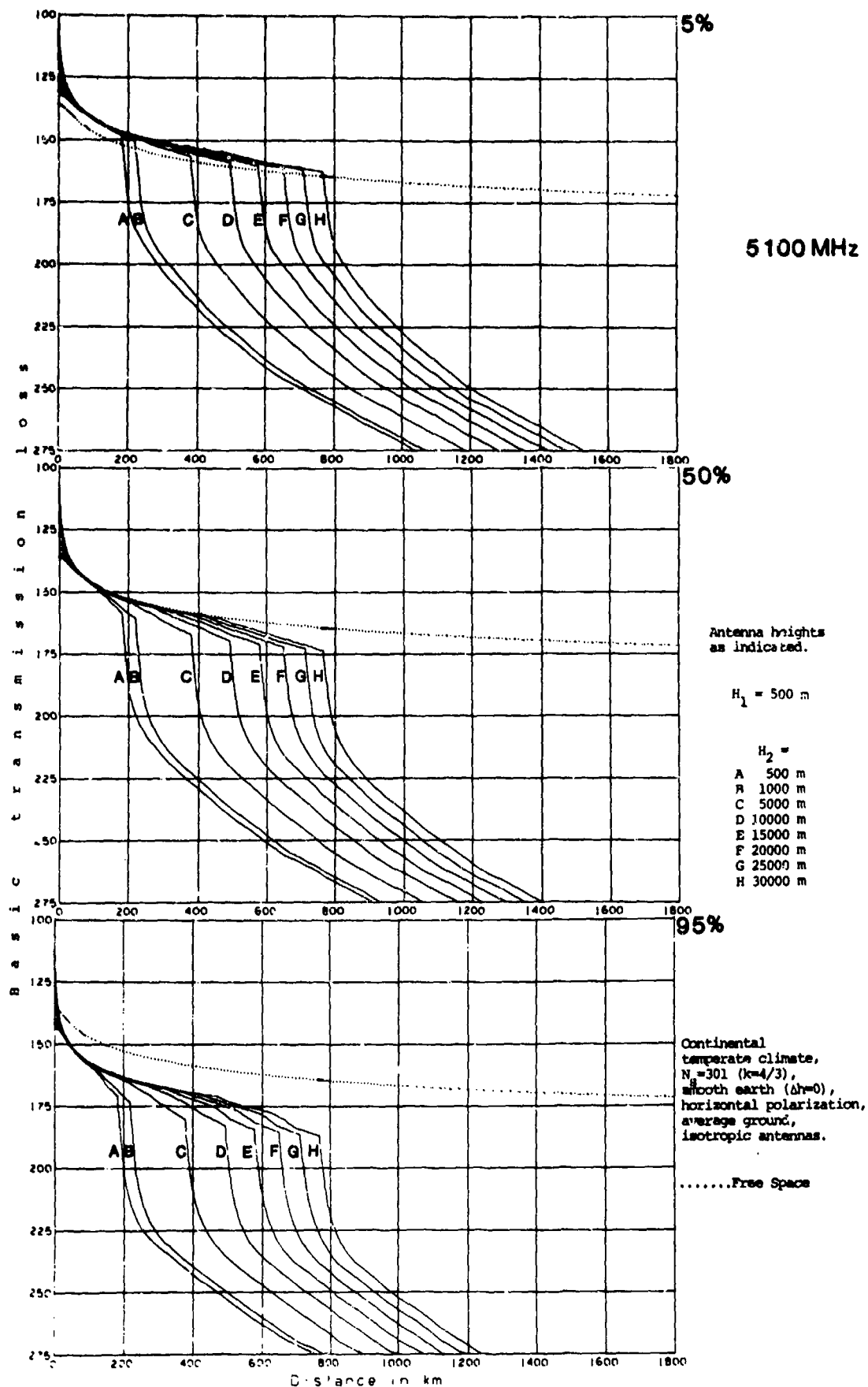


Figure 49. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 500$ m.

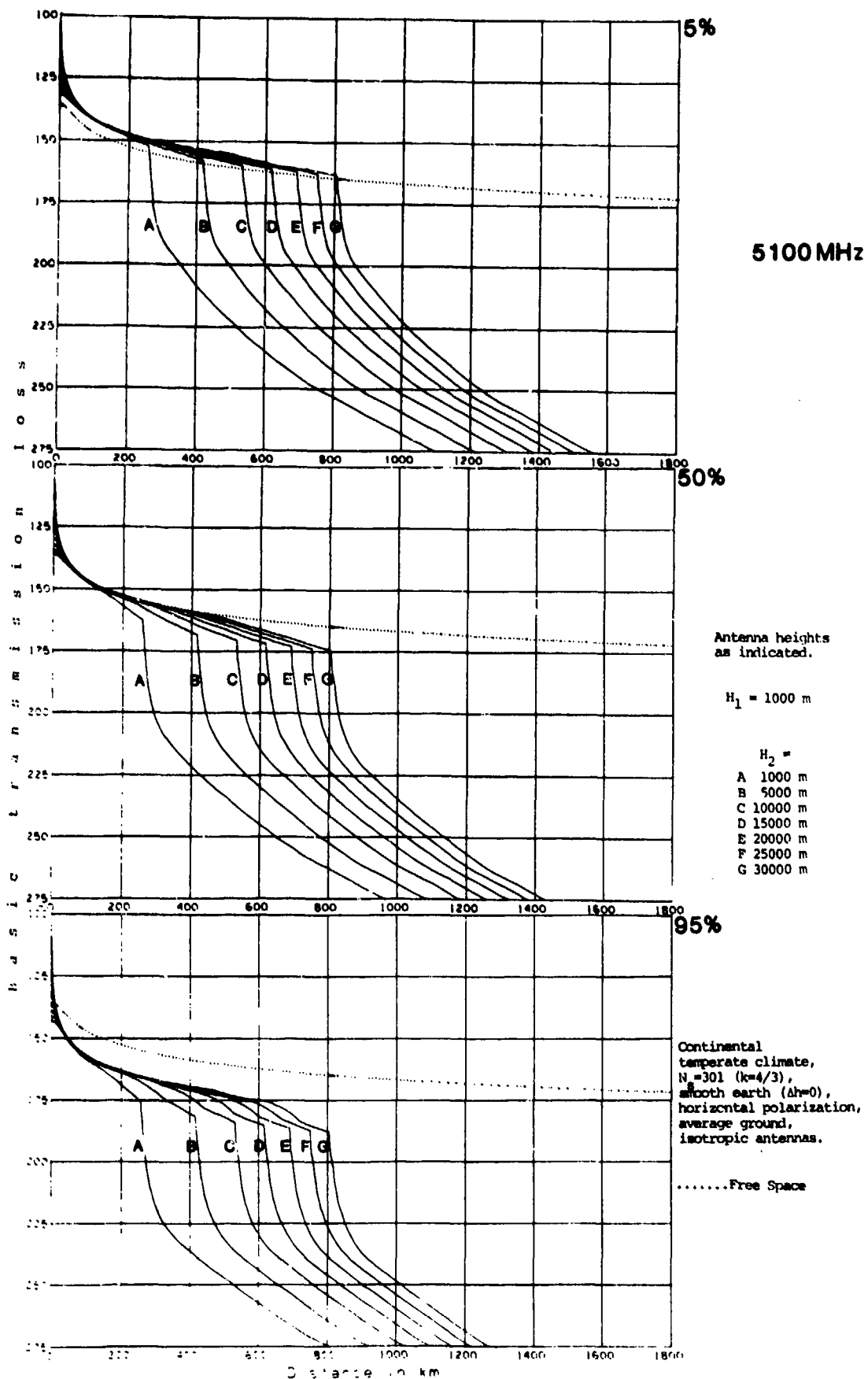


Figure 59. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 1000$ m.

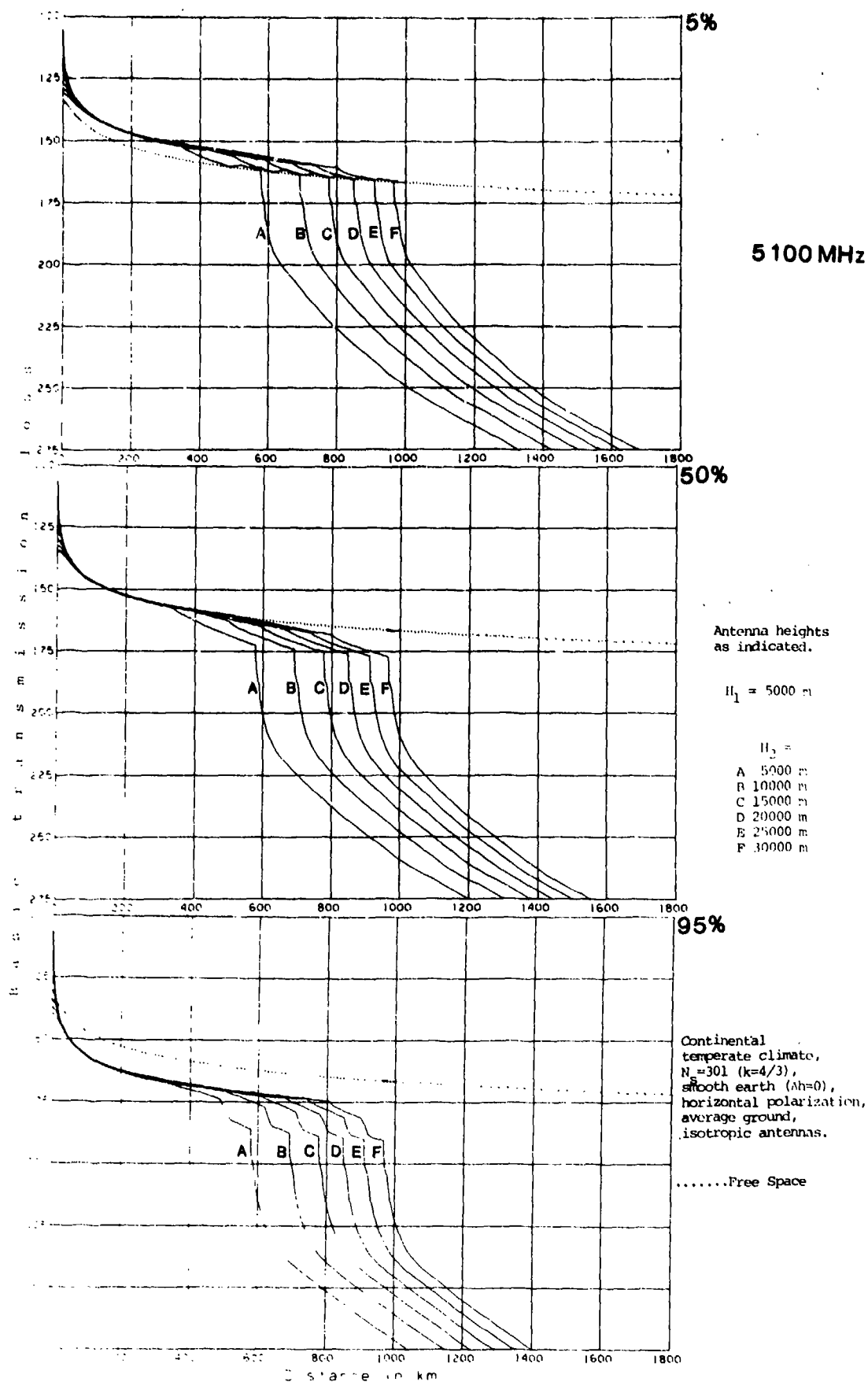


Figure 51. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 5000$ m.

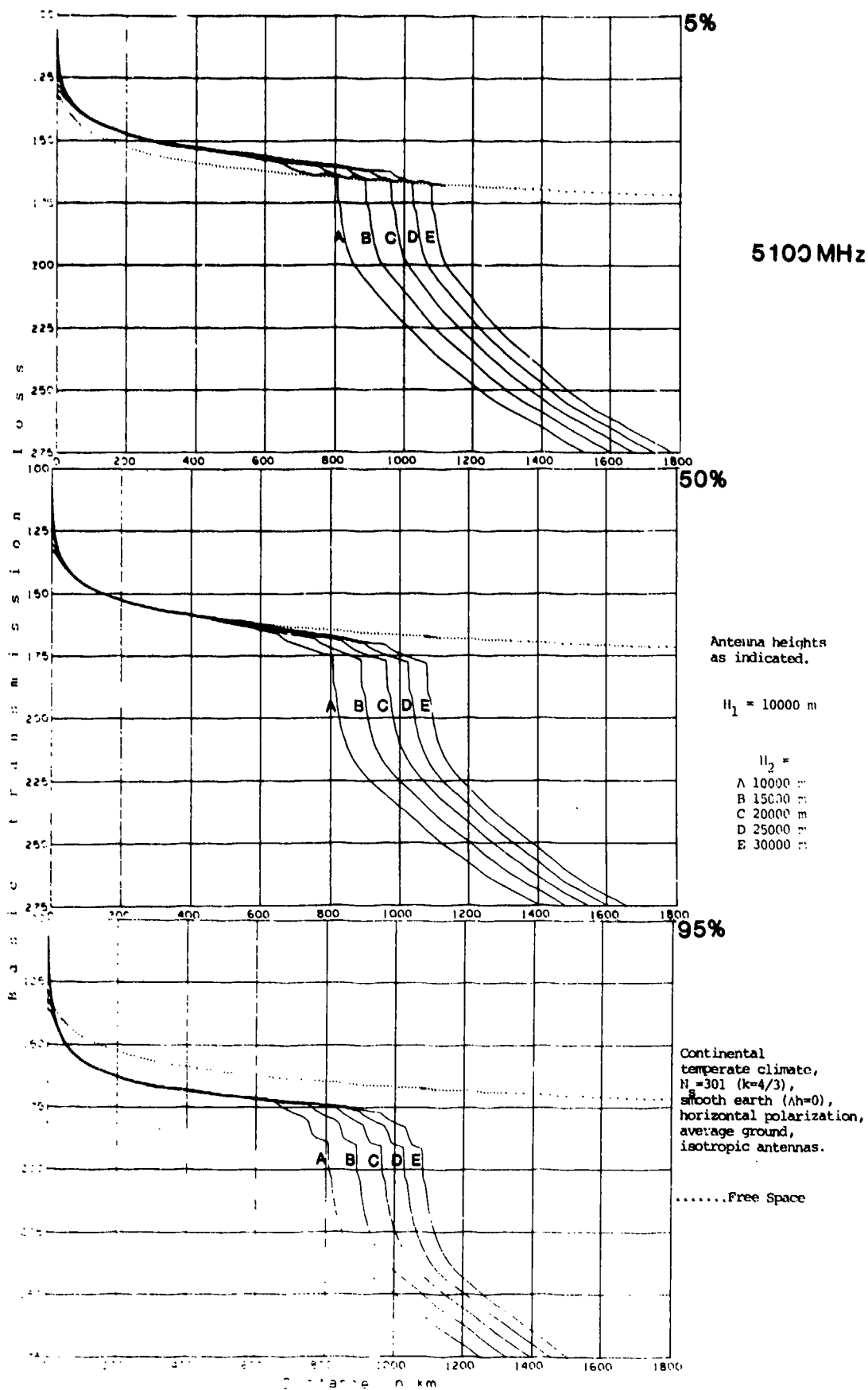


Figure 52. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 10\,000$ m.

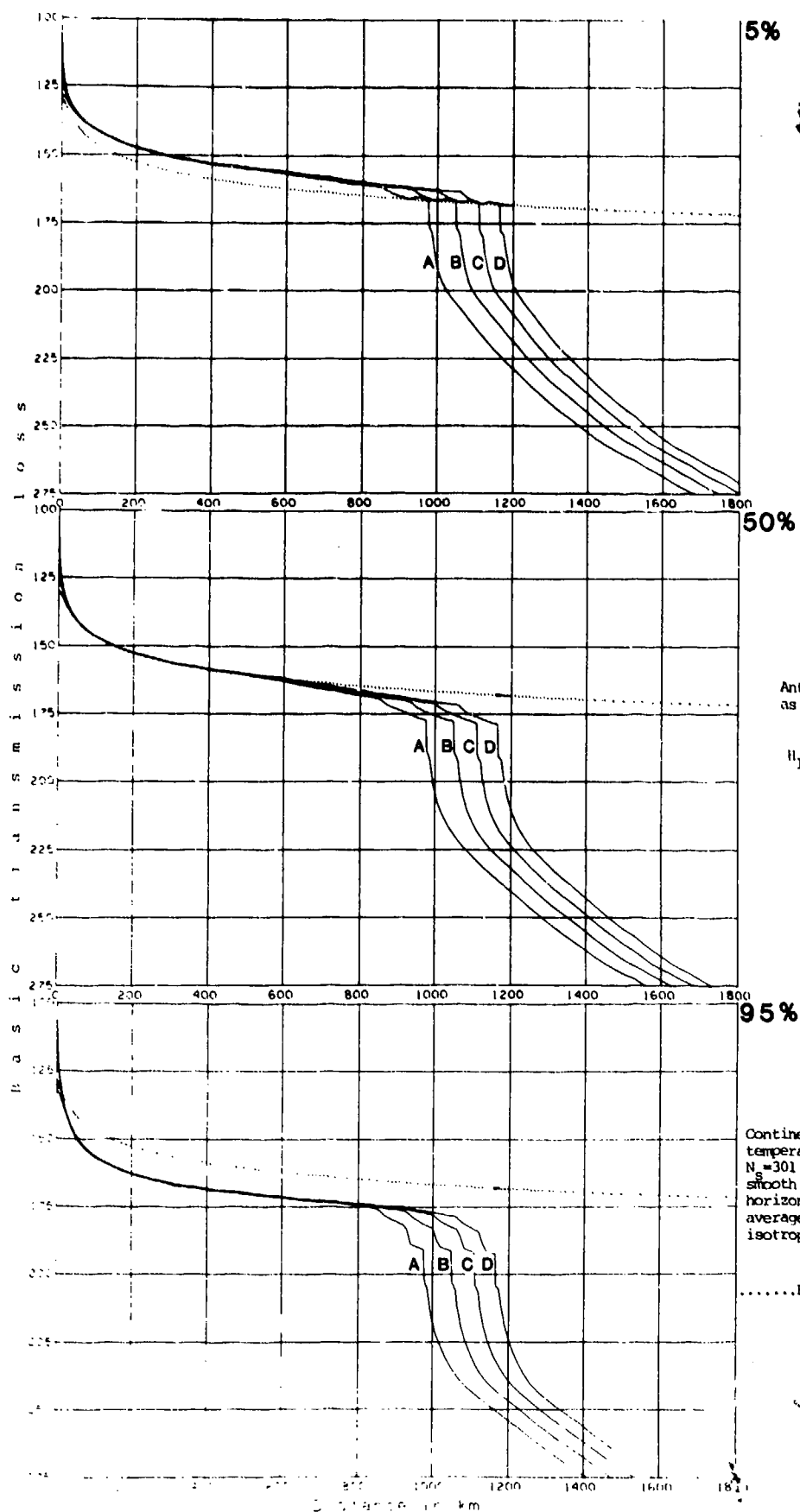


Figure 53. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 15000$ m.

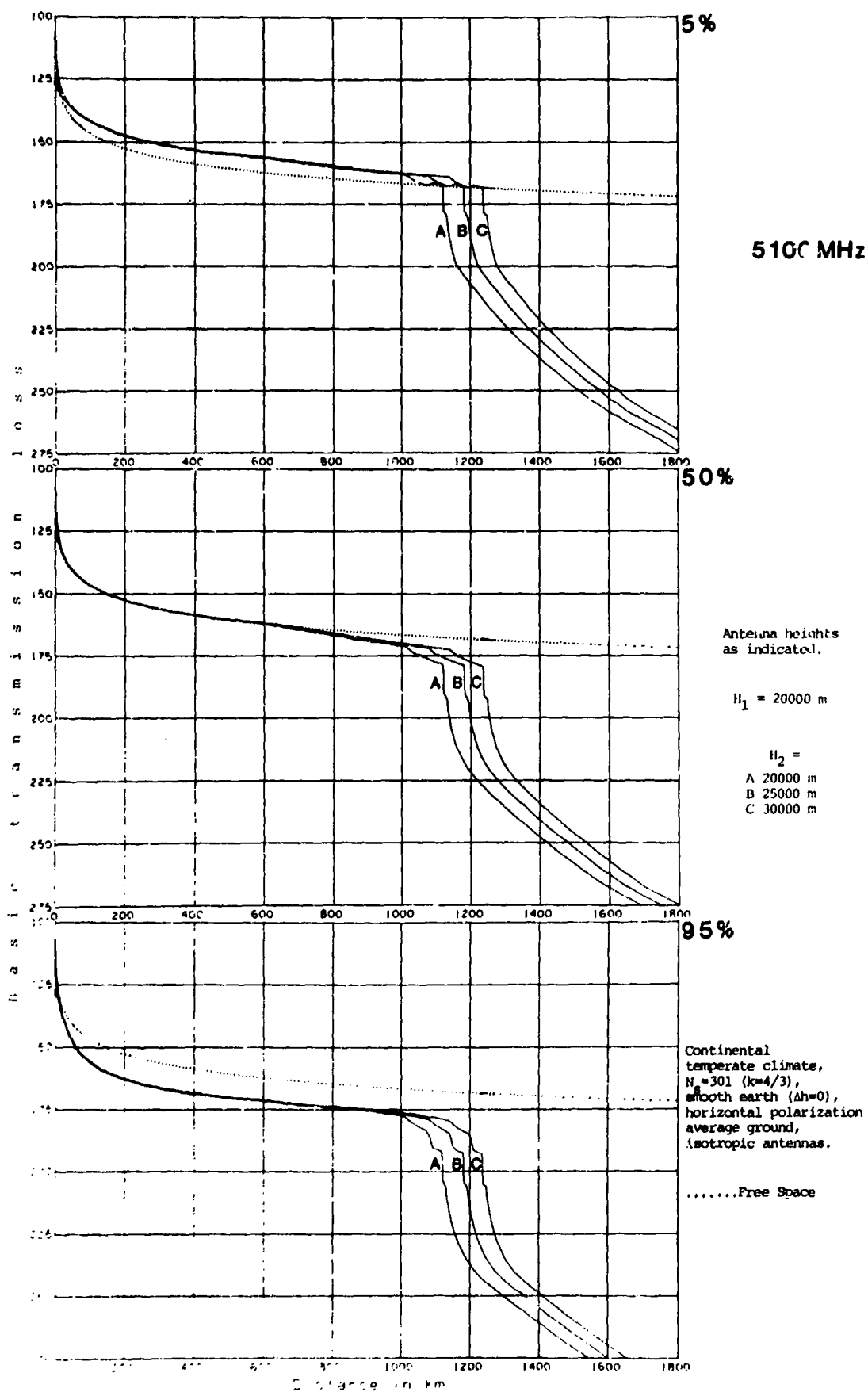


Figure 54. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 20\ 000$ m.

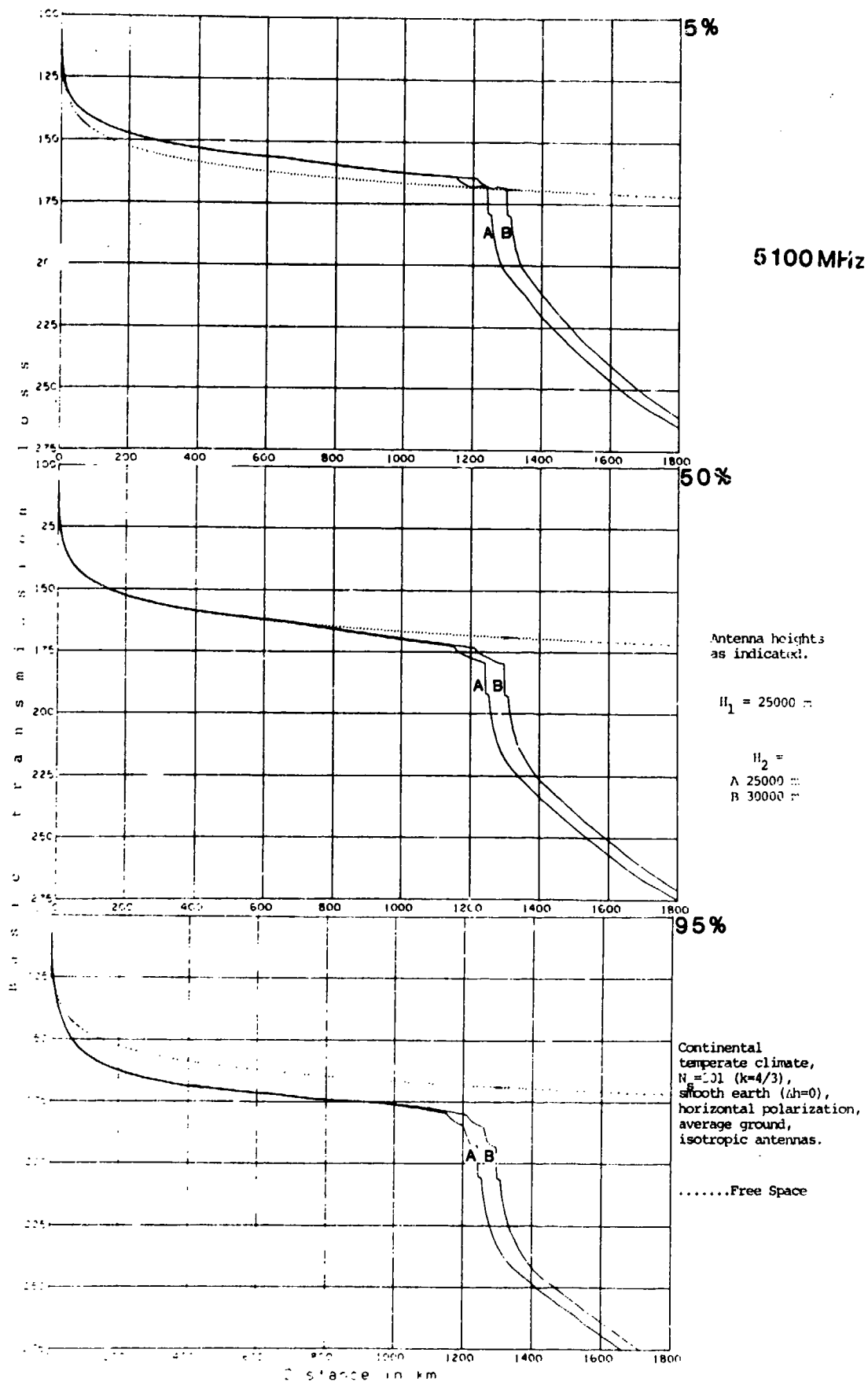


Figure 55. Basic transmission loss versus distance; $F = 5.1$ GHz, $H_1 = 25\ 000$ m.

