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HANDBOOK OF RADIO WAVE PROPAGATION LOSS (100 – 10,000 MHz)

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TABLE OF CONTENTS

Subsection ... Page

FOREWORD ... iv

ACKNOWLEDGEMENT ... vi

ABSTRACT ... vi

SECTION 1

INTRODUCTION

BACKGROUND ... 1

SCOPE ... 1

BASIC MEDIAN TRANSMISSION LOSS CURVES ... 3

EFFECTIVE ANTENNA HEIGHTS ... 6

SECTION 2

APPLICATIONS

GENERAL ... 10

Example Problem ... 12

PROPAGATION EQUATIONS AND CONVERSIONS ... 15

FREE-SPACE EQUATIONS ... 15

Power Density in Free Space ... 15

Received Power in Free Space ... 17

EQUATIONS USED WHEN THE ANTENNAS ARE NOT IN FREE SPACE ... 20

A General Equation for Received Power ... 20

A General Equation for Power Density ... 21

COMPUTING THE ELECTRIC FIELD STRENGTH ... 21

SECTION 3

TERMINOLOGY

SUPPLEMENTARY DEFINITIONS.. 23

MODIFICATIONS TO THE SMOOTH-EARTH MEDIAN TRANSMISSION LOSS............. 23

LIST OF ILLUSTRATIONS

Figure		Page
1	Transmission loss and path geometry............................	4
2	Sample format of transmission loss curves......................	5
3	Example of different effective antenna heights for the same structural antenna heights..................................	7
4	Transmission loss for different effective antenna heights......	8

LIST OF TABLES

Table		Page
1	PATH SURFACE ELECTRICAL PARAMETERS.............................	2
2	CONSTANTS FOR EQUATIONS..	17
3	CONVERSION OF POWER DENSITY TO ELECTRIC FIELD STRENGTH.........	22

REFERENCES 26

APPENDIX A: CURVES OF BASIC MEDIAN TRANSMISSION LOSS A-1

FOREWORD

The Integrated Propagation System (IPS) is a computerized propagation prediction model that was used to calculate the propagation loss values in this document. The methods in the IPS model predict the median value of radio wave propagation loss at far field distances over a spherical earth for the line-of-sight modes of surface wave, free space, and multipath; and for the beyond-line-of-sight modes of smooth earth diffraction and tropospheric scatter. The program includes routines that automatically select the appropriate propagation mode, based on input parameters and path geometry. The IPS model was developed using propagation methods described in CCIR Study Group 5, Volume V entitled Propagation in a Non-Ionized Media. The fundamental propagation methodologies used in the IPS and Ground Wave Propagation (GRWAVE) (see CCIR Report 714) models are similar except the IPS model includes the tropospheric forward scatter mode. The following is a list of reference CCIR Study Group V documents that describe the propagation methods incorporated in the IPS model:

Recommendation 310 - Definitions of Terms Relating to Propagation in the Troposphere

Recommendation 341 - The Concept of Transmission Loss for Radio Links

Recommendation 369 - Reference Atmosphere for Refraction

Recommendation 453 - The Formula for Radio Refractive Index

Recommendation 525 - Calculation of Free Space Attenuation

Recommendation 526 - Propagation by Diffraction

Recommendation 527 - Electrical Characteristics of the Surface of the Earth

Recommendation 530 - Propagation Data Required for Design of Tropospheric-Scatter Trans-Horizon Radio Relay Systems and Earth-Space Telecommunication Systems

Report 229 - Electrical Characteristics of the Surface of the Earth

Report 238 - Propagation Data Required for Trans-Horizon Radio-Relay Systems

Report 563 - Radiometeorological Data

Report 714 - Groundwave Propagation in an Exponential Atmosphere

Report 717 - World Atlas of Ground Conductivities

Report 719 - Attenuation by Atmospheric Gases

Report 878 - Special Features of the Concept of Transmission Loss in the Ground-Wave Propagation Case

ACKNOWLEDGMENT

Special appreciation is expressed for the efforts of Sharon Rugh and Robert Wilson for applying the Integrated Propagation System (IPS) computer model for calculating the transmission loss values, for applying graphics programs for preparing the curves and graphs included in this report, and for providing suggestions that were helpful in completing this task.