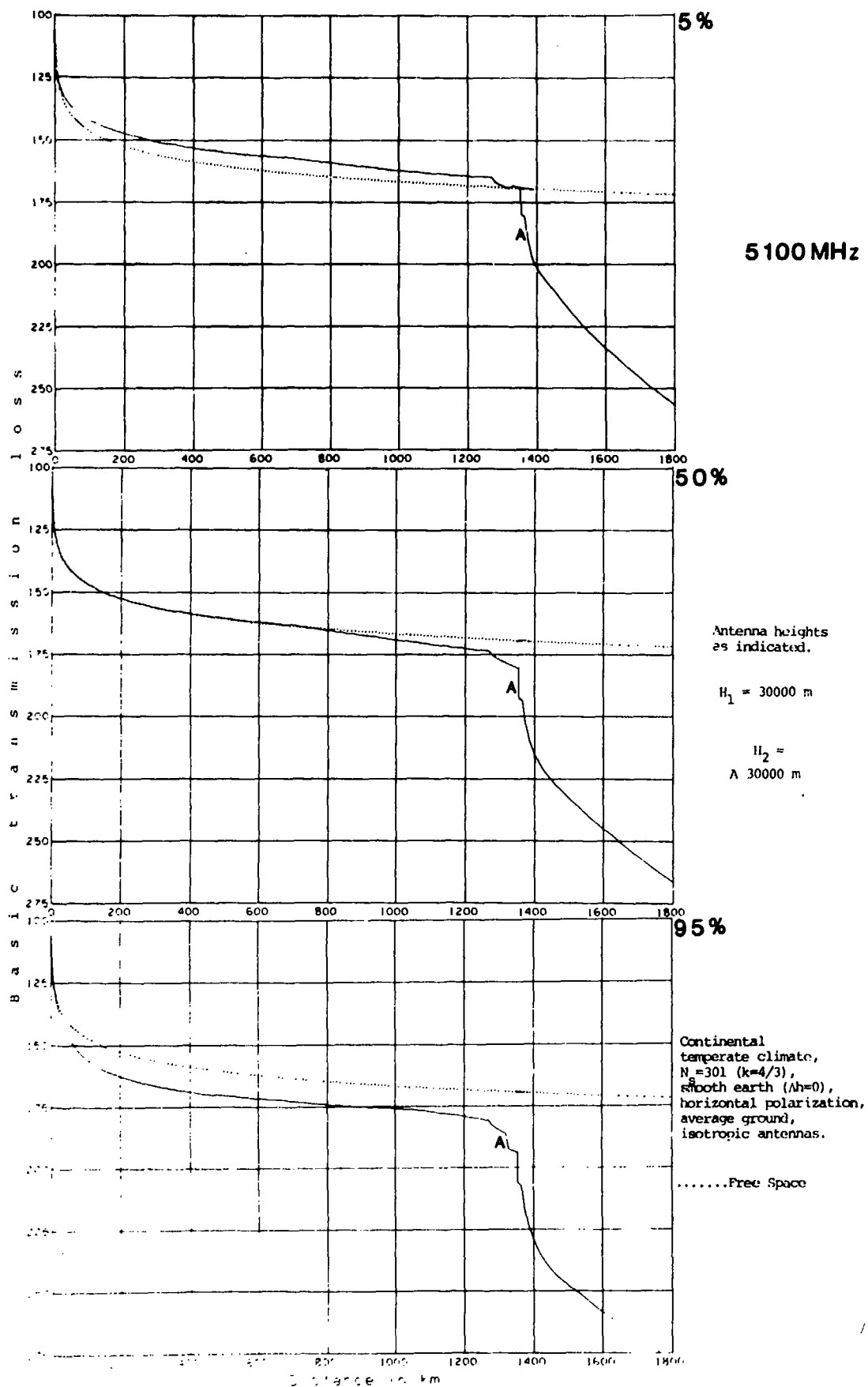


Figure 36. Basic transmission loss versus distance; $F = 5.1 \text{ GHz}$, $H_1 = 30000 \text{ m}$.

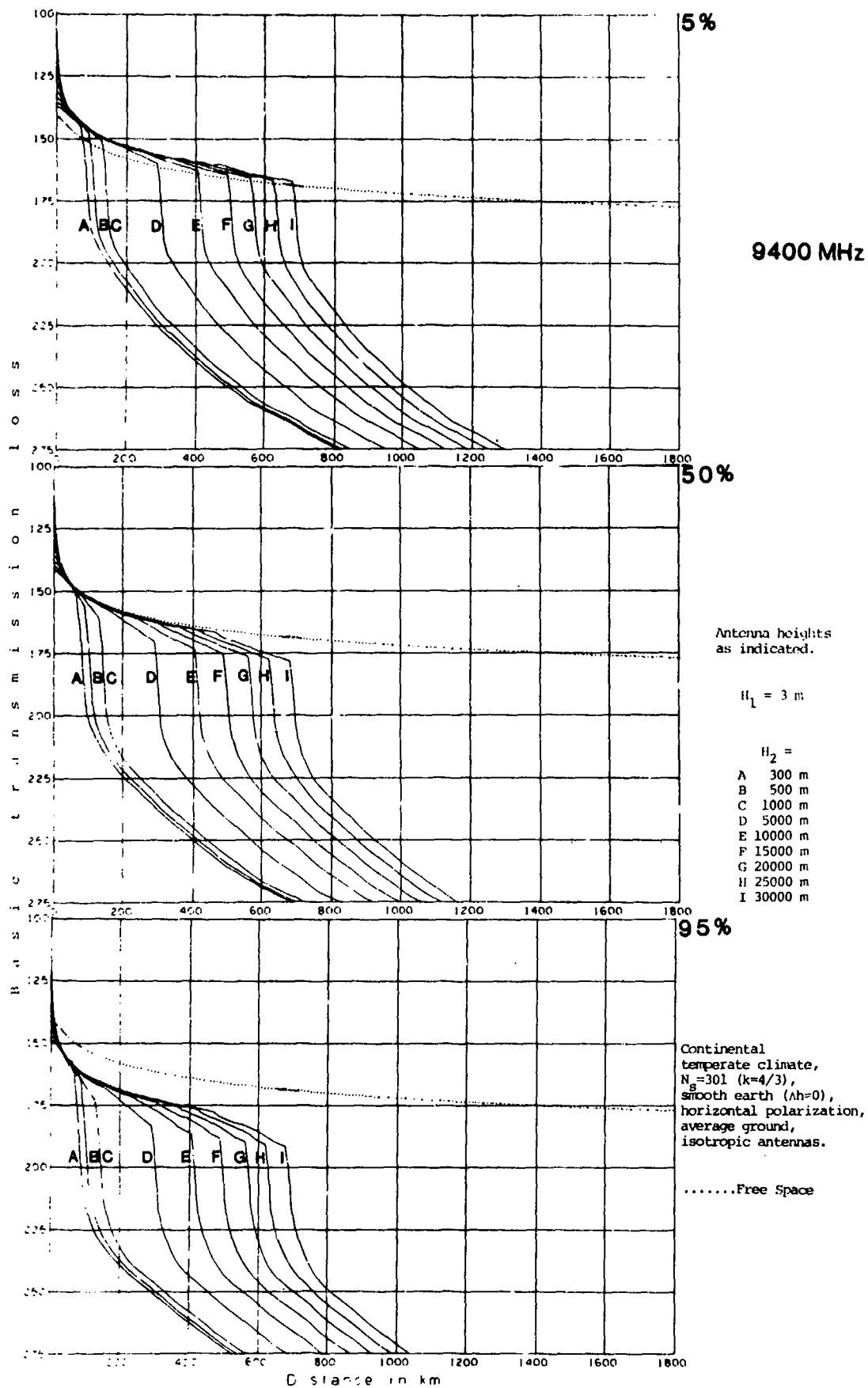


Figure 5". Basic transmission loss versus distance; $F = 9.4 \text{ GHz}$, $H_1 = 3 \text{ m}$.

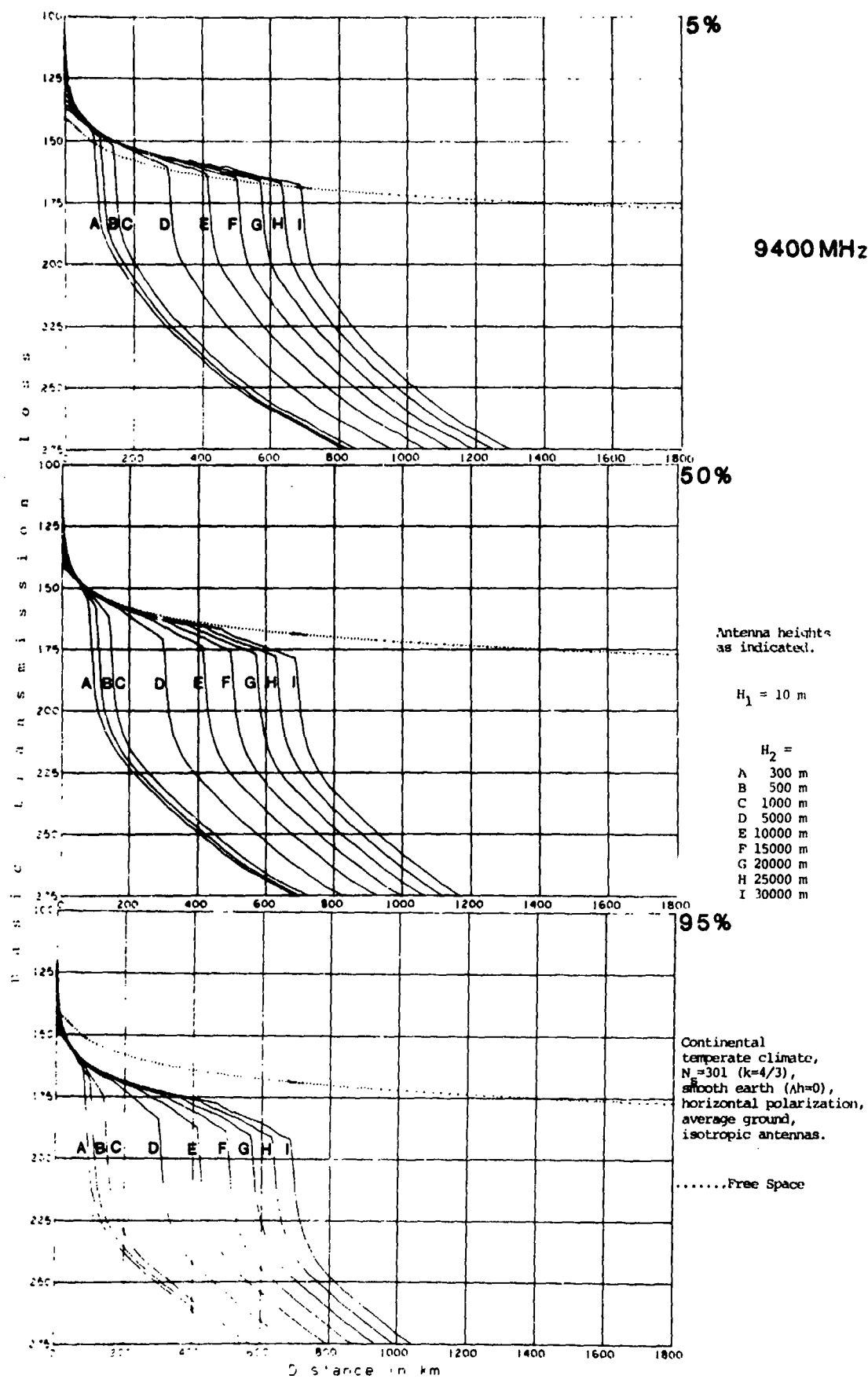


Figure 52. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 10$ m.

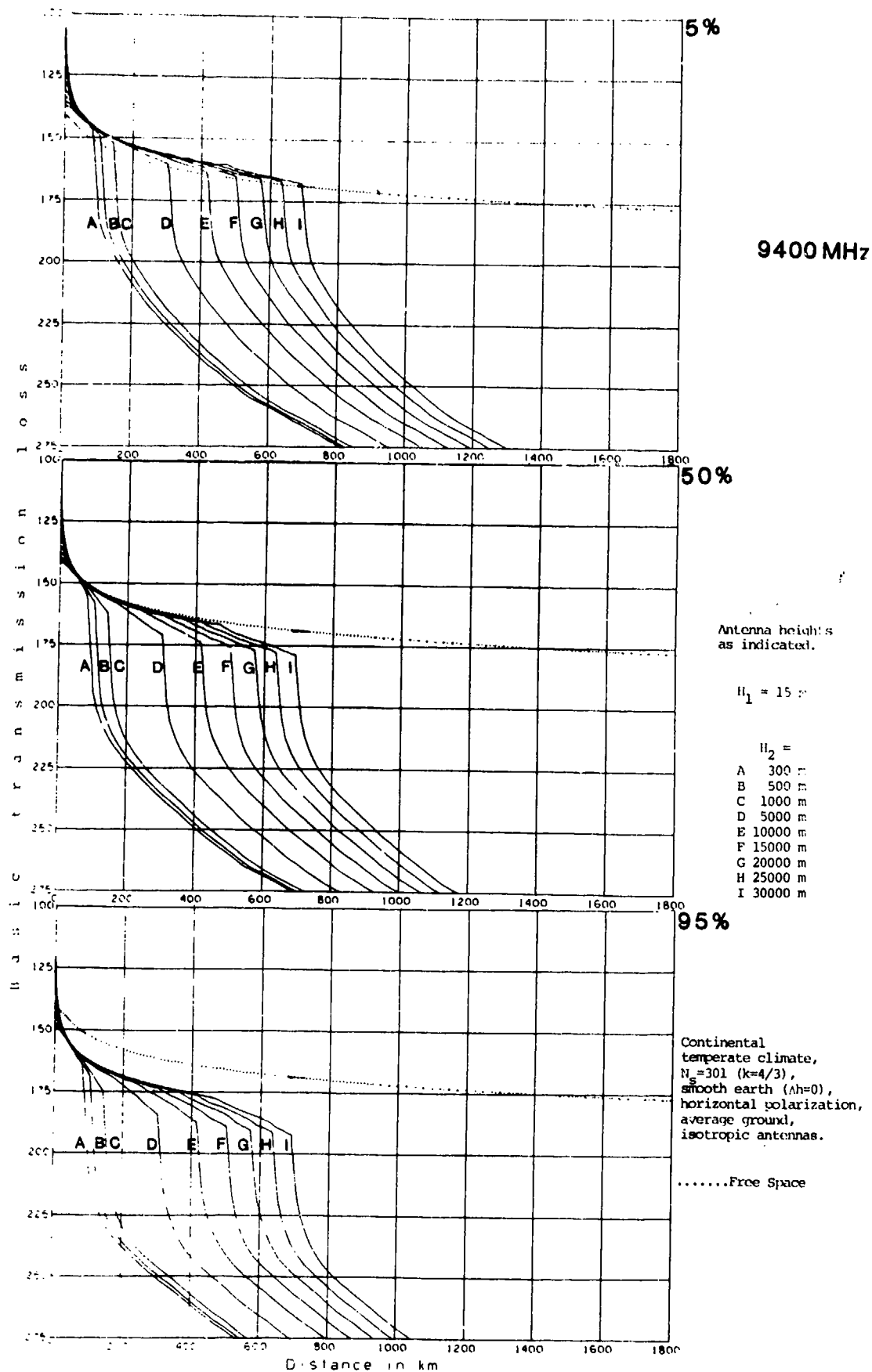


Figure 5a. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 15$ m.

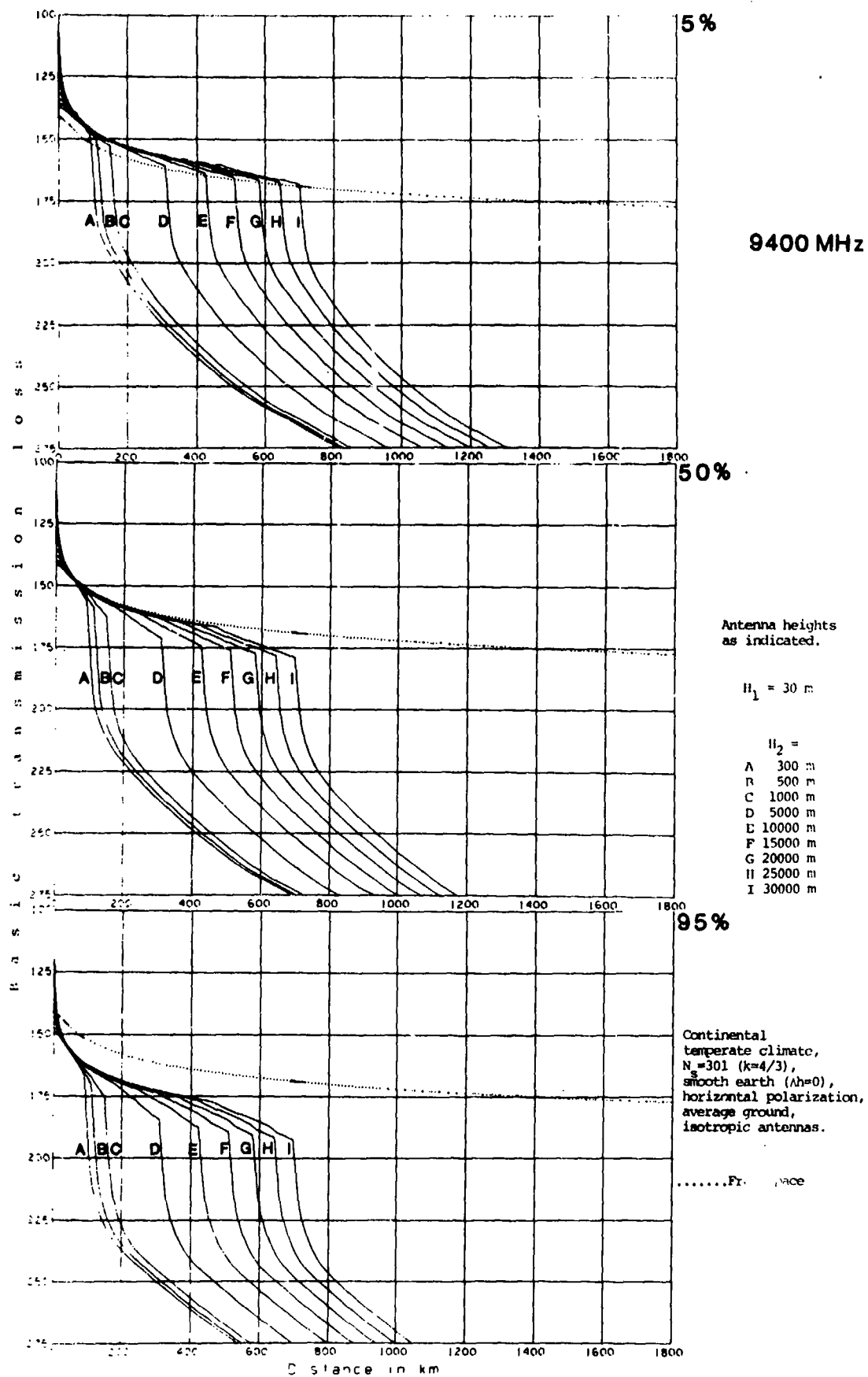


Figure 60. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 30$ m.

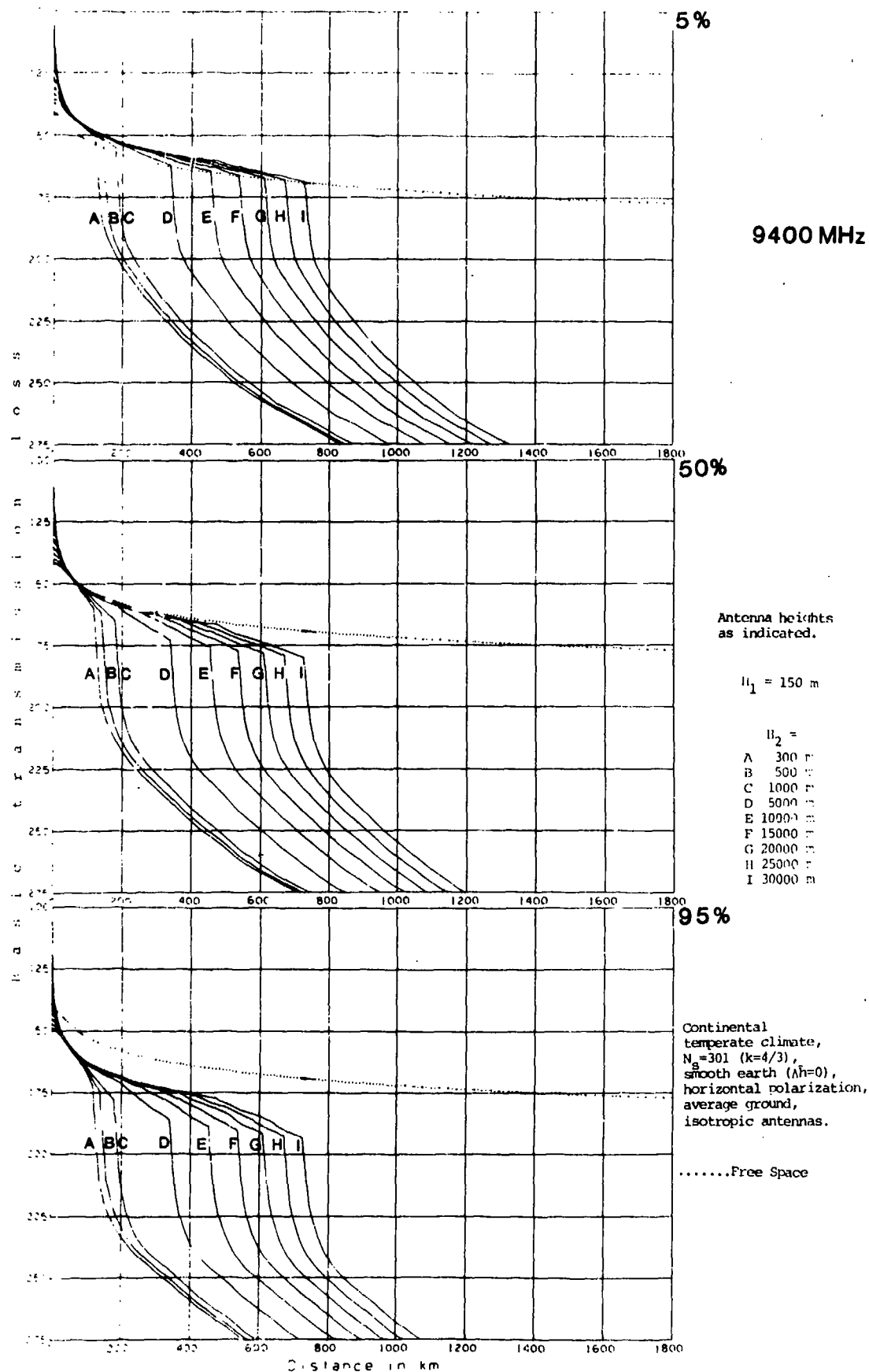


Figure 61. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 150$ m.

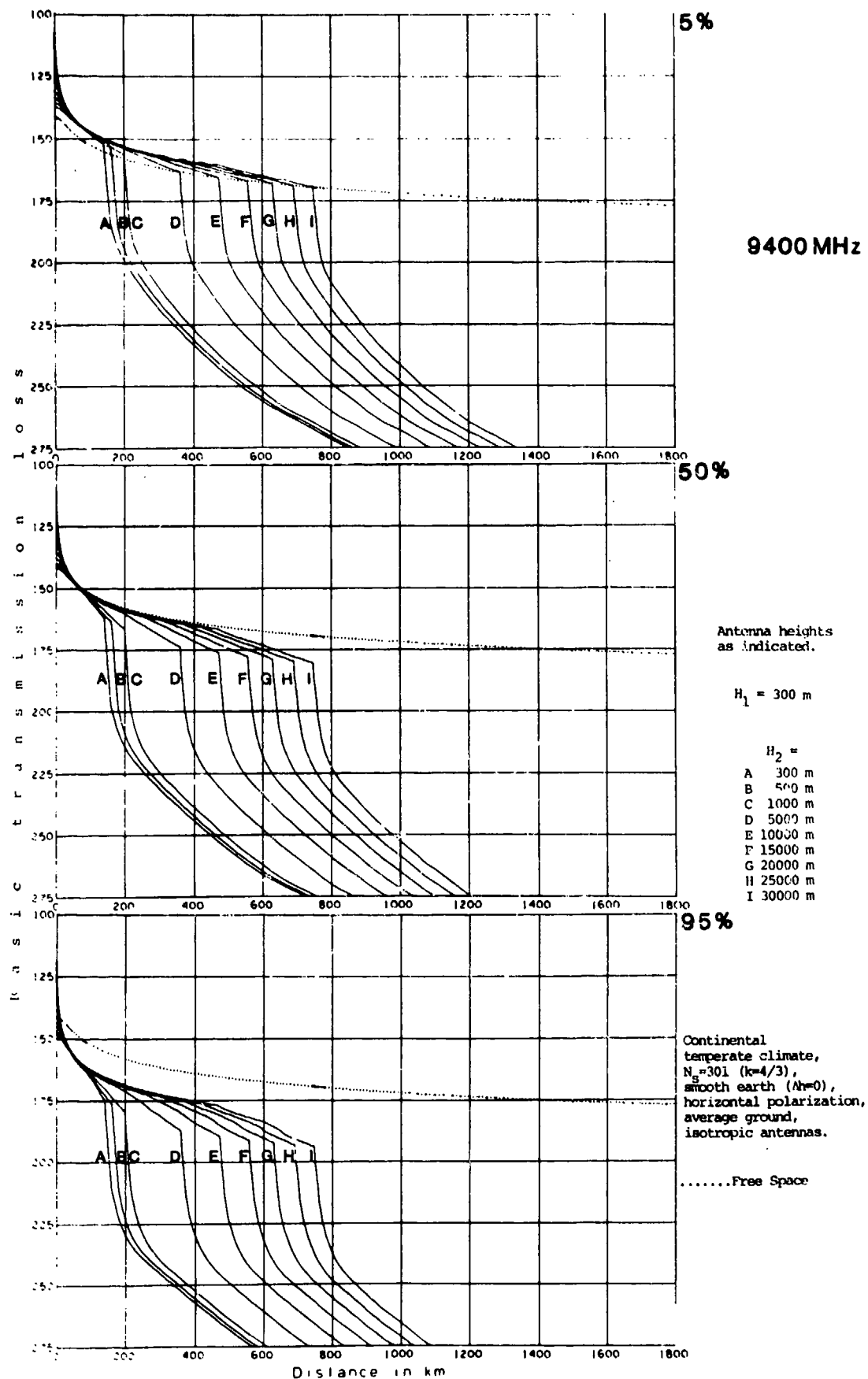


Figure 62. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 300$ m.

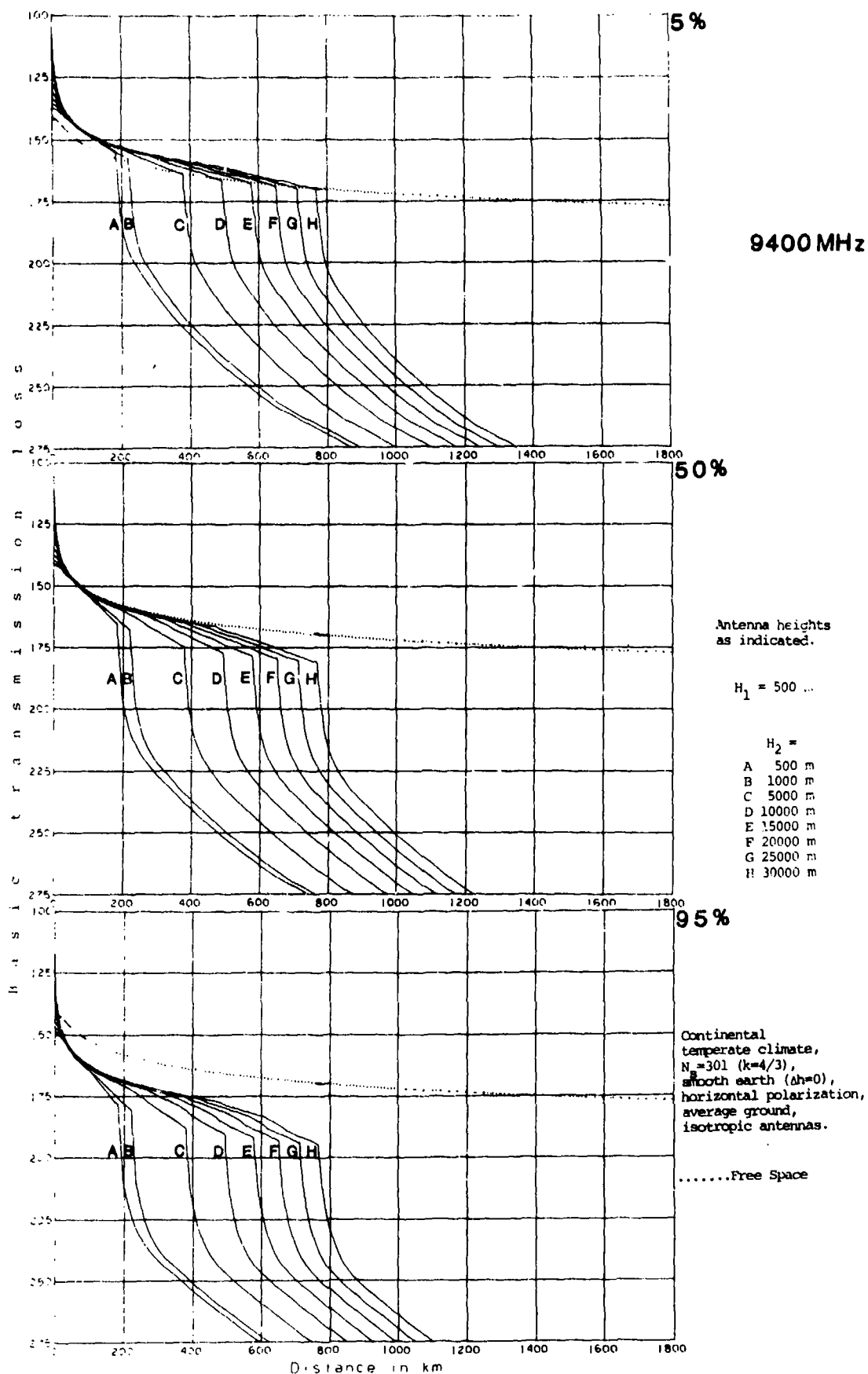


Figure 63. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 500$ m.

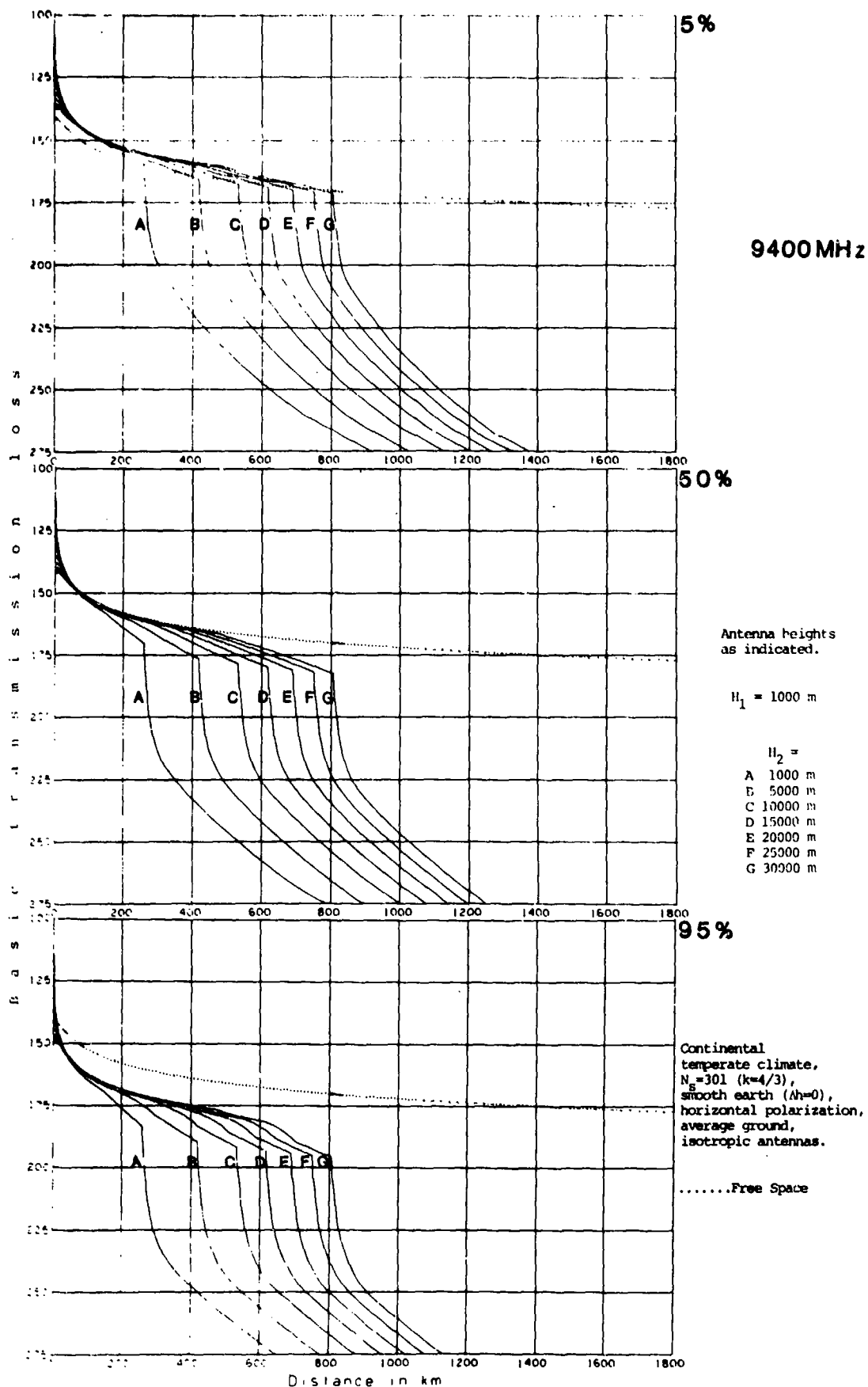


Figure 24. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 1000$ m.

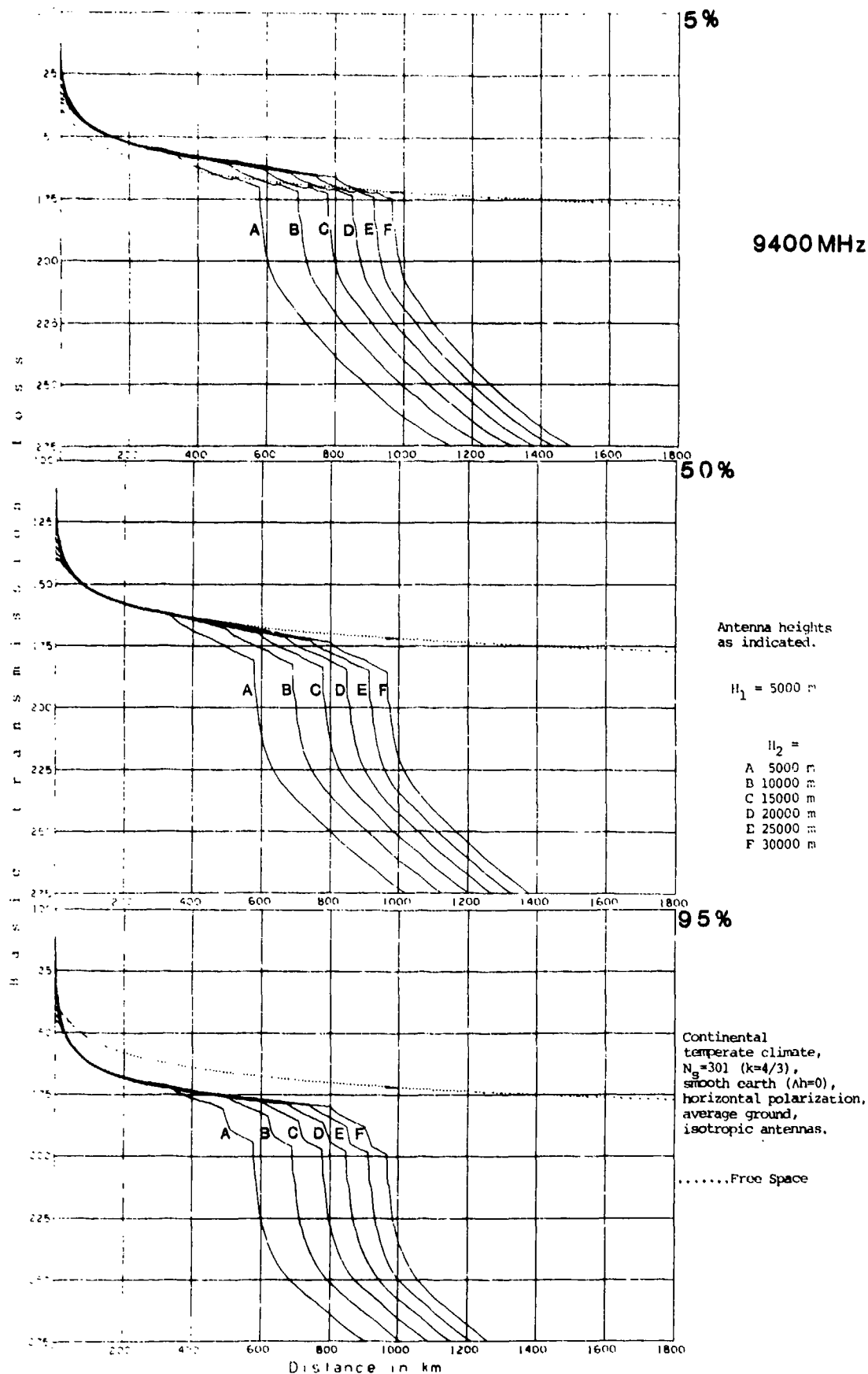


Figure 65. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 5000$ m.

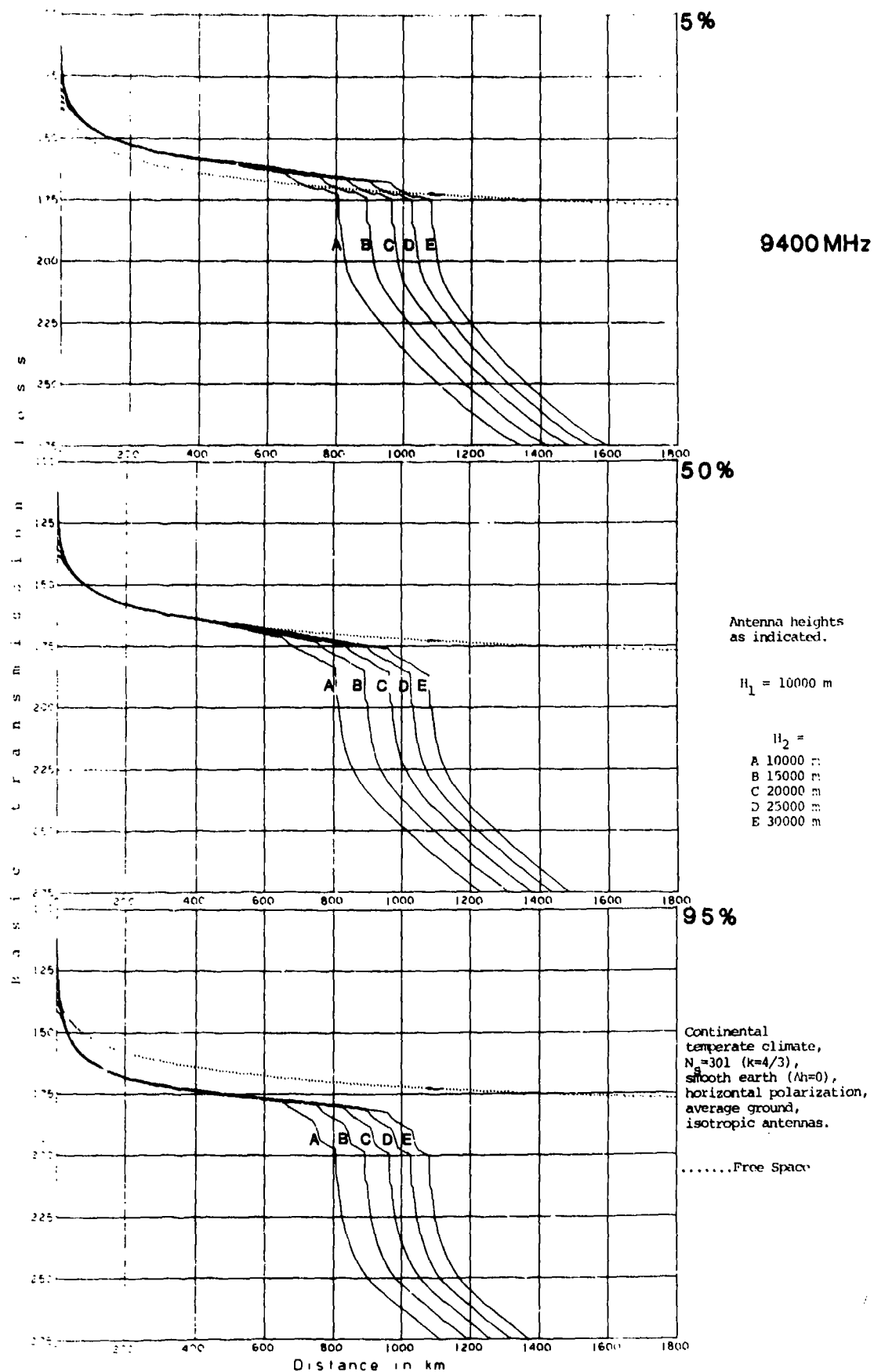


Figure 66. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 10000$ m.

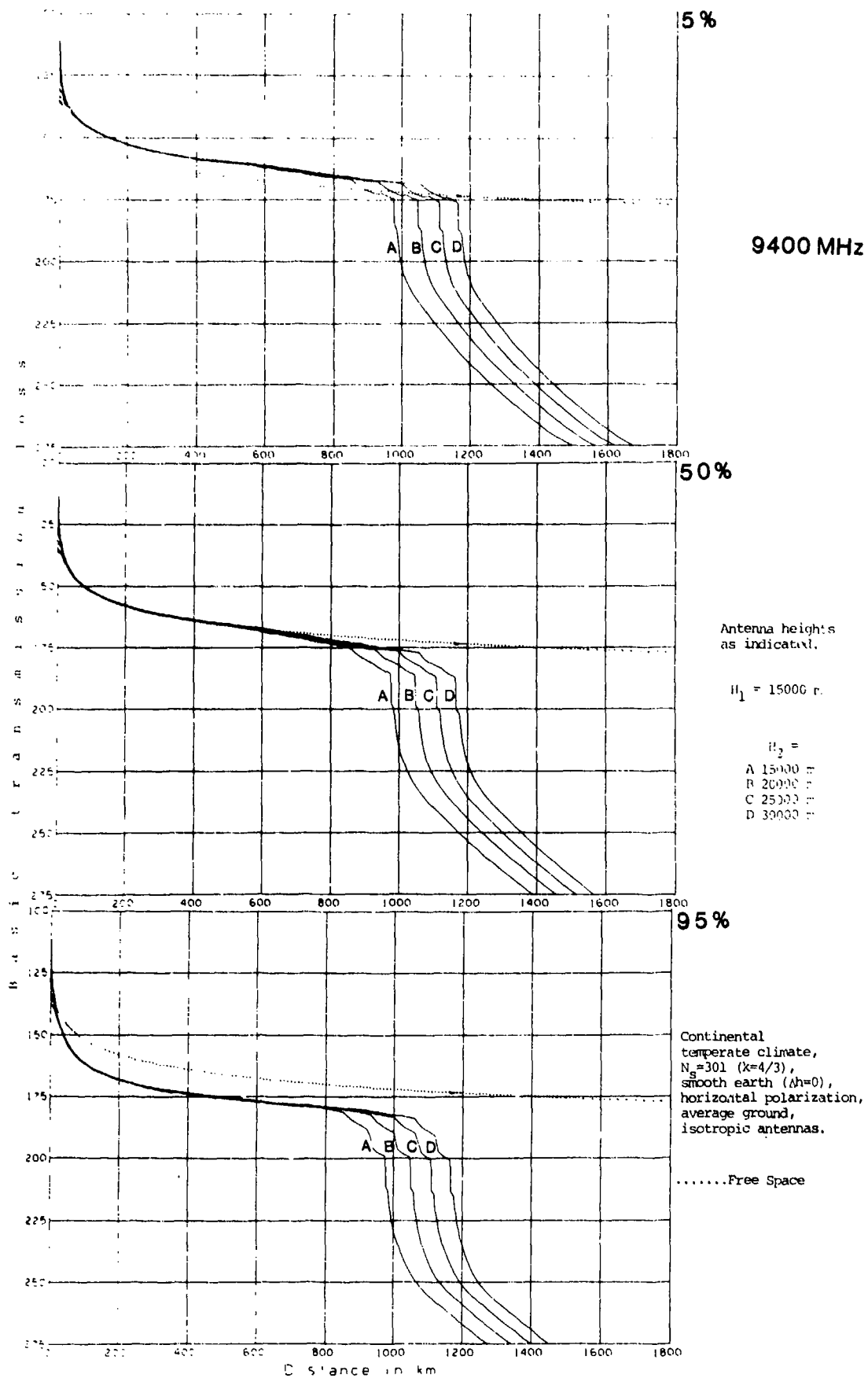
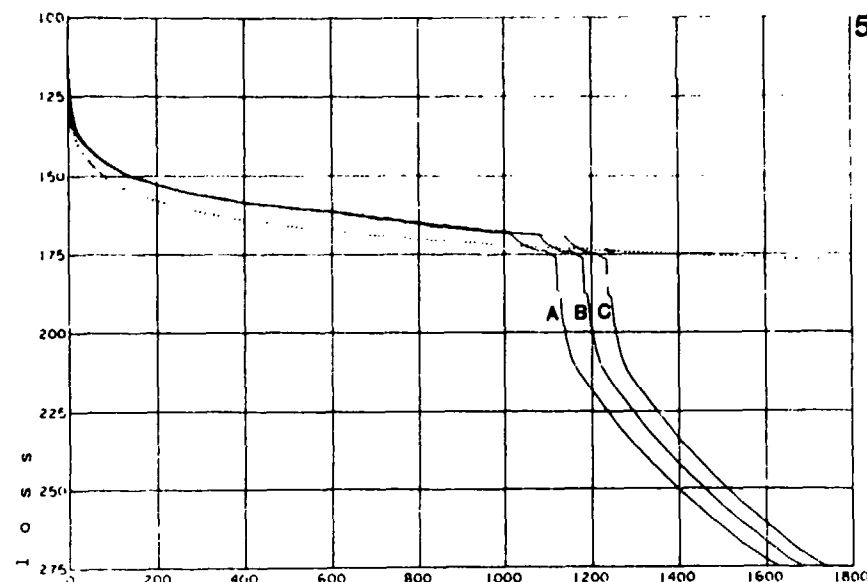
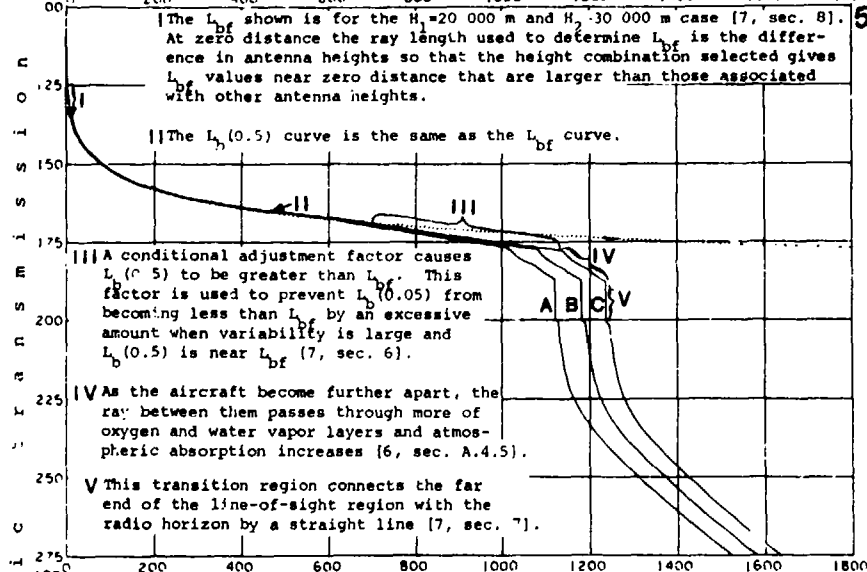


Figure 67. Basic transmission loss versus distance; $F = 9.4$ GHz, $H_1 = 15\ 000$ m.