ABSTRACT

This handbook is intended to assist in manual analysis techniques that must be used when an automated analysis is not possible. It provides estimates of radio wave propagation loss between transmitting and receiving antennas above the assumed smooth-earth surface that were calculated using the Integrated Propagation System (IPS) computer model. For many cases involving electromagnetic compatibility analysis, the curves of predicted transmission loss in this report may be used to estimate the transmission loss of the desired and undesired signals. These loss values are given in dB as BASIC MEDIAN TRANSMISSION LOSS for antennas with effective heights up to 5000 meters, operating in the 100 to 10,000 MHz frequency range, over land or sea, at great circle earth surface distances up to 1000 kilometers. This handbook is an initial document intended to be supplemented with additional curves that will be provided on an ongoing basis.

KEY WORDS

Basic Median Transmission Loss
Electromagnetic Compatibility
Radio Wave Propagation
Transmission Loss

SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the radio spectrum allocated to the U.S. Federal Government. Part of NTIA's responsibility is to: "...establish policies concerning spectrum assignment, allocation and use, and provide the various Departments and agencies with guidance to assure that their conduct of telecommunications activities is consistent with these policies" (Department of Commerce, 1983). In support of these requirements, NTIA periodically develops aids to assist in spectrum engineering and analysis techniques. This handbook provides estimates of radio wave far field propagation loss between transmitting and receiving antennas above the assumed smooth surface of the earth using the Integrated Propagation System (IPS) computer model. The objective of this handbook is to assist in manual analysis techniques that must be used when an automated analysis is not possible. This handbook is an initial document intended to be supplemented with additional curves that will be provided on an ongoing basis.

SCOPE

The curves in this handbook provide estimates of radio wave propagation loss between transmitter and receiver terminals elevated above the assumed smooth surface of the earth. The Integrated Propagation System (IPS) computer model was used to calculate or predict all transmission loss values (NTIS, 1983) (Frazier, 1963). These IPS predictions were automatically plotted using a graphics program and a computer-controlled plotter. The values are given in dB, as BASIC MEDIAN TRANSMISSION LOSS. This terminology is used to specify that the transmitting and receiving antennas are assumed to be isotropic and that the predicted loss is the median value (50%) of a large distribution of measured radio wave transmission losses, in dB. An isotropic antenna is a theoretical point source that radiates equally in all directions.

The BASIC MEDIAN TRANSMISSION LOSS estimates are for antennas, up to 5000 meters in height, operating in the 100-10,000 MHz frequency range over great-circle earth-surface distances up to 1000 kilometers. The antenna heights are "effective antenna heights" above the smooth surface of the earth. Effective antenna heights are discussed in detail later. All estimates are based on vertically polarized transmissions over a homogeneous earth surface, having electrical parameters of either sea water or average land. Sea water is typical of ocean water, having a high salt content that results in a good conducting surface along the transmission path. Average land is assumed to have a moisture content that results in a conductivity characteristic of soil that is neither too moist nor too dry. The conductivity and relative permittivity (dielectric constant) of sea water and average land in this report are given below in TABLE 1.

TABLE 1

PATH SURFACE ELECTRICAL PARAMETERS

SURFACE	CONDUCTIVITY	RELATIVE PERMITTIVITY
Sea water	4.64 mhos/meter	81
Average Land	0.005 mhos/meter	15

Transmission paths are assumed to be over a smooth spherical earth with an effective earth radius to compensate for ray bending at low-to-medium antenna elevations. An exponential reference atmospheric model was used to compensate for ray bending at high antenna elevations.

The transmission loss curves are intended to be used in estimating the signal level (field strength or power density) received at a given antenna. The curves are based on propagation modes that provide a median (50 percent) probability of occurrence. In an interference situation, there is at least one undesired, or interference signal, that is present at the receiver antenna along with the desired signal. The included transmission loss curves may be used for estimating transmission loss for both the desired and undesired signals.

Effects of terrain roughness, mixed path surfaces, vegetation, fading relative to the median loss, and tropospheric ducting are not included in the transmission loss curves. References are given for methods and data that may be used to estimate these effects relative to the transmission loss in this handbook.

Figure 1 illustrates the association between smooth-earth-path geometry and the propagation modes represented by the transmission loss curves. The lower part of Figure 1 shows the profile geometry of a smooth-earth path between two antennas. The upper part of Figure 1 shows the transmission loss relative to the path profile given in the lower part of the figure. On the profile, the antennas are separated by a distance that is equal to the smooth-earth radio line-of-sight (LOS) distance. This is the maximum distance at which the radio waves will be unobstructed by the curved surface of the earth for the specified antenna heights. The radio LOS distance is greater than the optical LOS distance on earth, in a normal atmosphere for the specified antenna heights. Figure 1 shows that the maximum path distance where the free-space loss is less than the smooth earth loss for specified antenna heights is actually less than the radio LOS distance. The curve in the upper part of Figure 1 shows that, at short distances, the transmission loss is due to free space or multipath, and at long distances, the transmission loss is due to diffraction or tropospheric scatter. At path lengths less than the maximum free-space-loss distance, reflections from the smooth earth may cause multipath fading as indicated in Figure 1. The smooth earth curves in this handbook follow the peak envelope of the multipath lobes and thus, the transmission loss at short distances is shown to be slightly less than the free-space loss.

BASIC MEDIAN TRANSMISSION LOSS CURVES

The basic transmission loss curves are plotted on standardized format graphs as shown in Figure 2. All the curves are done on two-cycle semilog graph paper, with the ordinate giving basic median transmission loss, in dB, and the abscissa giving the great-circle distance, in kilometers, along the surface of the earth between the transmitter and receiver antenna sites. There are two transmission loss curves on each graph. The straight line on each graph is the Free-Space Transmission Loss. This is the loss determined