5%

9400 MHz



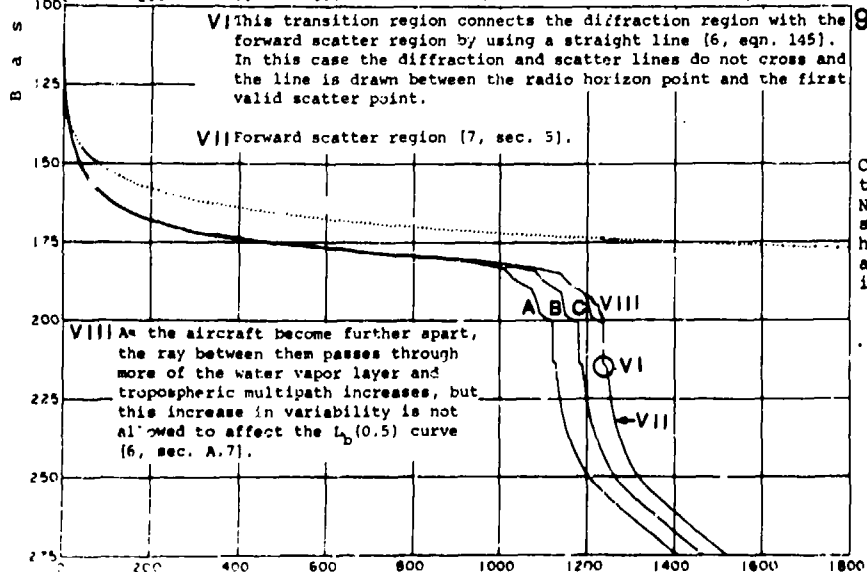
50%

Antenna heights
as indicated.

$H_1 = 20000\ m$

$H_2 =$

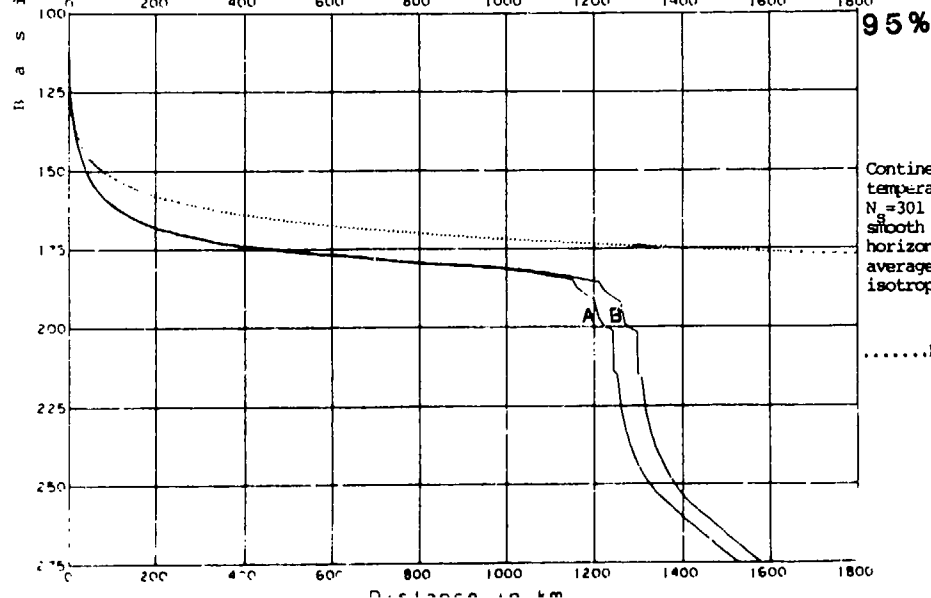
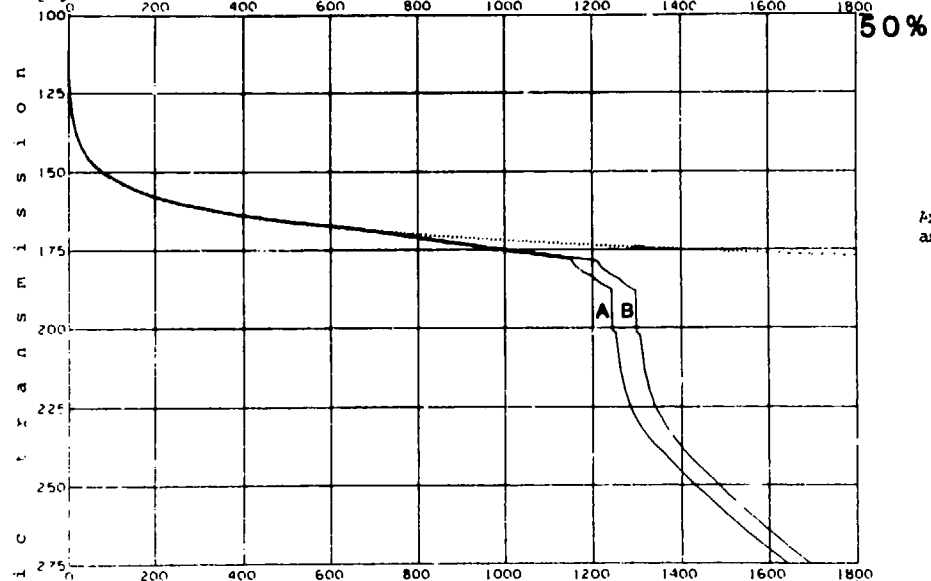
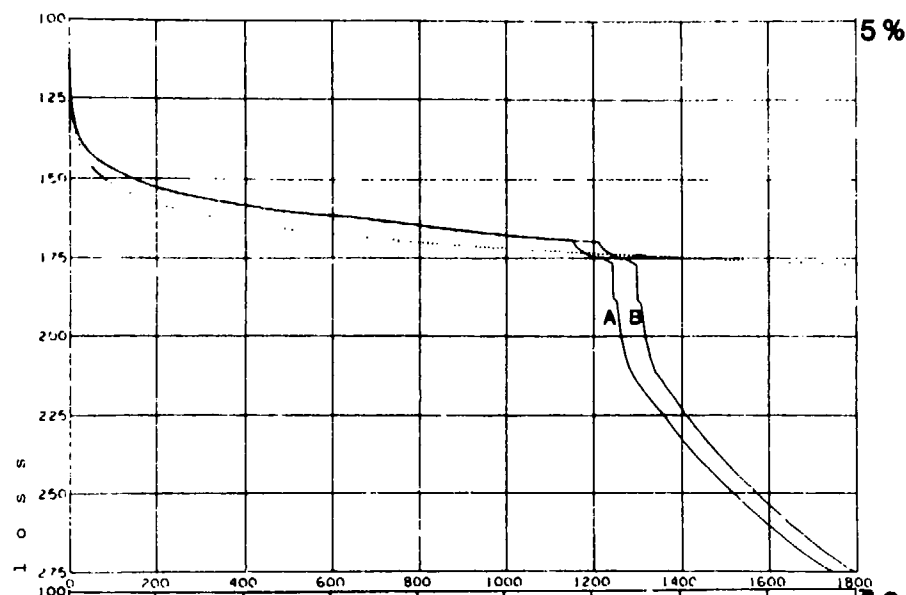
A 20000 m
B 25000 m
C 30000 m

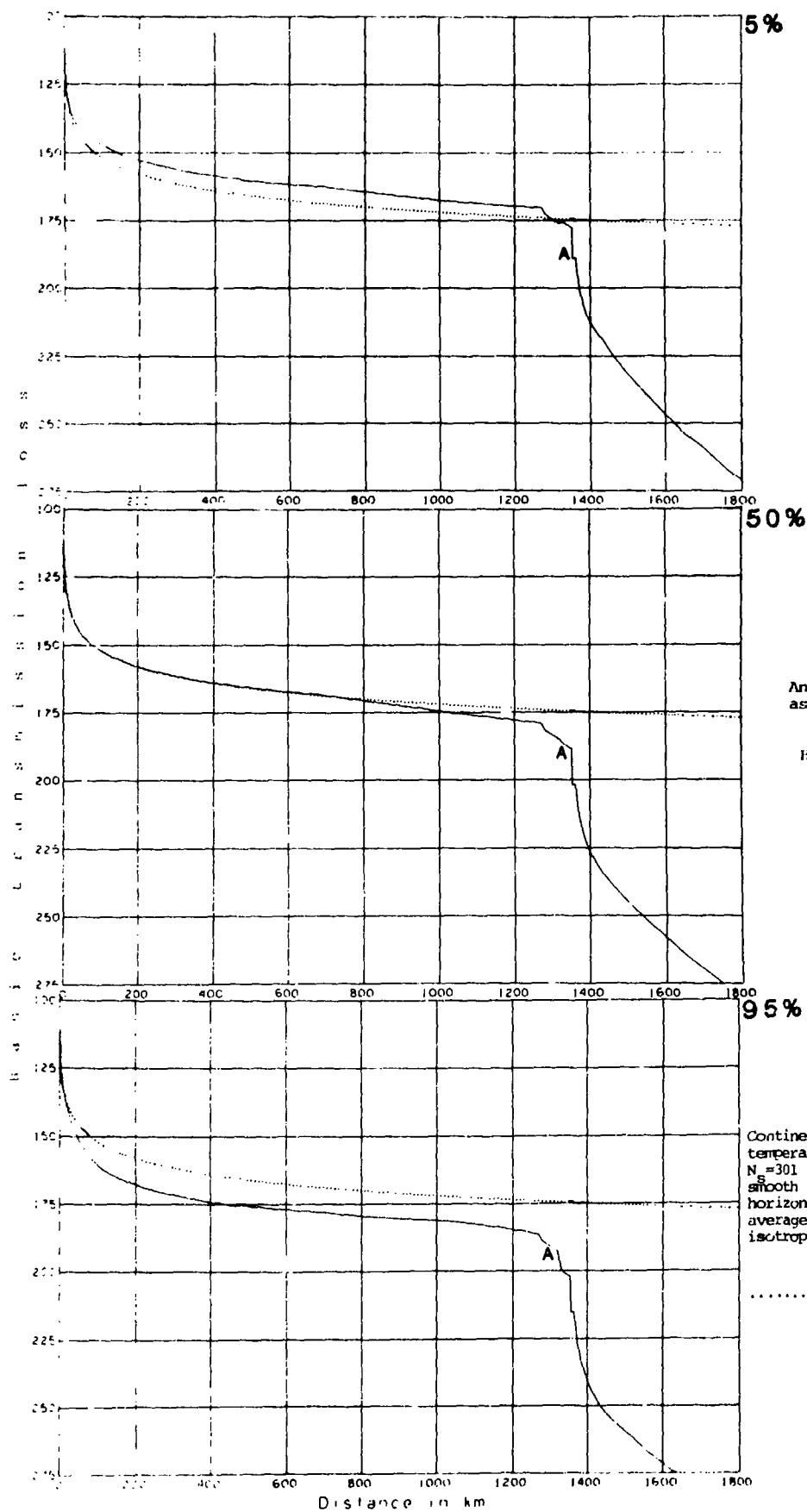


95%

Continental
temperate climate,
 $N_s=301$ ($k=4/3$),
smooth earth ($\Delta h=0$),
horizontal polarization,
average ground,
isotropic antennas.

.....Free Space





9400 MHz

Antenna heights
as indicated.

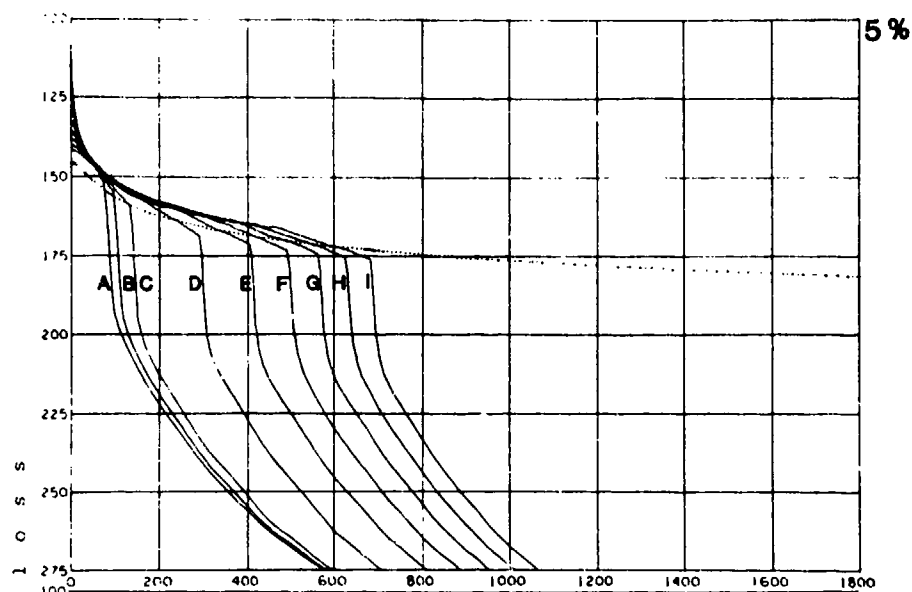
$H_1 = 30000$ m

$H_2 =$
A 30000 m

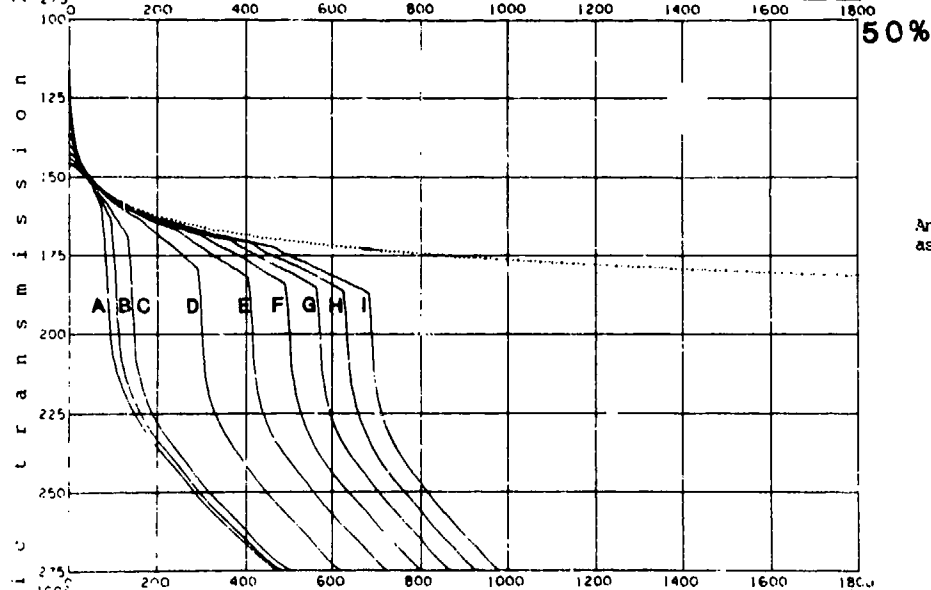
Continental
temperate climate,
 $N=301$ ($k=4/3$),
smooth earth ($h=0$),
horizontal polarization,
average ground,
isotropic antennas.

.....Free Space

Distance in km



15500 MHz

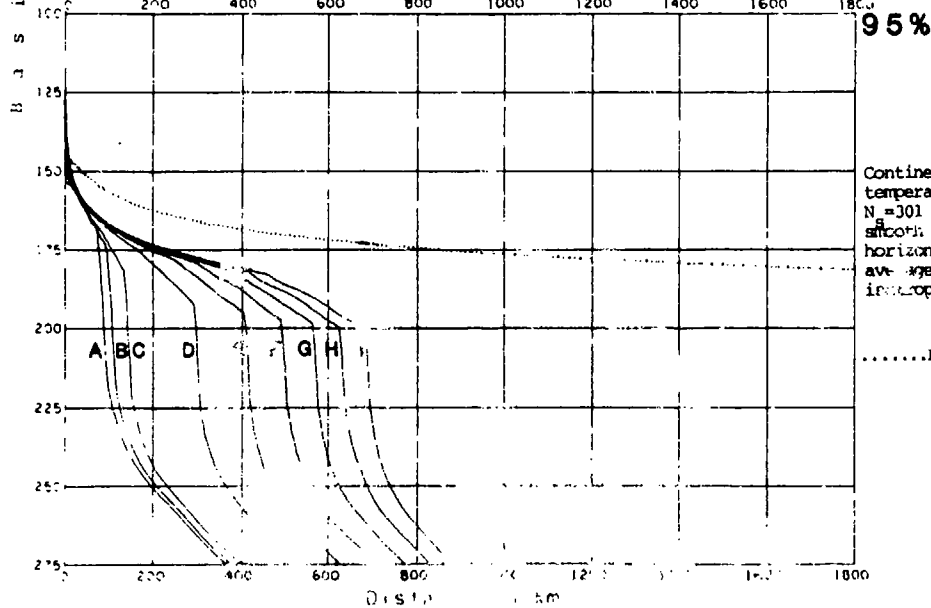


Antenna heights
as indicated.

$$H_1 = 3 \text{ m}$$

$$H_2 =$$

- A 300 m
- B 500 m
- C 1000 m
- D 5000 m
- E 10000 m
- F 15000 m
- G 20000 m
- H 25000 m
- I 30000 m



Continental
temperate climate,
 $N = 301$ ($k=4/3$),
smooth earth ($\Delta h=0$),
horizontal polarization,
average ground,
isotropic antennas.

.....Free Space

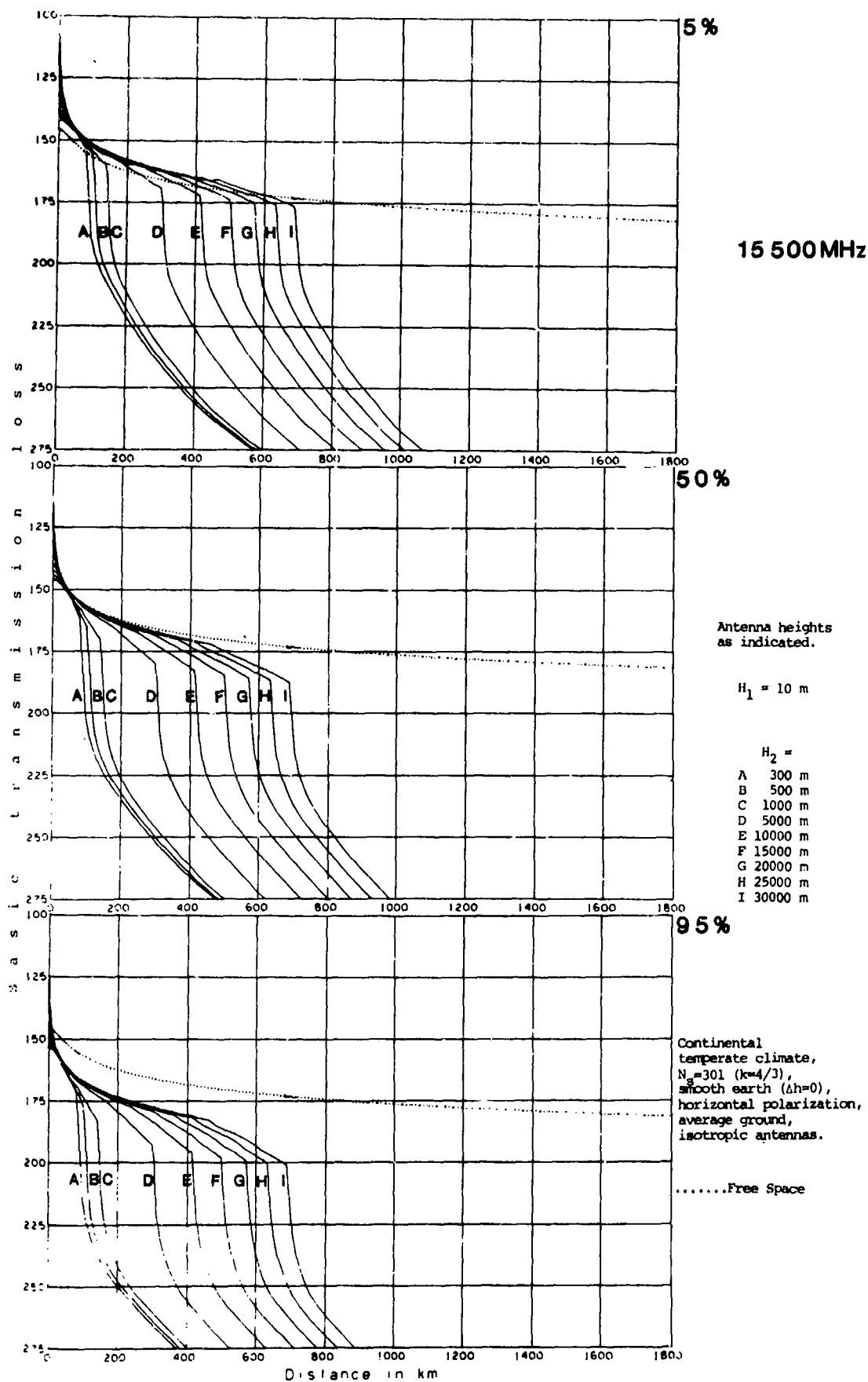


Figure 72 Basic Atmospheric Loss Models for 15,500 MHz

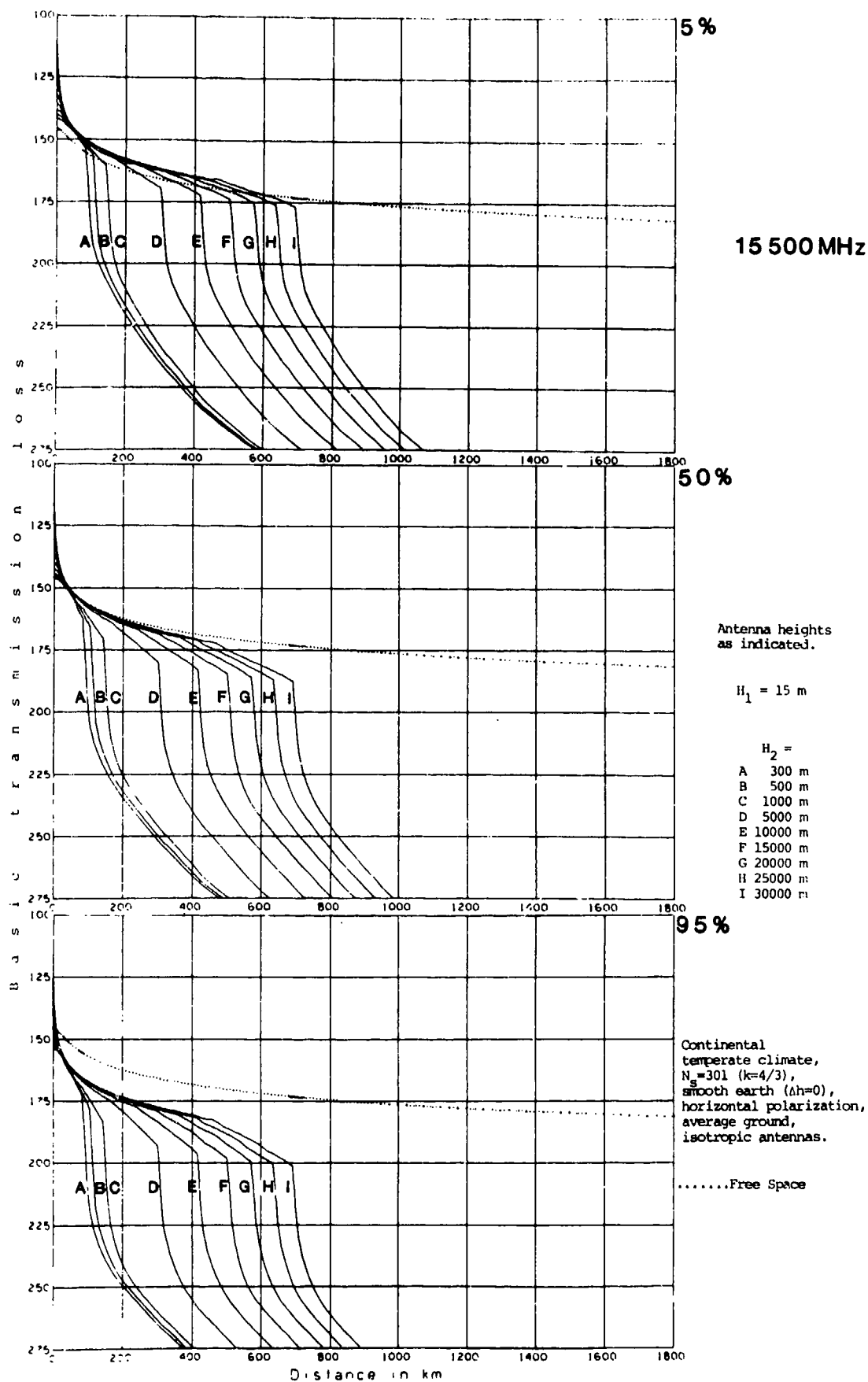


Figure 73. Basic transmission loss versus distance; $F = 15.5 \text{ GHz}$, $H_1 = 15 \text{ m}$.