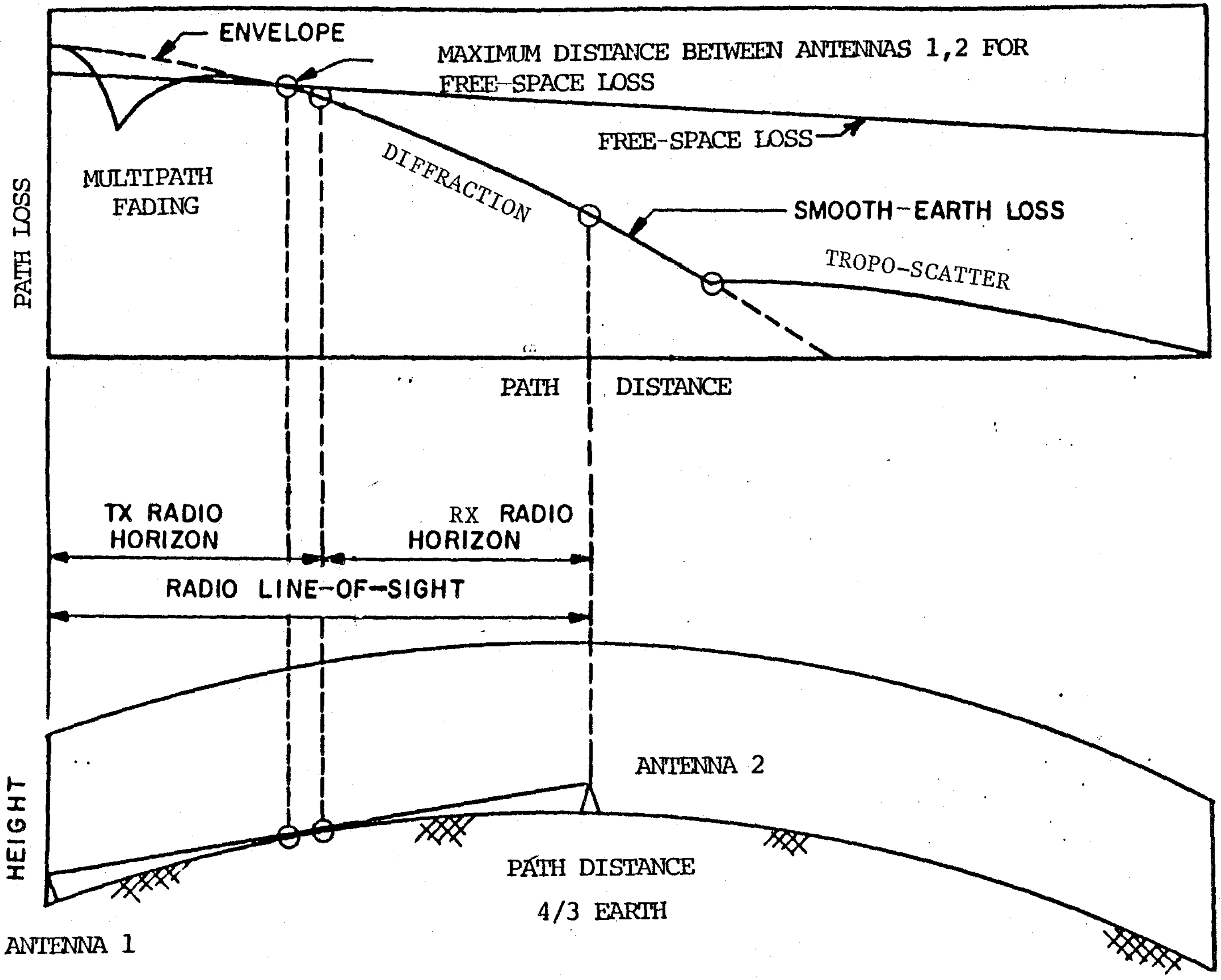

Figure 1. Transmission loss and path geometry.