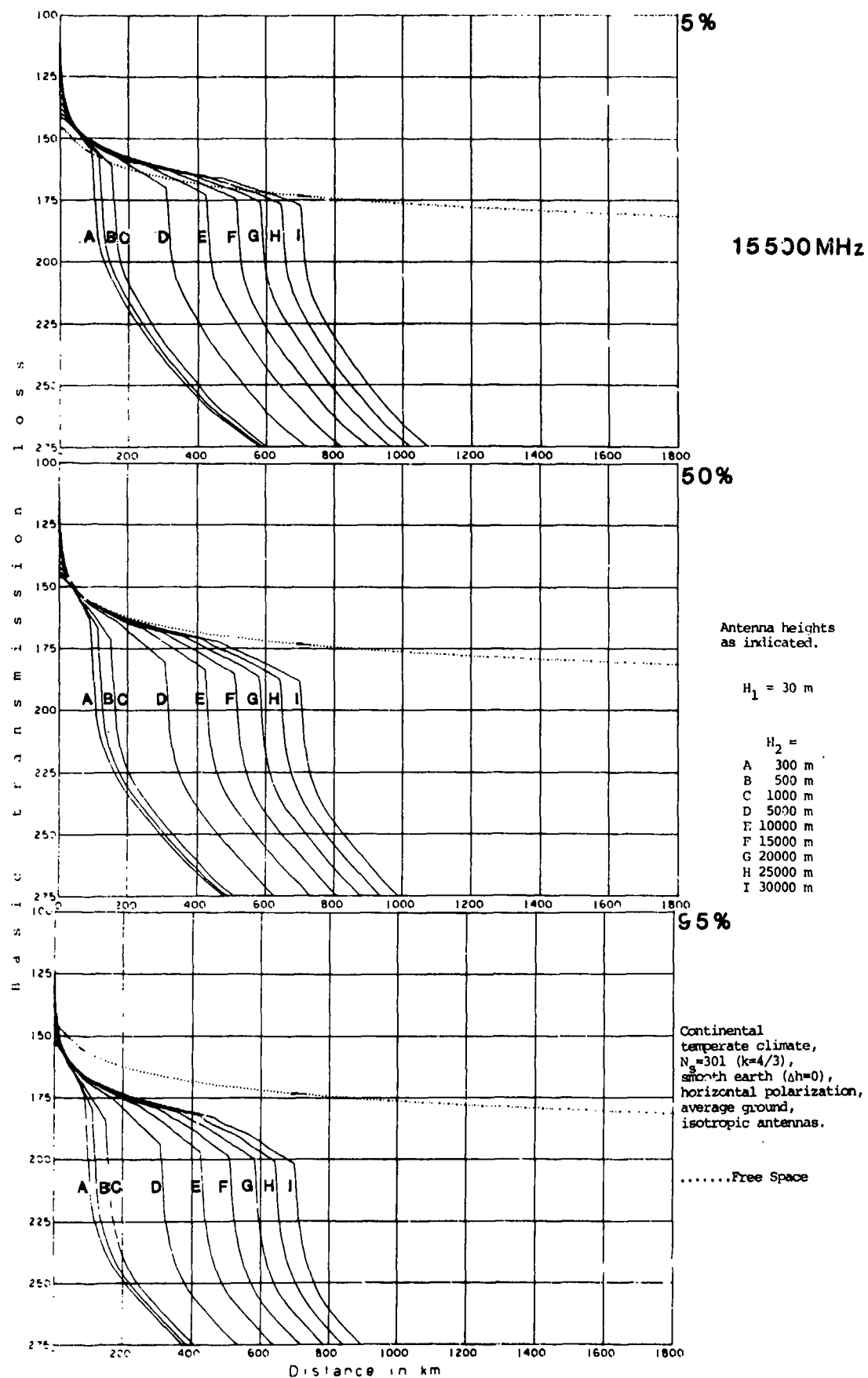


Figure 74. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 30$ m.

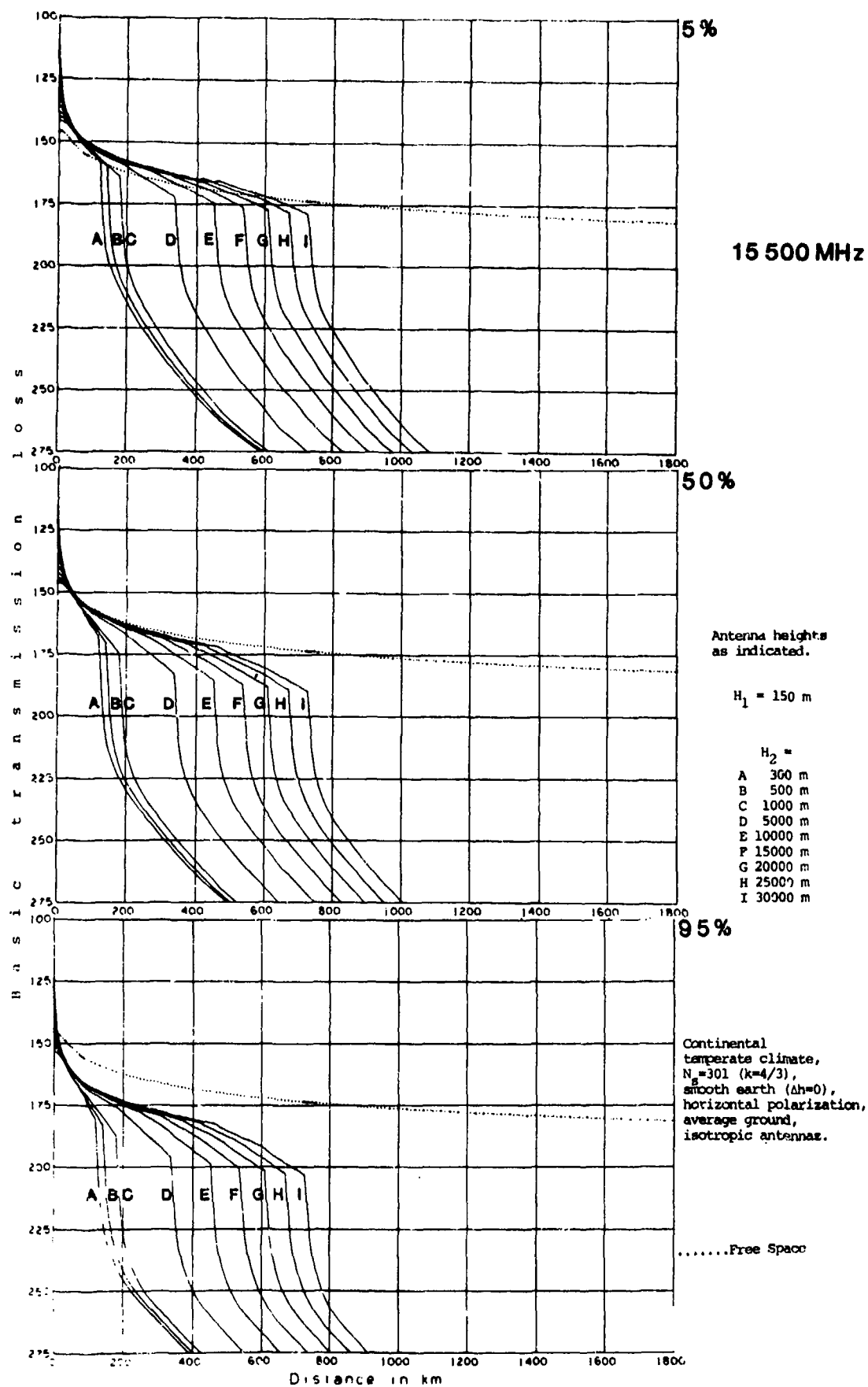
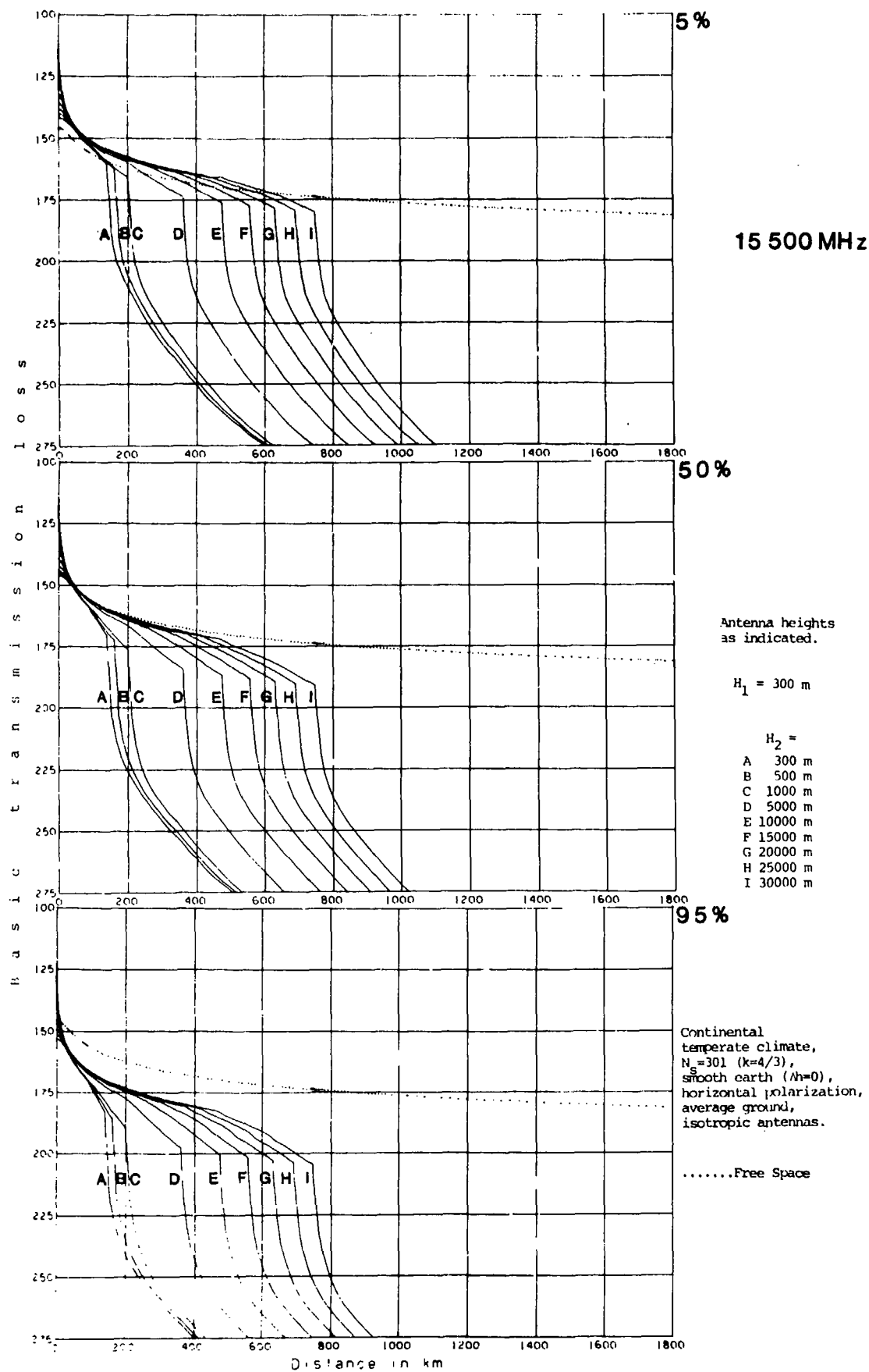


Figure 75. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 150$ m.



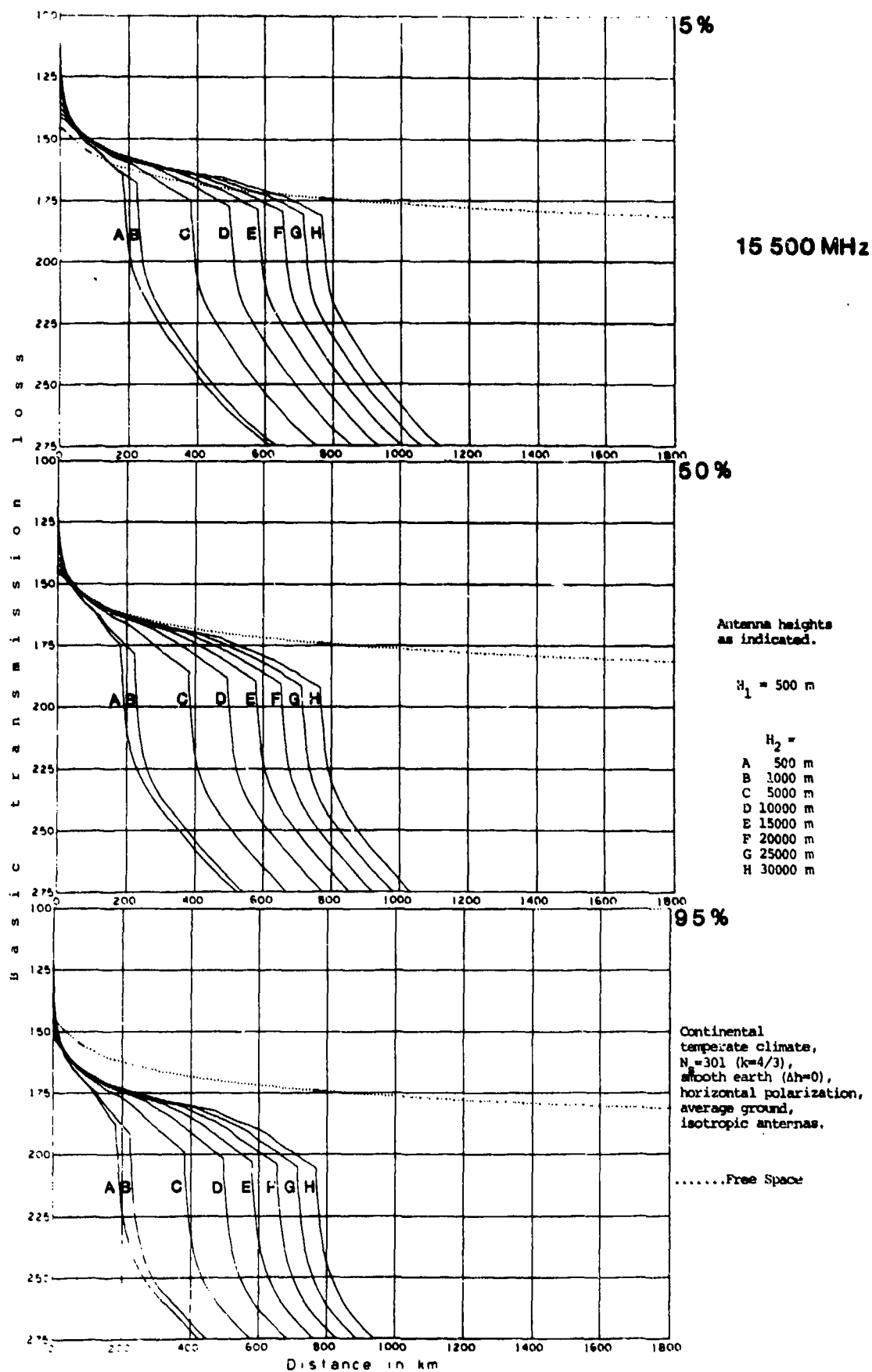


Figure 77. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 500$ m.

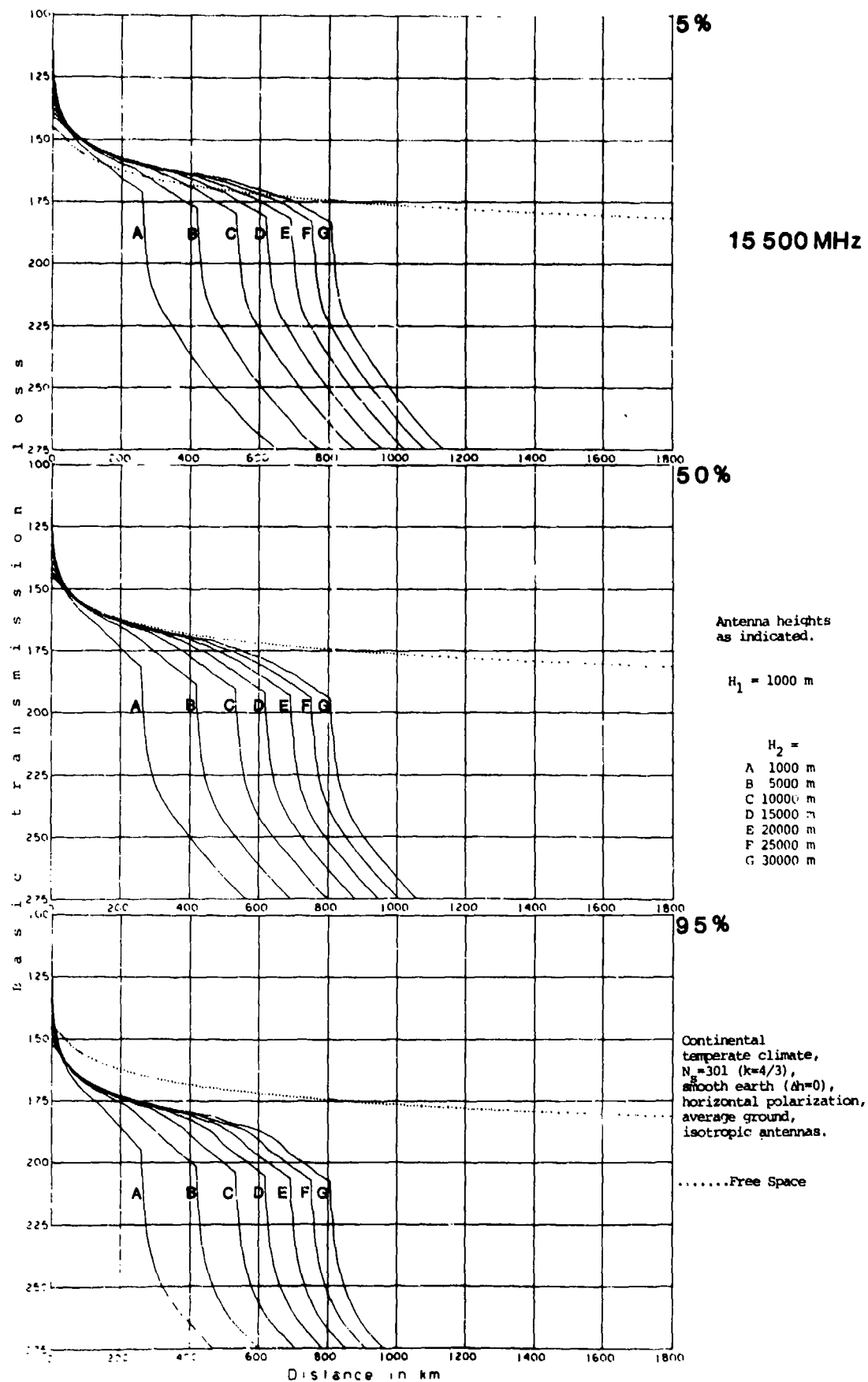


Figure 79. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 1000$ m.

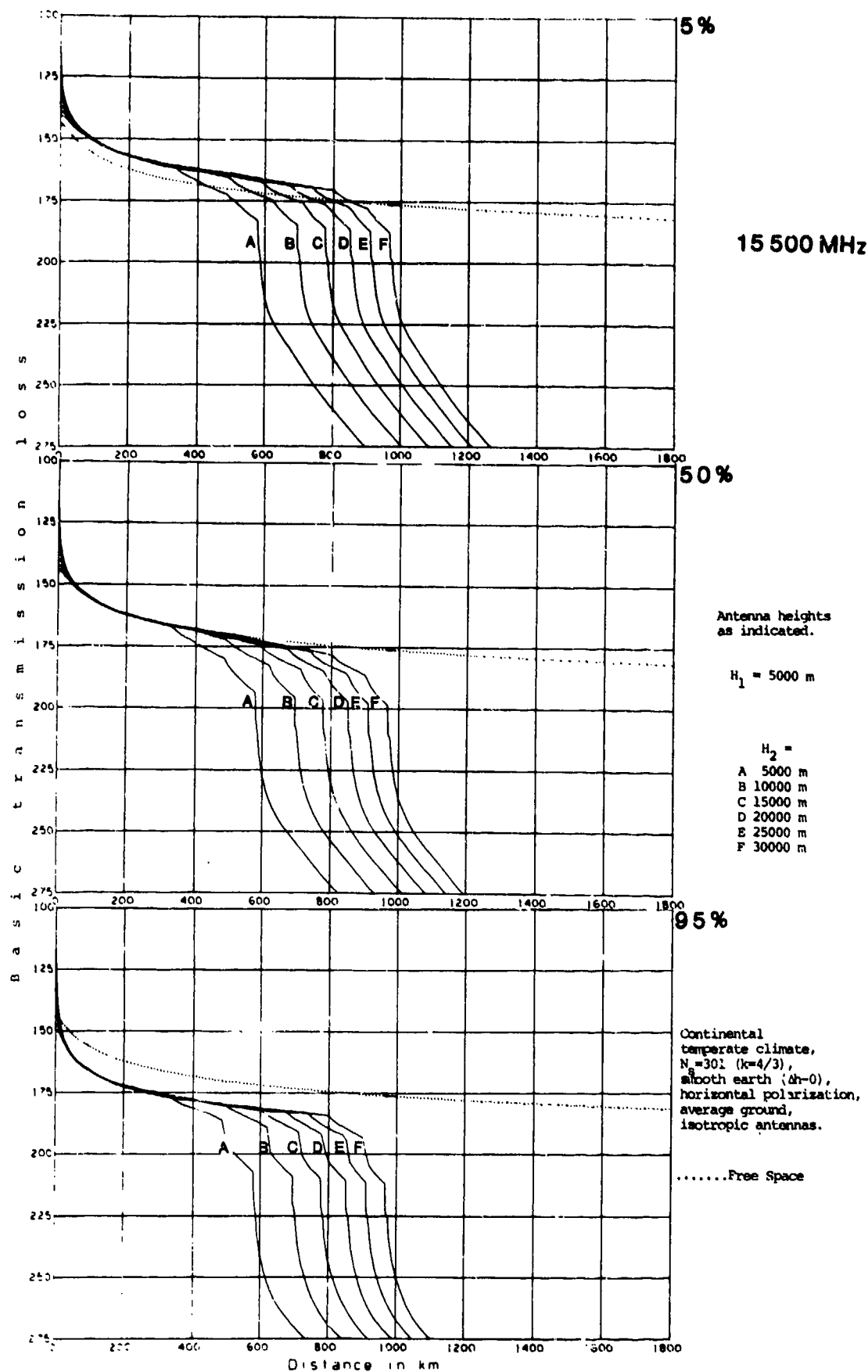


Figure 79. Basic transmission loss versus distance; $F = 15.5 \text{ GHz}$, $H_1 = 5000 \text{ m}$.

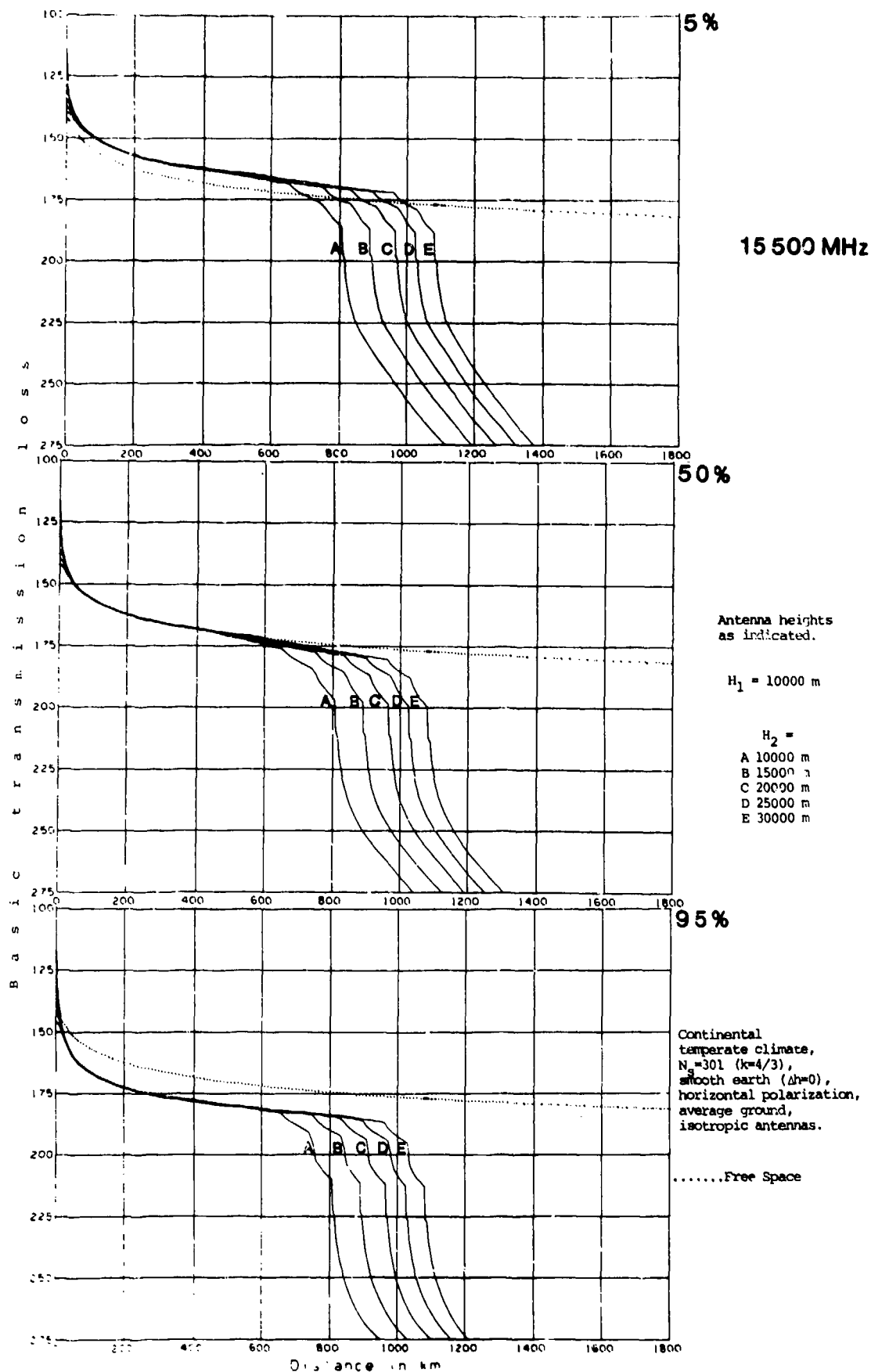


Figure 30. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 10\,000$ m.

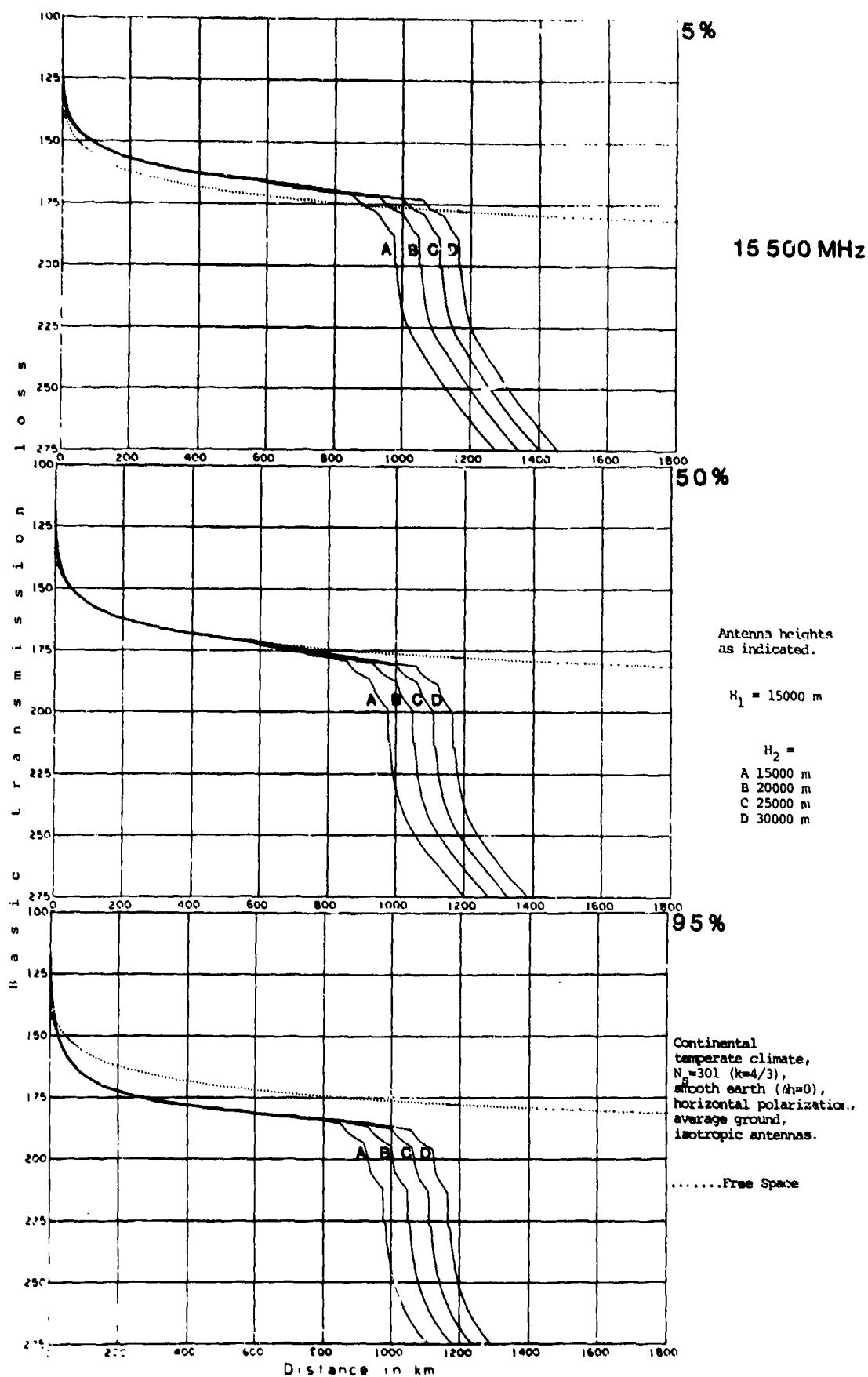


Figure 81. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 15000$ m.

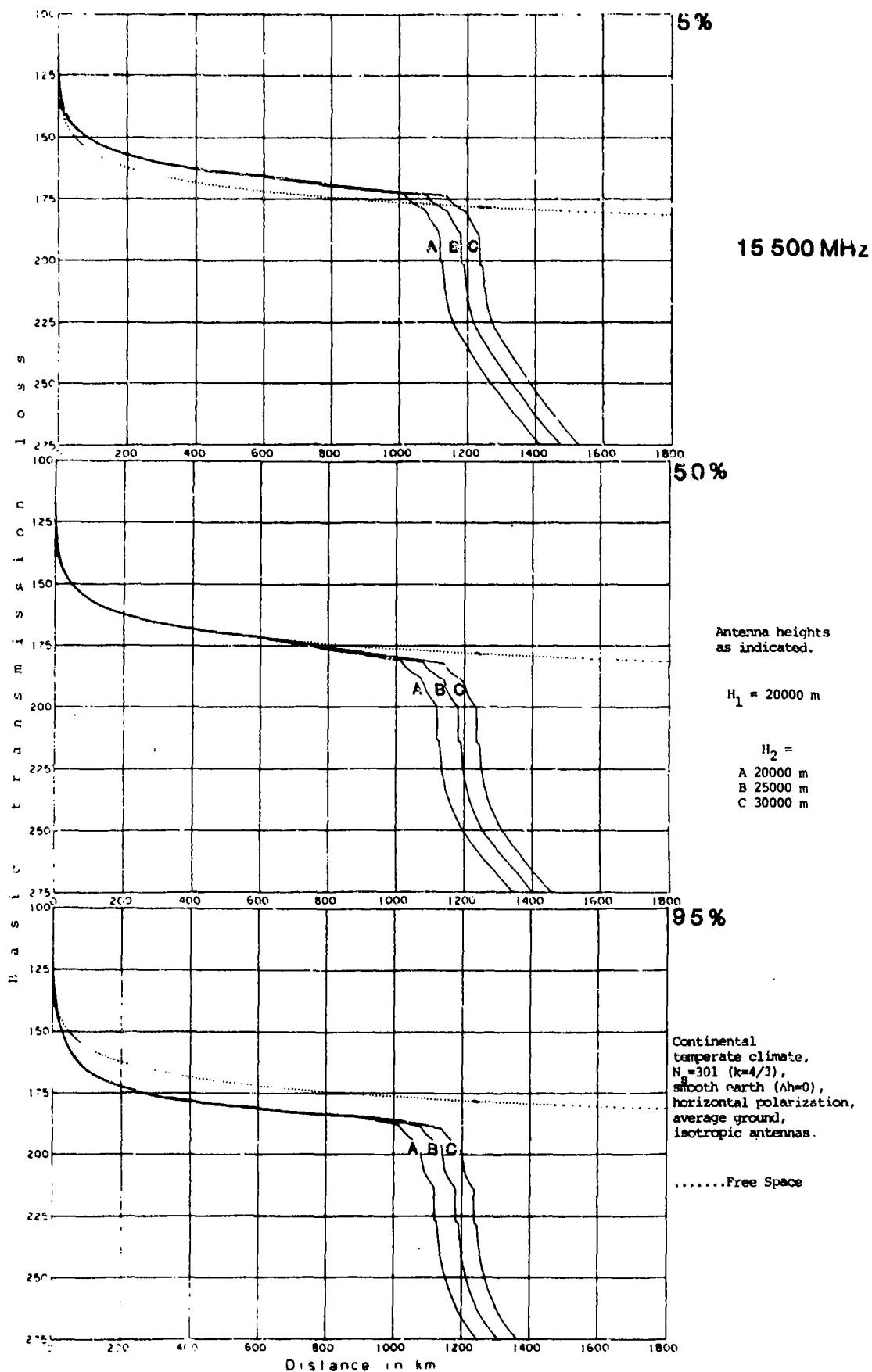


Figure 52. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 20\ 000$ m.

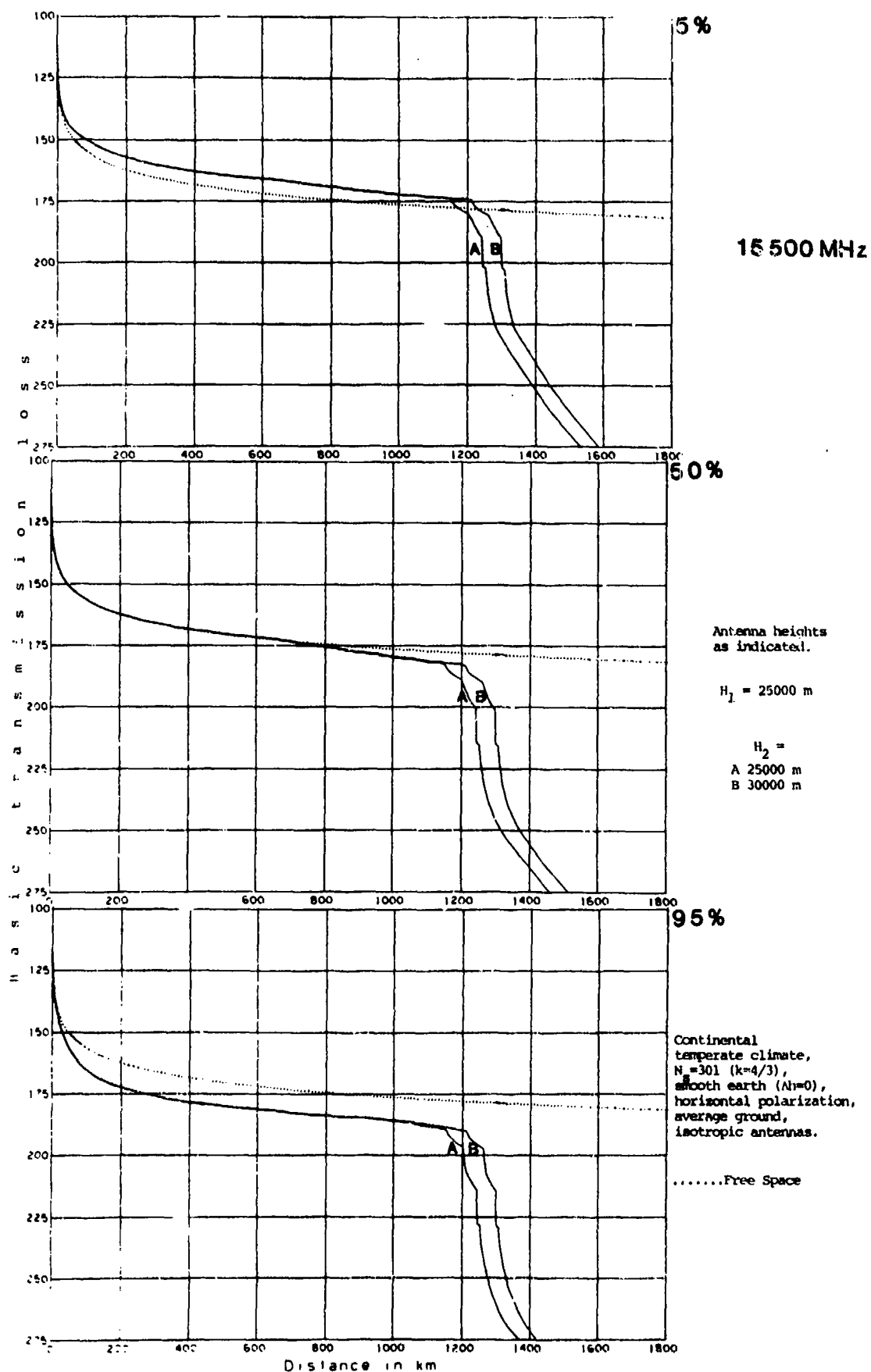


Figure 83. Basic transmission loss versus distance; $F = 15.5$ GHz, $H_1 = 25000$ m.

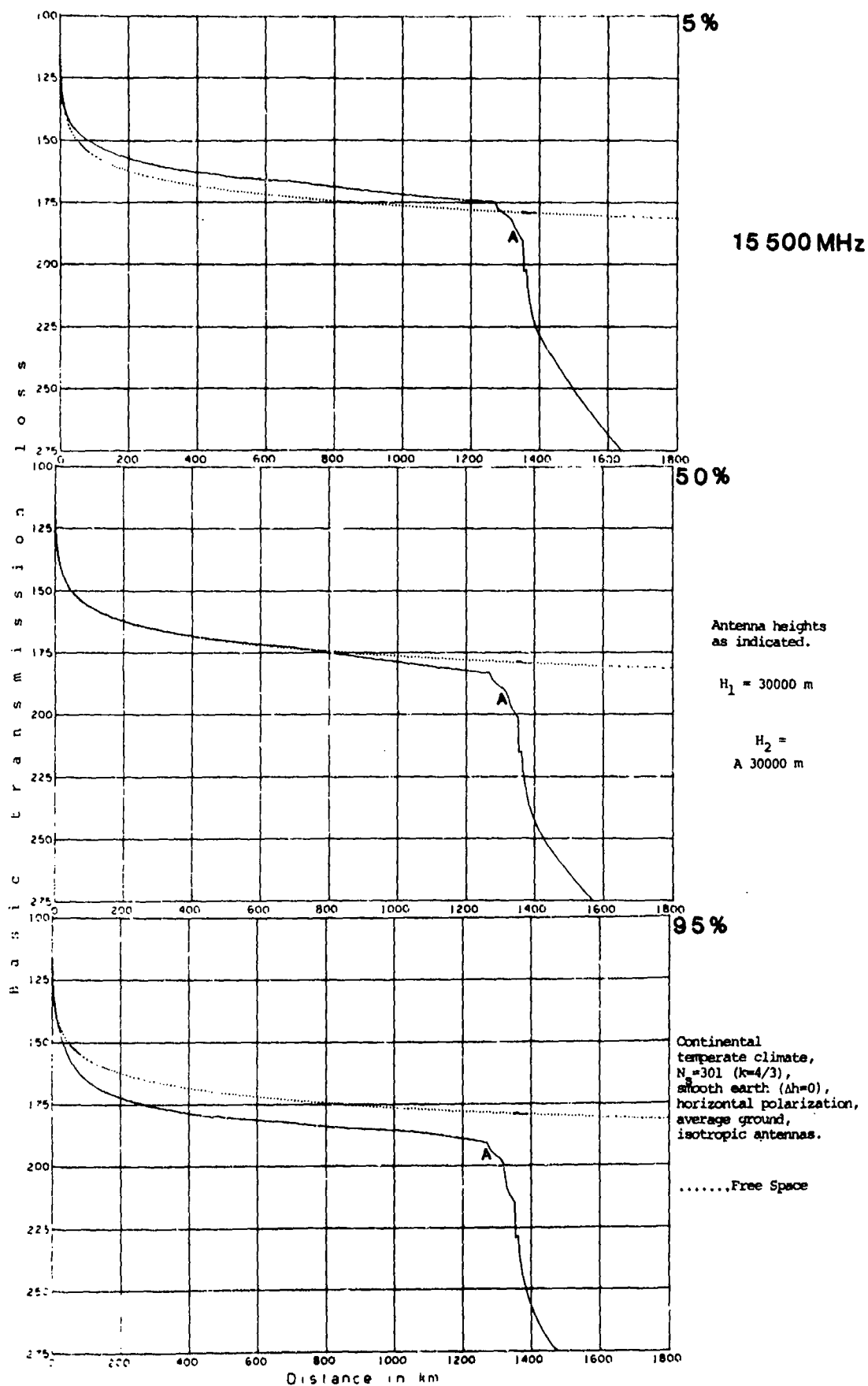


Figure 84. Basic transmission loss versus distance; $F = 15.5 \text{ GHz}$, $H_1 = 30\,000 \text{ m}$.

4. APPLICATION CONSIDERATIONS

Some application considerations for the curves provided in Section 3 are given in this section along with some sample problems. While use of these curves may provide rapid estimates of service limitations imposed by radio wave propagation for many problems, use of the computer programs built around IF-77 propagation model will provide more accurate answers and may also make a considerable reduction in the manual computation effort required to obtain some results. Atlas users are encouraged to obtain the "Applications Guide" [11] for the IF-77 program set since it contains a multitude of sample application problems along with the information needed to obtain computer generated curves for specific applications from ITS.

4.1 Received Signal Level

In addition to L_b , estimates of received signal level, RSL, from a desired facility, D, require information on the equivalent isotropically radiated power, EIRP, receiving antenna gain, G_r , and receiving antenna system line losses, L_r ; i.e.,

$$D(q) = \text{EIRP} + G_r - L_r - L_b(q) \quad , \quad (1)$$

where the $D(q)$ is the power level that is available at the receiver input for a fraction q of the time. Compatible decibel type units are used in (1); e.g., units of dBW for EIRP would result in dBW units for D . The transmitting antenna gain included in the EIRP and G_r (in dBi) should be applicable to the direction of propagation since the full main beam antenna gains may not be realized.

Received Signal Level (RSL)

Problem 1: Estimate the RSL available for at least 95% of the transmission time for an aircraft at 10,300 m above mean sea level (msl) and 400 km from the transmitting facility. Assume that a surface elevation of 300 m, a transmitting antenna height of 15 m, a radiated power of 10 dBW, an effective transmitting antenna gain of 6 dBi, an effective receiving antenna gain of 2 dBi, a receiving system line loss of 1 dB, and a frequency of 125 MHz are applicable.

Solution: The lower graph of Figure 3 is applicable to this problem, and it gives $L_b(0.95) = 147$ dB for $H_1 = 15$ m and $H_2 = 10\,300 - 300 =$

10 000 m. This value and the other parameters of the problem statement may be used in (1) to calculate $D(0.95)$; i.e.,

$$D(0.95) = \text{EIRP} + G_r - L_r - L_b(0.95) ,$$

$$D(0.95) = 10 + 6 + 2 - 1 - 147 ,$$

or

$$D(0.95) = -130 \text{ dBW} = -100 \text{ dBm} .$$

4.2 Power Density

Calculation of power density, S_R , at the receiving antenna is similar to the calculation of $D(q)$ except that the reciprocal of the effective receiving area of an isotropic antenna (A_I in dB-sq m)³ is used in place of $G_r - L_r$ in (1); i.e.,

$$S_R(q) = \text{EIRP} - A_I - L_b(q) . \quad (2)$$

Compatible decibel type units are used in (2); e.g., units of dBm for EIRP would result in dB-m/sq m units for S_R . Frequency (f) is used to calculate A_I from

$$A_I[\text{dB-sq m}] = 38.54 - 20 \log f[\text{MHz}] , \quad (3)$$

where log is the common (base 10) logarithm.

Power Density

Problem 2: Estimate the median power density available at a ground receiving facility from an aircraft at 10 500 m-msl and 400 km away. Assume that a surface elevation of 500 m, an aircraft transmitting EIRP of 45 dBm, a ground facility antenna height of 10 m, and a frequency of 300 MHz are applicable.

³The 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 $\lambda[\text{m}]$ is wavelength). Equations used in this report are dimensionally consistent. Where difficulties with units could occur, brackets are used to indicate proper units.

Solution: The middle graph of Figure 16 is applicable to this problem, and it gives $L_b(0.5) = 147$ dB for $H_1 = 10$ m and $H_2 = 10\ 500 - 500 = 10\ 000$ m. This value and the other parameters of the problem statement may be used in (3) and (2) to calculate $S_R(0.5)$; i.e.,

$$A_I[\text{dB-sq m}] = 38.54 - 20 \log f[\text{MHz}] ,$$

$$A_I = 38.54 - 20 \log(300) ,$$

$$A_I = -11.00 \text{ dB-sq m} ,$$

$$S_R(0.5) = \text{EIRP} - A_I - L_b(0.5) ,$$

$$S_R(0.5) = 45 - (-11) - 147 ,$$

and

$$S_R(0.5) = -91 \text{ dB-m/sq m} = -121 \text{ dB-W/sq m} .$$

4.3 Interpolation Between Curves

Interpolation between the curves supplied in Section 3 may be required for some problems. When an adequate estimate can not be made by visual means, a simple logarithmic interpolation method is expected to yield satisfactory results for most cases; i.e.,

$$L_b = L_{b1} + \frac{(L_{b2} - L_{b1}) \log(x/x_1)}{\log(x_2/x_1)} , \quad (4)$$

where L_b for x is calculated based on L_b and x values taken from the curves at points 1 and 2 ($L_{b1,2}$ and $x_{1,2}$). In (4), the parameter x can be either antenna height or frequency.

Interpolation for Height

Problem 3: Estimate the $L_b(0.95)$ for an aircraft at 10 000 m above the surface and 400 km from the transmitting facility by interpolation between curves for altitudes of 5000 and 15 000 m. Assume that a facility antenna height of 15 m and a frequency of 125 MHz are applicable.

Solution: Curves from the lower graph of Figure 3 are applicable; i.e., at $x_1 = 5000$ m, $L_{b1}(0.95) = 187$ dB, and at $x_2 = 15\ 000$ m, $L_{b2}(0.95) = 133$ dB. These values are used in (4) to obtain $L_b(0.95)$ for $x = 10\ 000$ m; i.e.,

$$L_b(0.95) = L_{b1}(0.95) + \frac{[L_{b2}(0.95) - L_{b1}(0.95)]}{\log(x_2/x_1)} \log(x/x_1) ,$$

$$L_b(0.95) = 187 + \frac{[133-187] \log(10000/5000)}{\log(15000/5000)} ,$$

and

$$L_b(0.95) = 153 \text{ dB} .$$

This value is 6 dB greater than the 147 dB level that would have been obtained by using the 10 000 m curve directly which is about 10% of the 54 dB interpolation range. Hence, values obtained by interpolation should be used with caution.

Interpolation for Frequency

Problem 4: Estimate the $L_b(0.5)$ for a frequency of 300 MHz by interpolation between curves for 125 and 1200 MHz. Assume that an aircraft altitude of 10 000 m, a facility antenna height of 10 m, and a distance of 400 km are applicable.

Solution: Curves from the middle graph of Figure 2 and 30 are applicable; i.e., for $x_1 = 125$ MHz, Figure 2 gives $L_{b1}(0.5) = 144$ dB, and for $x_2 = 1200$ MHz, Figure 30 gives $L_{b2}(0.5) = 152$ dB. These values are used in (4) to obtain $L_b(0.5)$ for $x = 300$ MHz; i.e.,

$$L_b(0.5) = L_{b1}(0.5) + \frac{[L_{b2}(0.5) - L_{b1}(0.5)] \log(x/x_1)}{\log(x_2/x_1)} ,$$

$$L_b(0.5) = 144 + \frac{(152-144) \log(300/125)}{\log(1200/125)} ,$$

and

$$L_b(0.5) = 147 \text{ dB} .$$

This value is the same as the value that would have been obtained by using the 300 MHz curve of Figure 16 directly. Hence, (4) can yield good results.

4.4 Service Range, Without Interference

The curves of Section 3 can be used directly to estimate service range when service is not limited by interference. Such service requirements specified in terms of $D(q)$ or S_R can be translated to a L_b level by rearrangement of (1) or (2); i.e.,

$$L_b(q) = \text{EIRP} + G_r - L_r - D(q) \quad , \quad (5)$$

or

$$L_b(q) = \text{EIRP} - S_R(q) - A_I \quad . \quad (6)$$

Service Range, Power Density

Problem 5: In the absence of interference, determine the maximum gap-less service range available to an air craft at 10 000 m above the surface when a power density of -106.6 dB-W/sq m with a time availability of 95% is used to define satisfactory service. Assume that a ground facility antenna height of 15 m, an EIRP of 20 dBW, and a frequency of 125 MHz is applicable to this problem.

Solution: The L_b value that corresponds to the edge of the service range is determined from (3) and (6); i.e.,

$$A_I[\text{dB-sq m}] = 38.54 - 20 \log f[\text{MHz}] \quad ,$$

$$A_I = 38.54 - 20 \log(125) = -3.40 \text{ dB-sq m} \quad ,$$

$$L_b(0.95) = \text{EIRP} - S_R(0.95) - A_I \text{ dB} \quad ,$$

$$L_b(0.95) = 20 - (-106.6) - (-3.4) \text{ dB} \quad ,$$

and

$$L_b(0.95) = 130 \text{ dB} \quad .$$

The lower graph of Figure 3 is applicable to this problem. However, the appropriate curve gives distance values of 213 and 261 km for an $L_b(0.95)$ of 130 dB. Hence, the maximum gap-less range for $S_R(0.95)$ = -106.6 dB-W/sq m at 10 000 m is 213 km.

4.5 Protection Ratio

The protection ratio or the desired-to-undesired signal ratio (D/U) exceeded at the receiver for at least 95% of the time, $D/U(0.95)$, can be estimated using the curves of this report as follows:

$$D/U(0.5) = \left[P_t + G_t + G_r - L_b(0.5) \right]_D - \left[P_t + G_t + G_r - L_b(0.5) \right]_U ; \quad (7)$$

$$Y(q) = L_b(0.5) - L_b(q) , \quad (8)$$

$$Y_{DU}(0.95) = -\sqrt{[Y(0.95)]_D^2 + [Y(0.05)]_U^2} , \quad (9)$$

and

$$D/U(0.95) = D/U(0.5) + Y_{DU}(0.95) . \quad (10)$$

In (9), P_t 's are radiated powers and $G_{t,r}$'s are transmitting and receiving antenna gains--all must be in consistent decibel type units. Bracket subscripts indicate that all items within the brackets are associated with either the desired (subscript D) or undesired (subscript U) facility.

Additional variabilities could easily be included in (9) for such things as antenna gain when variabilities for them can be determined. Continuous (100%) or simultaneous channel utilization is implicit in the $D/U(0.95)$ formulation provided above so that the impact of intermittent transmitter operation must be considered separately (Sec. 4.8.2).

Protection Ratio

Problem 6: Determine $D/U(0.5)$ and $D/U(0.95)$ for an aircraft receiving 125 MHz transmission at 10 000 m above the surface from a desired facility 300 km away and an undesired facility 600 km away. Assume that identical equipment parameters (P_t 's and $G_{t,r}$'s) for the facilities, facility antenna heights of 10 m, and simultaneous facility operation are applicable.

Solution: Equations (7) through (10) and values read from the curves of Figure 2 are used to solve this problem as follows:

$$[Y(0.95)]_D = [L_b(0.5) - L_b(0.95)]_D = 126.0 - 130.0 = -4.0 \text{ dB} ,$$

$$[Y(0.05)]_U = [L_b(0.5) - L_b(0.05)]_U = 176.8 - 167.1 = 9.7 \text{ dB} ,$$

$$Y_{DU}(0.95) = -\sqrt{[Y(0.95)]_D^2 + [Y(0.05)]_U^2} = -\sqrt{(-4.0)^2 + (9.7)^2} = -10.5 \text{ dB} ,$$

$$D/U(0.5) = [P_t + G_t + G_r - L_b(0.5)]_D - [P_t + G_t + G_r - L_b(0.5)]_U ,$$

$$D/U(0.5) = ([P_t + G_t + G_r]_D - [P_t + G_t + G_r]_U) + [L_b(0.5)]_U - [L_b(0.5)]_D ,$$

$$D/U(0.5) = 0 + 176.8 - 126.0 = 50.8 \text{ dB} ,$$

and

$$D/U(0.95) = D/U(0.5) + Y_{DU}(0.95) = 50.8 + (-10.5) = 40.3 \text{ dB} .$$

For this problem $D/U(0.5)$ exceeds $D/U(0.95)$ by 10.5 dB.

4.6 Station Separation

The geometry for station separation calculations is illustrated in Figure 85. Station separation, S , is the sum of the desired facility to aircraft distance, d_D , and the undesired facility to aircraft distance, d_U ; i.e.,

$$S = d_D + d_U , \tag{11}$$

where all terms of (11) are in the same units of length. While facility separation, S_f , is only equal to station separation when the aircraft is over the great-circle path connecting the facilities, many of the problems for which the use of this atlas is anticipated involve the $S = S_f$ case where the station separation required to protect an aircraft located at a "protection point" over the great-circle path must be determined. Even this simple case can involve tedious calculations because of the iterative procedure required when (10) is used. Other situations may be compounded by such things as facility antenna gain changes with azimuth, and serious

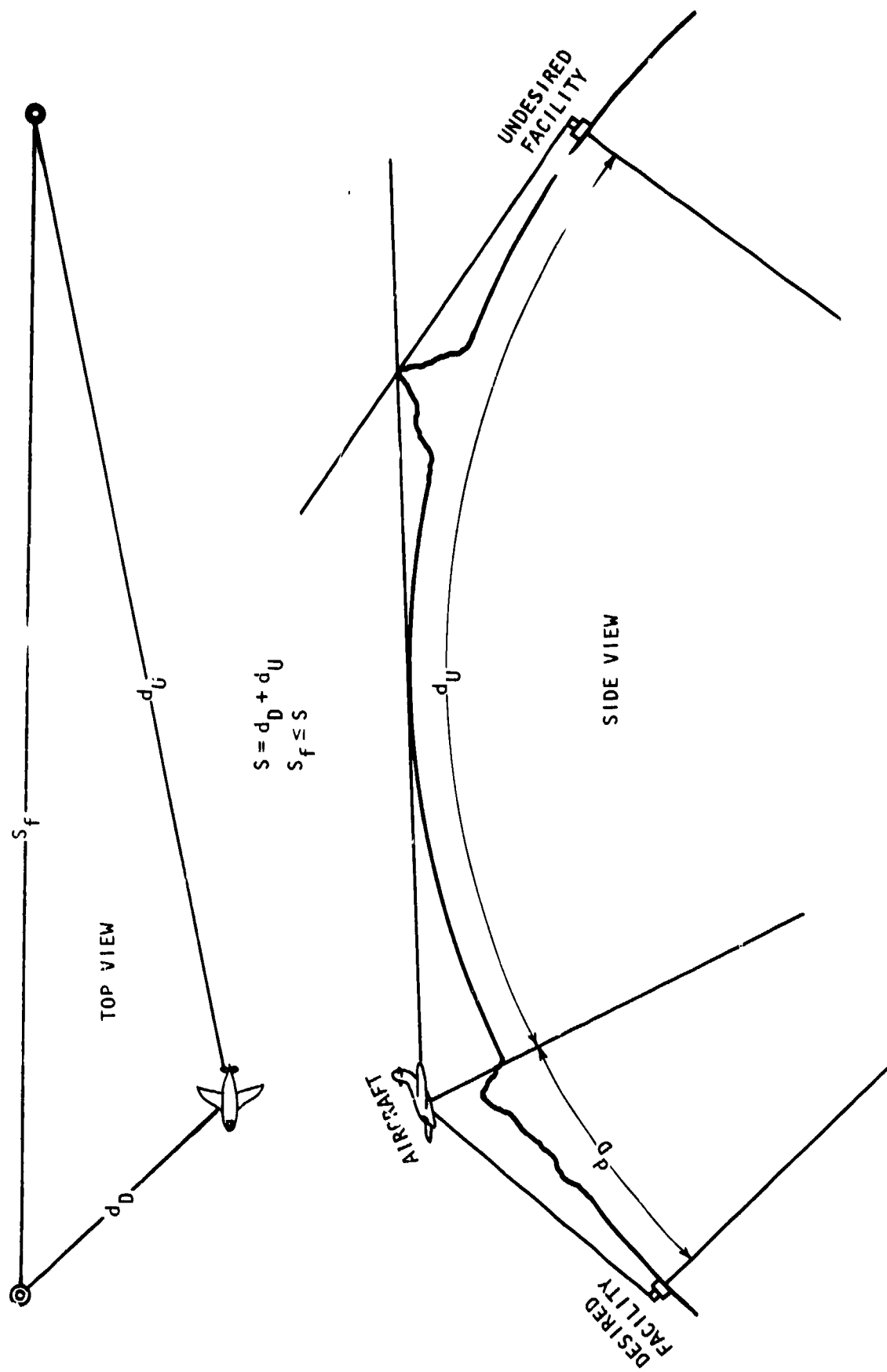


Figure 85. Sketch illustrating interference configuration.

consideration should be given to using special predictions made using one of the computer programs built around the IF-77 model [11].

Station separation required to obtain a specified $D/U(0.95)$ level at an aircraft location (protection point) fixed relative to the desired station may be estimated using the atlas curves as follows:

- (1) Determine $[L_b(0.95)]_D$ from the appropriate curve and calculate $[L_b(0.05)]_{U1}$ using

$$[L_b(0.05)]_{U1} = D/U(0.95) - [P_t + G_t + G_r - L_b(0.95)]_D + [P_t + G_t + G_r]_U. \quad (12)$$

- (2) Determine the first estimate of d_U , d_{U1} , by reading the appropriate curve at the $[L_b(0.05)]_{U1}$ level determined in step 1. If d_{U1} is multivalued, the largest value should be taken as d_{U1} . This estimate for d_U is somewhat larger than the d_U actually required and can be taken as a worst case value.
- (3) Determine the second estimate of d_U , d_{U2} , by taking the value calculated using (12) as a median value (i.e., $[L_b(0.5)]_{U2} = [L_b(0.05)]_{U1}$) and reading the appropriate median curve to obtain a value for d_{U2} . This estimate for d_U is somewhat smaller than the d_U actually required and can be taken as a best case value.
- (4) Values obtained for d_{U1} and d_{U2} in the previous step bracket d_U ; i.e.,

$$d_{U2} \leq d_U \leq d_{U1}.$$

The maximum amount that d_U can be decreased by additional calculations from the worst case (d_{U1}) value is $d_{U1} - d_{U2}$, and if this difference is small enough, the iterative calculations required to improve the initial estimate are not needed. When a better estimate is required, d_{Ui} values between d_{U2} and d_{U1} are selected, and the $D/U(0.95)_i$ associated with them calculated using (10). A

bracketing procedure based on previously obtained D/U $(0.95)_i$ values can be used to select the next d_{U_i} value. The process is continued until the $D/U(0.95)_i$ obtained is sufficiently close to the required $D/U(0.95)$. Then station separation is calculated from (11).

Station Separation

Problem 7: Determine the station separation necessary to obtain $D/U(0.95) = 20$ dB for a protection point at 10 000 m and 400 km from the desired station. Assume that identical equipment parameter (P_t 's and $G_{t,r}$'s) for the facilities, a frequency of 125 MHz, facility antenna heights of 10 m, and simultaneous facility operation are applicable.

Solution: The procedure given above and the curves of Figure 2 are used to solve this problem as summarized below.

$$(1) \quad [L_b(0.95)]_D = 150 \text{ dB} ,$$

$$[L_b(0.05)]_{U1} = D/U(0.95) - [P_t + G_t + G_r - L_b(0.95)]_D + [P_t + G_t + G_r]_U ,$$

$$[L_b(0.05)]_{U1} = D/U(0.95) + [L_b(0.95)]_D + \left([P_t + G_t + G_r]_U - [P_t + G_t + G_r] \right) ,$$

$$[L_b(0.05)]_{U1} = 20 + 150 + 0 = 170 \text{ dB} .$$

$$(2) \quad \text{For } [L_b(0.05)]_{U1} = 170, d_{U1} = 627 \text{ km.}$$

$$(3) \quad \text{For } [L_b(0.5)]_{U2} = 170, d_{U2} = 466 \text{ km.}$$

$$(4) \quad \text{Since } 466 \leq d_U \leq 627 \text{ km, calculate } [D/U(0.95)]_3 \text{ for}$$

$$d_{U3} = d_{U2} + (d_{U1} - d_{U2})/2$$

$$d_{U3} = 466 + (627 - 466)/2 = 546 \text{ km} ;$$

that is,

$$[Y(0.95)]_D = [L_b(0.5) - L_b(0.95)]_D = 143.8 - 150 = -6.2 \text{ dB} ,$$

$$[Y(0.05)]_{U3} = [L_b(0.5) - L_b(0.05)]_{U3} = 177.9 - 161.9 = 16 \text{ dB} ,$$

$$Y_{DU3} = -\sqrt{[Y(0.95)]_D^2 + [Y(0.05)]_{U3}^2} = -\sqrt{(-6.2)^2 + 16^2} = -17.2 \text{ dB} ,$$

$$[D/U(0.5)]_3 = [L_b(0.5)]_{U3} - [L_b(0.5)]_D + ([P_t + G_t + G_r]_D - [P_t + G_t + G_r]_U) ,$$

$$[D/U(0.5)]_3 = 177.9 - 143.8 + 0 = 34.1 \text{ dB} ,$$

and

$$[D/U(0.95)]_3 = [D/U(0.5)]_3 + Y_{DU3}(0.95) = 34.1 + (-17.2) = 16.9 .$$

Therefore, $d_{U3} = 546 < d_U < 627 = d_{U1}$. and a new trial is needed; i.e., $d_{U4} = 546 + (627-546)/2 = 586 \text{ km}$. Values resulting from the new trial are as follows:

$$[Y(0.05)]_{U4} = 179.7 - 165.3 = 14.4 ,$$

$$Y_{DU4} = -\sqrt{(-6.2)^2 + (14.4)^2} = -15.7 ,$$

$$[D/U(0.5)]_4 = 179.7 - 143.8 + 0 = 35.9 ,$$

and

$$[D/U(0.95)]_4 = 35.9 + (-15.7) = 20.2 \text{ or } 20 \text{ dB} .$$

Hence, $d_U = d_{U4} = 586 \text{ km}$ will give $D/U(0.95) = 20 \text{ dB}$ for the conditions of the problem. Note that d_{U1} was high by 41 km (7%) while d_{U2} was low by 120 km (20%).

4.7 Constant Protection Ratio Locus

A method of approximating the locus of a constant protection ratio as a circle enclosing the undesired facility has been developed [8, pp. 104-107] and is illustrated in Figure 86. This method is useful in estimating the region around an adjacent-channel undesired

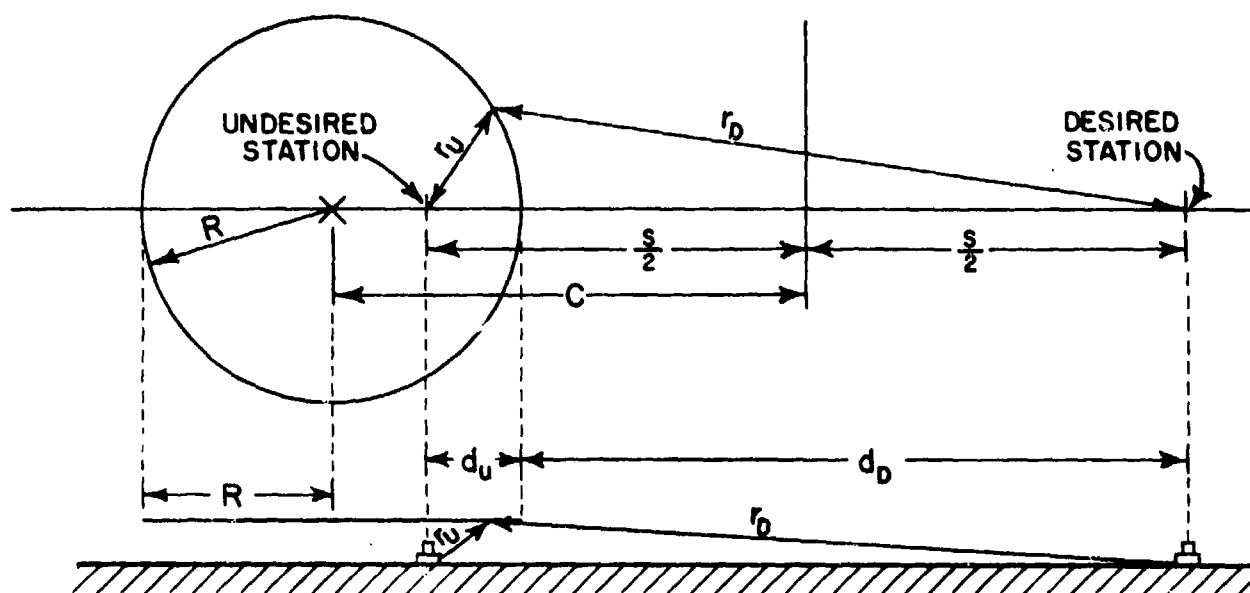


Figure 86. Locus of constant $D/U(q)$ for an adjacent-channel undesired facility.

facility in which service is unsatisfactory. For a given aircraft altitude, the circle has radius R given by

$$R = \frac{SB}{B^2 - 1} \quad (13)$$

where S is calculated using (11) and the ratio B is calculated from

$$B = d_D/d_U \quad (14)$$

The circle is centered on the undesired facility side of an extension to the line connecting the ground facilities at a distance

$$C = \frac{S(B^2 + 1)}{2(B^2 - 1)} \quad (15)$$

from the point half-way between the facilities. Generally, service can be regarded as being unsatisfactory within the circle, even

though some locations having satisfactory service may exist above the undesired facility because of the vertical pattern of its antenna.

The two basic assumptions associated with this method are as follows:

- (a) The geometry of Figure 86 can be treated as plane geometry; i.e., the earth is assumed to be flat, and slant range projections, $d_{D,U}$, onto the horizontal plane are approximately equal to the actual ranges, $r_{D,U}$. This assumption is reasonable if $d_D > d_U \geq \text{aircraft altitude}/260$ for distances in kilometers and aircraft altitude in meters.
- (b) The protection ratio, $D/U(q)$, is assumed to be proportional to the logarithm of the ratio of the distances; i.e., $D/U(q) = M \log (d_D/d_U)$, where M is a constant.

This method is only approximate. The second assumption, (b), is violated by lobing in the transmission loss versus distance curve, which may occur at any constant altitude because of ground reflections or by facility antenna patterns that are not omnidirectional in the horizontal plane. Assumption (b) is also violated by a change in the slope of the transmission loss versus distance curve which, as an example, occurs in the vicinity of the radio horizon. However, the use of the smallest d_D corresponding to a particular station spacing and a particular protection ratio avoids the ambiguity due to lobing. Furthermore, in most applications service is limited by noise rather than by interference if ranges beyond the radio horizon of the desired station are encountered.

Protection Ratio Locus

Problem 8: Find the locus of the $D/U(0.95) = -40$ dB contour about an adjacent-channel undesired facility at an altitude of 5000 m. Assume that the $D/U(0.95) = -40$ dB location on the great circle connecting the facility has been previously determined so that $d_D = 200$ km and $d_U = 40$ km.

Solution: This problem is solved by using the d_D and d_U provided in the problem statement in equations (11) and (13) through (15); i.e.,

$$S = d_D + d_U = 200 + 40 = 240 \text{ km},$$

$$B = d_D/d_U = 200/40 = 5,$$

$$R = B/(B^2-1) = (240)(5)/(5^2-1) = 50 \text{ km, and}$$

$$C = \frac{3(B^2+1)}{2(B^2-1)} = \frac{(240)(5^2+1)}{2(5^2-1)} = 130 \text{ km.}$$

Hence, at 5000 m harmful adjacent-channel interference ($D/U(0.95) \geq -40$ dB) occurs about the undesired facility in the region defined by a 50 km radius circle centered at 10 km ($C-S/2$) on the far side of the undesired facility along the line connecting the facilities.

4.8 Multiple Interference Sources

Two types of interference from multiple sources will be considered. The first type involves the case where the interfering or undesired power results from incoherent statistically independent multiple sources that all operate continuously. These are called "simultaneous independent sources" and are discussed in Section 4.8.1.

The other type is the case where the undesired power results from multiple sources that are operated intermittently in a coordinated fashion such that only one transmits at a time, and periods with no transmissions are possible. These are called "intermittent coordinated sources" and are discussed in Section 4.8.2.

4.8.1 Simultaneous Independent Sources

A method for estimating $D/U(0.95)$ when the undesired power is made up of contributions from incoherent statistically independent multiple sources is provided in this section. It is the "log-normal" method developed by Norton et al. [16] and previously used for this purpose [8, Sec. 3.2]. The method may be summarized as follows:

- (1) For each i th facility of the n undesired facilities involved, determine its median received power $[U(0.5)]$ and standard deviation σ_i in using

$$[U(0.5)]_i = [P_t + G_t + G_r + L_r - L_b(0.5)]_i, \quad (16)$$

$$[Y(0.05)]_i = [L_b(0.05) - L_b(0.5)]_i , \quad (17)$$

and

$$\sigma_i = [Y(0.05)]_i / 1.6448 , \quad (18)$$

where the variables involved are as previously defined. However, all radiated powers, P_t 's, must be in the same decibel type unit such as dBW.

- (2) For each i th undesired facility, determine the mean power, α_i , and variance, μ_i , in nondecibel or watt type units using

$$\alpha_i = \exp[0.5(\sigma_i/c)^2 + [U(0.5)]_i/c] \quad (19)$$

and

$$\mu_i = \alpha_i^2 (\exp[(\sigma_i/c)^2] - 1) , \quad (20)$$

where

$$c = 10 \log e = 4.3429 . \quad (21)$$

If $[U(0.5)]_i$ was in dBW, α_i will be in watts and μ_i in watts squared.

- (3) Determine $[Y(0.05)]_U$ and $U(0.5)$ for the resulting total undesired power from the n undesired facilities using

$$\sigma_U = c \sqrt{\ln(1 + [\sum \mu_i / (\sum \alpha_i)^2])} , \quad (22)$$

$$[Y(0.05)]_U = 1.6448 \sigma_U , \quad (23)$$

and

$$U(0.5) = c [\ln(\sum \alpha_i) - 0.5(\sigma_U/c)^2] , \quad (24)$$

where $\ln$ is the natural (base e) logarithm. Note that σ_U is in dB and $U(0.5)$ is in the same decibel type units used for the $[U(0.5)]_i$'s.

(4) Determine $D/U(0.95)$ using

$$D(0.5) = [P_t + G_t + G_r - L_r - L_b(0.50)]_D, \quad (25)$$

$$D/U(0.5) = D(0.5) - U(0.5), \quad (26)$$

with (9) and (10).

Multiple Simultaneous Sources

Problem 9: Find $D/U(0.95)$ when the undesired power is made up of contributions from four undesired facilities that may be treated as multiple simultaneous sources. Assume that the facilities have received power parameters as explained below.

i	$[U(0.50)]_i$ dBW	$[Y(0.05)]_i$ dB
1	- 95	0
2	-100	5
3	-105	10
4	-110	15
5	-115	20
$D(0.50) = -65$ dBW		$[Y(0.95)]_D = -5$ dB

Solution: The step-by-step procedure as given above is followed;
i.e.,

(1)-(2) the first two steps result in the values tabulated below which also include the summation terms required in step 3.

i	σ_i dB	α_i W	μ_i W ²
1	0	3.1616×10^{-10}	0
2	3.0399	1.2773×10^{-10}	1.0315×10^{-20}
3	6.0798	8.4229×10^{-11}	4.3264×10^{-20}
4	9.1196	9.0657×10^{-11}	6.6761×10^{-19}
5	12.1595	1.5927×10^{-10}	6.4363×10^{-17}
TOTALS		7.780×10^{-10}	6.508×10^{-17}

$$(3) \quad \sigma_U = c \sqrt{\ln(1 + [\sum \mu_i / (\sum \alpha_i)^2])} ,$$

$$\sigma_U = 4.3429 \sqrt{\ln(1 + [(6.508 \times 10^{-17}) / (7.780 \times 10^{-10})^2])} = 9.402 \text{ dB}$$

$$[Y(0.05)]_U = 1.6448 \sigma_U = (1.6448)(9.402) = 15.46 \text{ dB}$$

$$U(0.5) = c[\ln(\sum \alpha_i) - 0.5(\sigma_U/c)^2] ,$$

and

$$U(0.5) = 4.3429 [\ln(7.782 \times 10^{-10}) - 0.5(9.402/4.3429)^2] = -101.27 \text{ dBW},$$

(4)

$$D/U(0.50) = D(0.50) - U(0.50) = -65 - (-101.27) = 36.27 \text{ dB} ,$$

$$Y_{DU} = -\sqrt{[Y(0.95)]_D^2 + [Y(0.05)]_U^2} = -\sqrt{(-5)^2 + (15.46)^2} = -16.25 \text{ dB} ,$$

and

$$D/U(0.95) = D/U(0.5) + Y_{DU} = 36.27 + (-16.25) = 20 \text{ dB} .$$

4.8.2 Intermittent Coordinated Sources

A method is provided in this section for estimating $D/U(0.95)$ when the undesired power is made up of contributions from multiple sources that are operated intermittently in a coordinated fashion such that only one transmits at a time, and periods with no transmissions are possible. This method is applicable to an air traffic control (ATC) situation where the undesired signals come from another sector, but it estimates a $D/U(0.95)$ value instead of a "probability of interference" [13]. Users in the interfering or undesired sector are assumed to transmit one at a time, and $D/U(0.95)$ is taken over the time that the desired facility transmits; i.e., channel utilization for the desired facility is neglected by assuming D/U values when no desired power is available are not of interest. The method is summarized as follows:

- (1) Determine $D(0.5)$ and $[Y(0.95)]_D$ using (25) and (8) along with transmission loss values read from the appropriate curves.
- (2) Divide the airspace of the undesired sector into volumes and characterize each by single values of $[U(0.05)]_i$, $[U(0.5)]_i$, and $[U(0.95)]_i$ where these are calculated as in (16) from L_p values read from the appropriate curves. Estimate the channel utilization expected for aircraft transmitting from each volume under the conditions of full sector utilization. Channel utilization, U_C , is the percent of time that transmissions from aircraft within the volume takes place. Pair each power level with a level utilization, U_L , where

$$U_L = \begin{cases} 0.8 U_C & \text{for } [U(0.5)]_i \\ 0.1 U_C & \text{for } [U(0.05)]_i \text{ and } [U(0.95)]_i \end{cases} \quad (27)$$

- (3) Repeat step 2 for each undesired facility of the interfering sector.

- (4) Reorder the "level- U_L " pairs determined in steps 2 and 3 by decreasing power levels and calculate an accumulated utilization, U_A , that gives channel utilization percentage for levels equal to or greater than a particular tabulated value; i.e.,

$$U_A([U(q)]_j) = \sum_j [U_L]_i \text{ for all } [U(q)]_i \geq [U(q)]_j . \quad (28)$$

- (5) Using the tabulation of step 4, estimate levels for $U(0.05)$ and $U(0.5)$. Then calculate $[Y(0.05)]_U$ from

$$[Y(0.05)]_U = U(0.05) - U(0.5) , \quad (29)$$

and determine $D/U(0.95)$ using (9) and (10).

Multiple Simultaneous Sources

Problem 10: Find $D/U(0.95)$ when the undesired power is made up of contributions from aircraft and a facility in an interfering sector. Assume that steps 1 through 3 of the procedure given above have resulted in the following:

- (1) Values obtained for step 1 are $D(0.5) = -95$ dBW and $[Y(0.95)]_D = -3$ dB.
- (2) (3) Values obtained for steps 2 and 3 are as shown below.

U_C %	$[U(0.05)]_i$ dBW	U_L %	$[U(0.5)]_i$ dBW	U_L %	$[U(0.95)]_i$ dBW	U_L %
5	-100	0.5	-105	4	-110	0.5
5	-103	0.5	-108	4	-113	0.5
10	-106	1	-112	8	-116	1
5	-109	0.5	-115	4	-119	0.5
40	-148	4	-160	32	-172	4

In the tabulation above, transmissions with $U_c = 40\%$ are from the undesired facility, and the remaining utilization (20%) is from four different aircraft volumes. Note that the total utilization for the undesired sector is 65% so that there are no transmissions from the undesired sector during 35% of the time.

Solution: In this case, the solution starts with step 4 of the provided procedure.

- (4) Reorder the values obtained in steps 2 and 3 and calculate U_A 's using (28) as shown.

Level	U_L	U_A
dBW	%	%
-100	0.5	0.5
-103	0.5	1
-105	4	5 ← $U(0.05) = -105$ dBW
-106	1	6
-108	4	10
-109	0.5	10.5
-110	0.5	11
-112	8	19
-113	0.5	19.5
-115	4	23.5
-116	1	24.5
-119	0.5	25
-148	4	29 ← Interpolate to get $U(0.5)$
-160	32	61
-172	4	65
None	35	100

- (5) Use the step (4) tabulation to obtain $U(0.05)$ and $U(0.5)$. Since a $U_A = 5\%$ value is given in the tabulation, $U(0.05)$ is obtained directly as $U(0.05) = -105$ dBW. However, $U(0.5)$ is determined using linear interpolation between -148 and -160 dBW; i.e.,

$$U(0.5) = \frac{(160-148)(61-50)}{(61-29)} - 160 = -156 \text{ dBW} .$$

Then determine $D/U(0.95)$ using (26), (29), (9), and (10); i.e.,

$$D/U(0.5) = D(0.5) - U(0.5) = -95 - (-156) = 61 \text{ dB} ,$$

$$[Y(0.05)]_U = U(0.05) - U(0.5) = -105 - (-156) = 51 \text{ dB} ,$$

$$Y_{DU}(0.95) = -\sqrt{[Y(0.95)]_D^2 + [Y(0.05)]_U^2} = -\sqrt{(-3)^2 + 51^2} = -51 \text{ dB} ,$$

and

$$D/U(0.95) = D/U(0.5) + Y_{DU}(0.95) = 61 + (-51) = 10 \text{ dB} .$$

4.9 Service Probability

Semi-empirical methods of predicting the time variability, location-to-location variability, and prediction uncertainty of transmission loss for tropospheric communication circuits have been developed and incorporated in the concept of service probability [2; 3; 15, Annex I; 17, Annex V]. Although a comprehensive discussion of these methods is beyond the scope of this report, a simple method of using the service probability concept with the atlas curves is given in this section.

Service probability is taken here as the probability that satisfactory service will be obtained where satisfactory service is defined by a required time availability for a critical signal or protection ratio level. (This assumes that the transmitter is always on, and the transmitter down time is not considered in this analysis.) It may be interpreted as bias or margin used in addition to time availability. A link designed so that the critical signal level is available when the transmission loss for the path corresponds to $L_p(0.95)$ could have a time availability of 0.95 and a service probability of 0.5; i.e., the probability that a particular link will provide a time availability of 0.95 is 0.5. Variation from this design may be interpreted as a change of time availability and/or service probability [8, Fig. 33].

Selection of time availability, q , and service probability, Q , requirements for a particular situation should be determined by the user. In general, higher values will mean more reliability at a higher cost where cost may include a requirement for more frequencies

to provide a particular service. Except when $Q=0.5$, the inclusion of service probability complicates the prediction process.

Experience at the FAA indicates that predictions made with $q=0.95$ and $Q=0.5$ are adequate to define service volumes for air navigation aids when known equipment degradation factors are accounted for by adjusting prediction parameters, such as transmitted power, and caution is used to avoid situations where conditions such as terrain differ significantly from those assumed in the predictions.

The $D/U(0.95)$ that is available with probability Q or $D/U(0.95, Q)$ may be estimated by using Figure 87, which gives the standard normal deviation z_{mo} as a function of Q and the method that follows:

- (1) Estimate the extra standard error, σ_e , that is needed to account for uncertainties other than the path-to-path variance, σ_c^2 [17, eqn. V40], such as those associated with equipment performance parameters for the desired facility. Then solve for $\sigma(q, Q)$ by using parameters applicable to the desired facility, $q=0.95$, and the following:

$$\sigma_c^2(q) = 12.73 + 0.12 Y^2(q) \quad , \quad (30)$$

$$\sigma_{ce}^2(q) = \sigma_c^2(q) + \sigma_e^2 \quad , \quad (31)$$

$$\sigma^2(q, Q) = \begin{cases} \sigma_{ce}^2(q) & \text{if } L_b(q) + z_{mo}(Q) \sigma_e \leq L_{bf} - 6 \\ \sigma_e^2 & \text{otherwise} \end{cases} \quad , \quad (32)$$

where L_{bf} is the free space basic transmission loss obtained from the appropriate atlas curve, and the test in (32) is intended to prevent the use of power levels that are in excess of free space values by an unrealistic amount. The resulting $\sigma^2(q, Q)$ will be called $[\sigma^2(0.95, Q)]_D$.

- (2) Repeat step 1 with parameters applicable to the undesired facility, $q=0.05$ and Q set to $Q-1$; e.g., if $Q=0.9$, take Q as 0.1 for this step. The resulting $\sigma^2(q, Q)$ will be called $[\sigma^2(0.05, Q-1)]_U$.

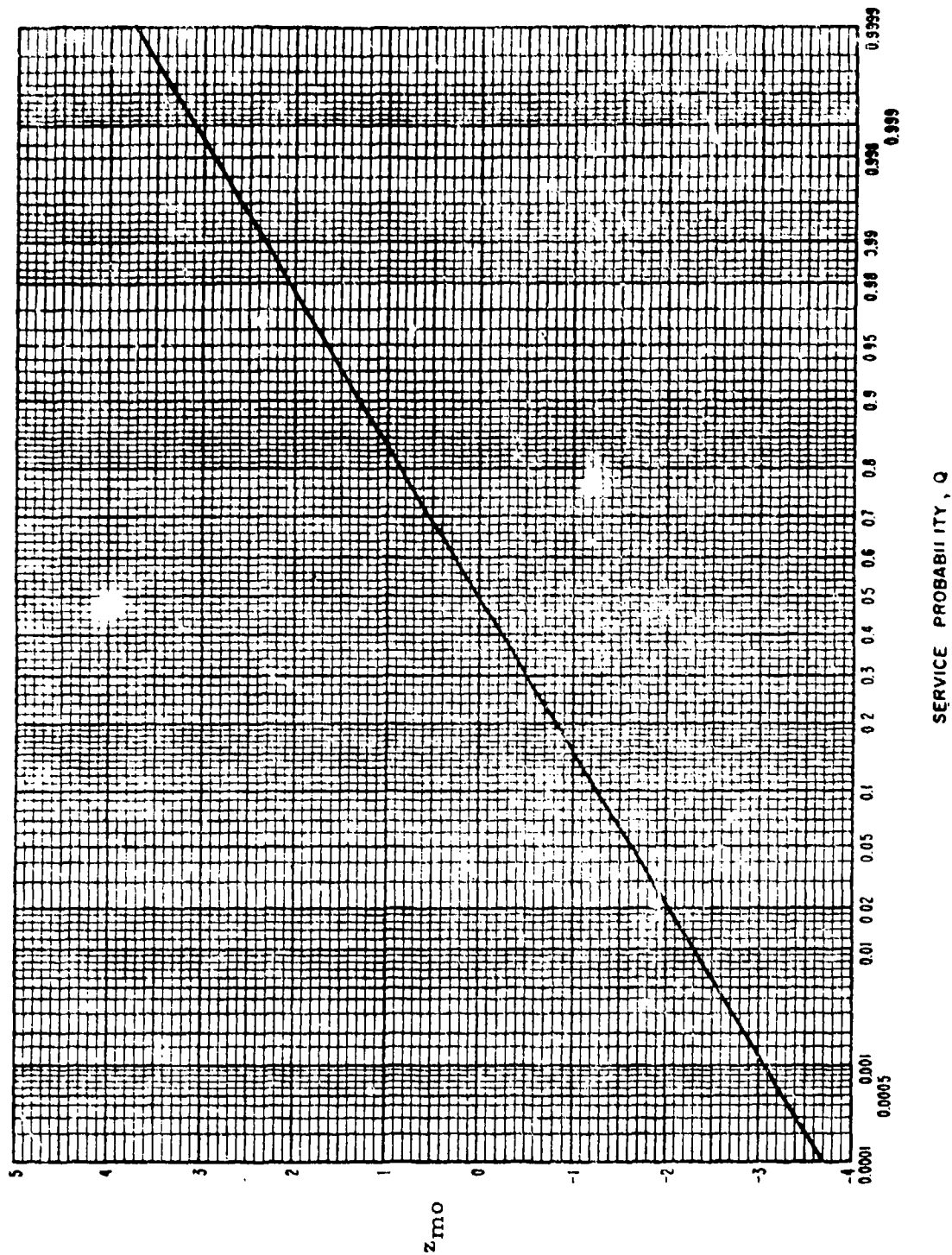


Figure 87. The standard normal deviate z_{mo} versus service probability Q [17, Fig. V.7].

- (3) Use the results of steps 1 and 2 along with a $D/U(q)$ determined using one of the methods previously discussed in the following:

$$\sigma_{DU}(0.95, Q) = \sqrt{[\sigma^2(0.95, Q)]_D + [\sigma^2(0.05, Q-1)]_U} , \quad (33)$$

$$D/U(0.95, Q) = D/U(0.95, 0.5) - z_{mo}(Q) \sigma_{DU}(0.95, Q) . \quad (34)$$

Service Probability

Problem 11: Determine $D/U(0.95, 0.9)$ when $D/U(0.95, 0.5) = 20.2$ dB and other parameters are as follows:

Desired Facility

$$\begin{aligned} \sigma_e &= 2 \text{ dB} \\ L_{bf} &= 126.8 \text{ dB} \\ L_b(0.95) &= 150 \text{ dB} \\ Y(0.95) &= -6.2 \text{ dB} \end{aligned}$$

Undesired Facility

$$\begin{aligned} \sigma_e &= 3 \text{ dB} \\ L_{bf} &= 129.9 \text{ dB} \\ L_b(0.05) &= 165.3 \text{ dB} \\ Y(0.05) &= 14.4 \text{ dB} . \end{aligned}$$

Solution:

- (1) For the desired facility,

$$\sigma_c^2(0.95) = 12.73 + 0.12 Y^2(0.95) = 12.73 + (0.12)(-6.2)^2 = 17.34 \text{ dB}^2 ,$$

$$\sigma_{ce}^2(0.95) = \sigma_c^2(0.95) + \sigma_e^2 = 17.34 + (2)^2 = 21.34 \text{ dB}^2 ,$$

$$L_b(0.95) + z_{mo}(0.9) \sigma_e = 150 + (1.3)(2) = 152.6 \text{ dB} ,$$

$$L_{bf} - 6 = 126.8 - 6 = 120.8 \text{ dB} ,$$

therefore,

$$L_b(0.95) + z_{mo}(0.9) \sigma_e \leq L_{bf} - 6 ,$$

so that

$$[\sigma^2(0.95, 0.9)]_D = \sigma_{ce}^2(0.95) = 21.34 \text{ dB}^2 .$$

(2) For the undesired facility,

$$\sigma_c^2(0.05) = 12.73 + 0.12 Y^2(0.05) = 12.73 + (0.12)(14.4)^2 = 37.61 \text{ dB}^2,$$

$$\sigma_{ce}^2(0.05) = \sigma_c^2(0.05) + \sigma_e^2 = 37.61 + (3)^2 = 46.61 \text{ dB}^2,$$

$$L_b(0.05) + z_{mo}(1-0.9) \sigma_e = 165.3 + (-1.3)(3) = 161.4 \text{ dB},$$

$$L_{bf} - 6 = 129.9 - 6 = 123.9 \text{ dB},$$

therefore,

$$L_b(0.05) + z_{mo}(1 - 0.9) \sigma_e \leq L_{bf} - 6,$$

so that

$$[\sigma^2(0.05, 0.1)]_U = \sigma_{ce}^2(0.05) = 46.61 \text{ dB}^2,$$

$$\sigma_{DU}(0.95, 0.9) = \sqrt{[\sigma^2(0.95, 0.9)]_D + [\sigma^2(0.05, 0.1)]_U},$$

$$\sigma_{DU}(0.95, 0.9) = \sqrt{21.34 + 46.61} = 8.2 \text{ dB},$$

$$D/U(0.95, 0.9) = D/U(0.95) - z_{mo}(0.9) \sigma_{DU}(0.95, Q),$$

and

$$D/U(0.95, 0.9) = 20.2 - (1.3)(8.2) = 9.5 \text{ dB}.$$

4.10 Radar Application

Basic transmission loss for radar applications, $L_{bR}(0.95)$, can be estimated from $L_b(0.5)$ and $Y(0.95)$ values determined for the radar-to-target path by using the appropriate curves and (8) along with A_I from (3), and the distribution of expected radar cross-section values, $A_\sigma(q)$ [dB - sq m], as follows:

$$Y_\sigma(q) = A_\sigma(q) - A_\sigma(0.5), \quad (35)$$

$$Y_R(0.95) = - \sqrt{2[Y(0.95)]^2 + [Y_Q(0.95)]^2} , \quad (36)$$

and

$$L_{bR}(0.95) = 2L_b(0.5) + A_I - A(0.5) - Y_R(0.95) . \quad (37)$$

Here, $A_Q(q)$ is the radar cross section available or exceeded for a fraction q of the time and is expressed as decibels greater than 1 sq m; i.e., $10 \log$ (sq m cross section).

Radar cross section "... can be expressed as 4π times the power delivered per unit solid angle in the direction of the receiver divided by the power per unit area incident at the target" where "... 4π enters from the definition of solid angle" [18, p. 8]. It may also be taken as "...the area which would intercept sufficient power out of the transmitted field to produce the given echo by isotropic reradiation" [18, p. 9].

The radar cross section of a particular object is dependent upon such things as its shape, orientation, and composition along with the frequency and polarization of the radar. A more comprehensive discussion is beyond the scope of this report, and interested readers are referred to the Radar Cross Section Handbook [18] for additional information.

Basic Transmission Loss for Radar

Problem 12: Determine $L_{bR}(0.95)$ for parameters specified as follows:

$$A_Q(0.5) = 13 \text{ dB-sq m (20 sq m cross section)} ,$$

$$A_Q(0.95) = 0 \text{ dB-sq m (1 sq m cross section)} ,$$

$$f = 9.4 \text{ GHz} = 9400 \text{ MHz} ,$$

$$L_b(0.5) = 169.6 \text{ dB} ,$$

and

$$Y(0.95) = -7.5 \text{ dB} .$$

Solution: By using (3), (35), (36), and (37), $L_{bR}(0.95)$ is calculated as follows:

$$A_I = 38.54 - 20 \log f[\text{MHz}] ,$$

$$A_I = 38.54 - 20 \log(9400) = -40.9 \text{ dB-sq m} ,$$

$$Y_O(0.95) = A_O(0.95) - A_O(0.5) = 0 - 13 = -13 \text{ dB-sq m} ,$$

$$Y_R(0.95) = -\sqrt{2[Y(0.95)]^2 + [Y_O(0.95)]^2} ,$$

$$Y_R(0.95) = -\sqrt{2(-7.5)^2 + (-13)^2} = -16.8 \text{ dB} ,$$

$$L_{bR}(0.95) = 2 L_b(0.5) + A_I - A_O(0.5) - Y_R(0.95) ,$$

and

$$L_{bR}(0.95) = 2(169.6) + (-40.9) - 13 - (-16.8) = 302 \text{ dB} .$$

APPENDIX. 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 [8, 11, 17]. 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 consistent 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.

ATC	Air traffic control.
A_I	Effective receiving area [dB-sq m] of an isotropic antenna from (3).
$A_\sigma(q)$	The radar cross section available or exceeded for a fraction q of the time. It is expressed as decibels greater than 1 sq m; i.e., $10 \log (\text{sq m cross section})$.
B	A ratio shown in Figure 86.
c	$10 \log e = 4.3429$.
C	A distance shown in Figure 86.
dB	Decibels, $10 \log$ (dimensionless ratio of powers).
dB _i	Antenna gain in decibels greater than isotropic.
dB _m	Power in decibels greater than 1 milliwatt.
dB _W	Power in decibels greater than 1 watt.
dB-sq m	Effective antenna aperture area in decibels greater than 1 square meter.
dB-W/sq m	Power density as decibels greater than 1 watt per square meter.
d_D	Desired facility to aircraft distance as shown in Figure 85.
d_U	Undesired facility to aircraft distance as shown in Figure 85.
d_{U1}	A "worst case" d_U used in Section 4.5.

d_{U2}	A "best case" d_U used in Section 4.5.
$D(q)$	The RSL from the desired facility that is available or exceeded for at least a fraction q of the time.
$D/U(0.95)$	The desired-to-undesired signal ratio [dB] that is available or exceeded for 95% of the time, from (10).
$D/U(0.95,Q)$	The $D/U(0.95)$ available with probability Q , from (34).
e	2.718281828
EIRP	Equivalent <u>i</u> sotropically <u>r</u> adiated <u>p</u> ower (Sec. 4.1) in decibel type units; e.g., dBW or dBm.
f	Frequency [MHz], used in (3).
FAA	<u>F</u> ederal <u>A</u> viation <u>A</u> dministration.
GHz	Gigahertz (10^9 Hz).
$G_{r,t}$	Gain [dBi] of receiving or transmitting antenna in applicable direction (Sec. 4.1).
$H_{1,2}$	Terminal 1 or 2 antenna elevation [m] above the earth's surface.
i	Used to indicate i th item.
IF-73	The <u>I</u> TS- <u>F</u> AA-197 <u>3</u> propagation model [6].
IF-77	The <u>I</u> TS- <u>F</u> AA-197 <u>7</u> propagation model [11].
ITS	<u>I</u> nstitute for <u>T</u> elecommunication <u>S</u> ciences.
j	A subscript used in (28) to designate a specific member of a set of power levels.
k	Effective earth radius factor; i.e., effective radius/actual radius [11, Sec. 4.1, refractivity discussion; 17, Sec. 4].
km	Kilometers (10^3 m).
$\ln$	Natural (base e) logarithm.
$\log$	Common (base 10) logarithm.
L_b	Basic transmission loss in decibels [17, Sec. 2.4].
L_{bf}	L_b for free space propagation conditions [17, Sec. 2.4].
L_{bR}	L_b for radar-target-radar path as calculated from (37).
$L_{b1,2}$	L_b values for points 1 or 2 between which a value is interpolated using (4).

$L_b(q)$	An L_b level <u>not</u> exceeded for a fraction q of the time.
L_r	Line loss [dB] of receiving antenna system (Sec. 4.1).
m	Meters.
M	A constant used in Section 4.7.
n	Number of undesired signal sources, see Section 4.8.1.
N_s	Minimum monthly surface refractivity in N-units [11, Sec. 4.1, refractivity discussion].
N-units	Units of refractivity corresponding to (refractive index-1) $\times 10^6$.
P_t	Radiated power in decibel type units (dBm, dBW), used in (7).
q	Time availability (Sec. 1).
Q	Service probability, see Section 4.9.
r_D	A slant range shown in Figure 86.
r_U	A slant range shown in Figure 86.
R	A radius shown in Figure 86.
RSL	<u>R</u> ecieved <u>s</u> ignal <u>l</u> evel.
S	Station separation shown in Figure 85.
S_f	Facility separation shown in Figure 85.
$S_R(q)$	Power density at the receiving antenna [dB-W/sq m] that is available or exceeded for a fraction of time q , from (2).
UHF	<u>U</u> ltra- <u>H</u> igh <u>F</u> requency (300 to 3000 MHz).
U_A	Accumulated utilization [%], from (28).
U_C	Channel utilization [%], see Section 4.8.2.
U_L	Level utilization [%], from (27).
VHF	<u>V</u> ery <u>H</u> igh <u>F</u> requency (30 to 300 MHz).
x	Variable (height or frequency) value for which an interpolated L_b value from (4) is desired.
$x_{1,2}$	Variable (height or frequency) values for points 1 or 2 between which interpolation using (4) is desired.

$Y(q)$	Normalized (about median) variability [dB] of L_b for time availability q . Calculated using (8).
$[Y(0.05)]_U$	Normalized (about median) variability for the 5% ($q=0.05$) interference level from the undesired source(s). Calculated using (8), (23), or (29).
$Y_{DU}(0.95)$	Normalized (about median) variability [dB] of D/U for $q=0.95$ from (9).
$Y_R(0.95)$	Normalized variability for a radar-target-radar path with $q=0.95$. Calculated from (36).
$Y_\sigma(q)$	Normalized variability for radar cross section, from (35).
$z_{mo}(Q)$	Value of the standard normal deviate for a particular Q , from Figure 87.
α_i	Mean power [watt type units] for i th undesired facility, from (19).
Δh	Terrain parameter used to characterize terrain [11, Table 7, Fig. 53; 15, Sec. 2.2].
λ	Wavelength.
μ_i	Variance of power [watts ² type units] for i th undesired facility, from (20).
π	3.141592654.
$\sum_i$	Used to indicate a summation over n undesired sources, see (22).
$\sigma^2(q, Q)$	Total standard error for an L_b for a particular q and Q , from (32).
$\sigma^2(q)$	Prediction errors or path-to-path variance, from (30).
$\sigma_{ce}^2(q)$	Combined standard error variance, from (31).
$\sigma_{DU}(0.95, Q)$	Standard error for a D/U(0.95) prediction for a particular value of Q , from (33).
σ_e^2	Standard error variance used to account for uncertainties associated with equipment performance parameters, see (31).
σ_i	Standard deviation [dB] for i th undesired facility, from (18).
σ_U	Standard deviation [dB] for contributions from simultaneous independent undesired sources, from (22).

- [...] _D Used to indicate that the bracketed items are associated with the desired facility.
- [...] _i Used to indicate that the bracketed items are associated with the *i*th undesired facility or volume.
- [...] _U Used to indicate that the bracketed items are associated with the undesired facility.

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