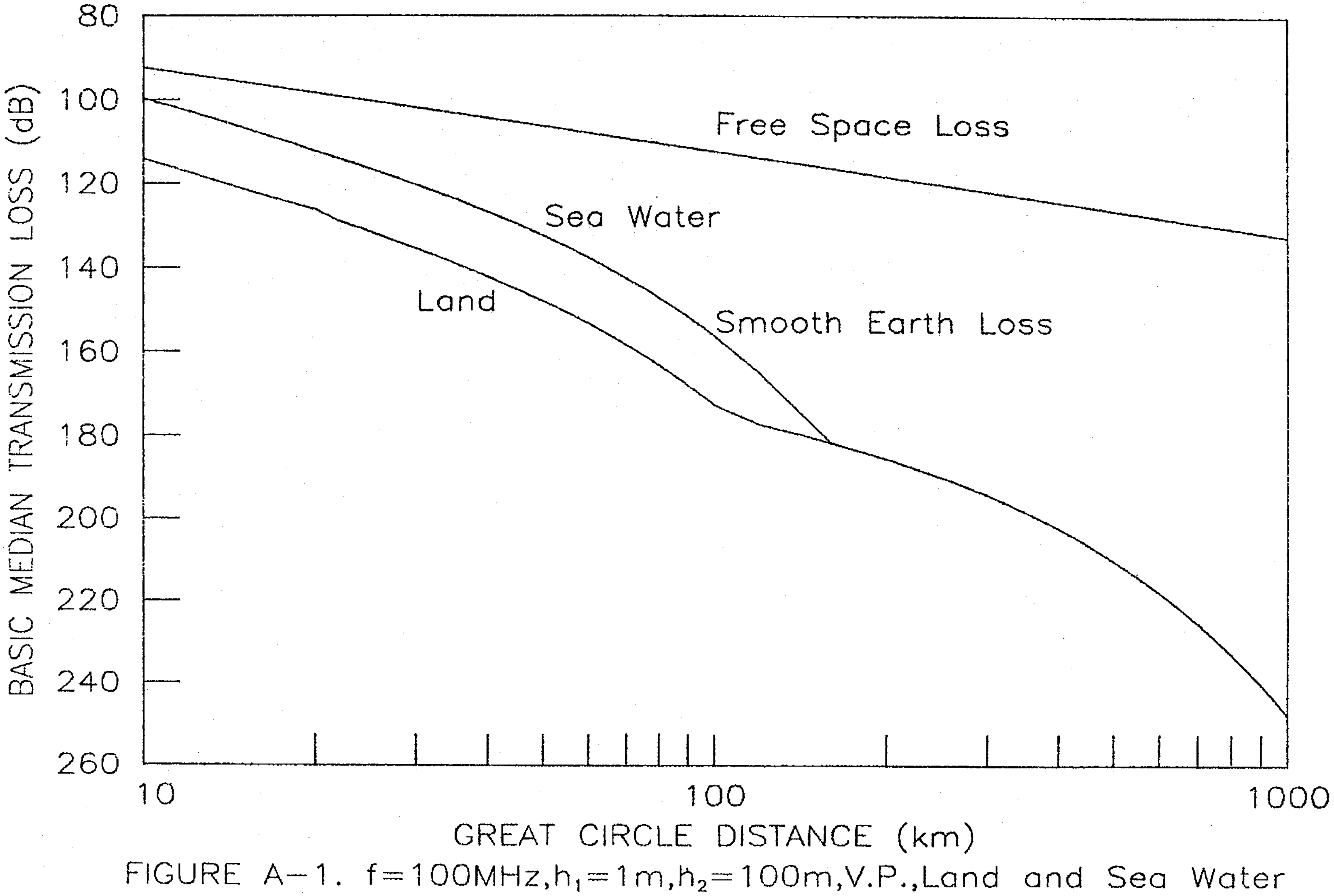

Figure 2. Sample format of transmission loss curves.

by the given frequency and distance in free space, which does not include the effects of the earth or of antenna heights. The other curve gives the Smooth-Earth Transmission Loss. This loss includes the effects of a smooth spherical earth and is the value that should be used for the frequency, distance, and effective antenna heights given. All the figures in this handbook have a standardized and abbreviated summary of the parameters under the figure. These standardized abbreviations of the parameters include the transmission frequency, in MHz; one antenna height (h_1), in meters; the other antenna height (h_2), in meters; V.P. for vertical polarization; and the path surface type (sea water and or land). Note that the path transmission loss will be the same regardless of which antenna is identified as the transmitter or receiver.

For the actual transmission loss curves (see Figures A-1 through A-132 in APPENDIX A), there are two smooth earth transmission loss curves, one for land and one for sea water. There are a number of figures where the land and sea water curves are identical and thus, appear as a single curve for both.

To obtain values of transmission loss from the curves in APPENDIX A for frequency, antenna heights, and path surface that are different from those on the curves, but within the range of parameter values on the curves, an interpolation procedure should be used to estimate an intermediate value between the curves.

EFFECTIVE ANTENNA HEIGHTS

An effective antenna height is the structural antenna height that is increased to take into account the average terrain elevation along the transmission path. The effective antenna height is never less than the structural antenna height. The input antenna heights to the IPS model must be the effective antenna heights. Therefore, in order to utilize transmission loss values from the curves, the antenna heights on the curves must be representative of the effective antenna heights for the user's transmission path.

Figures 3 and 4 are illustrated examples of effective antenna heights and the transmission loss prediction errors that could result from using incorrect effective heights. Figure 3 shows two different transmission path geometries

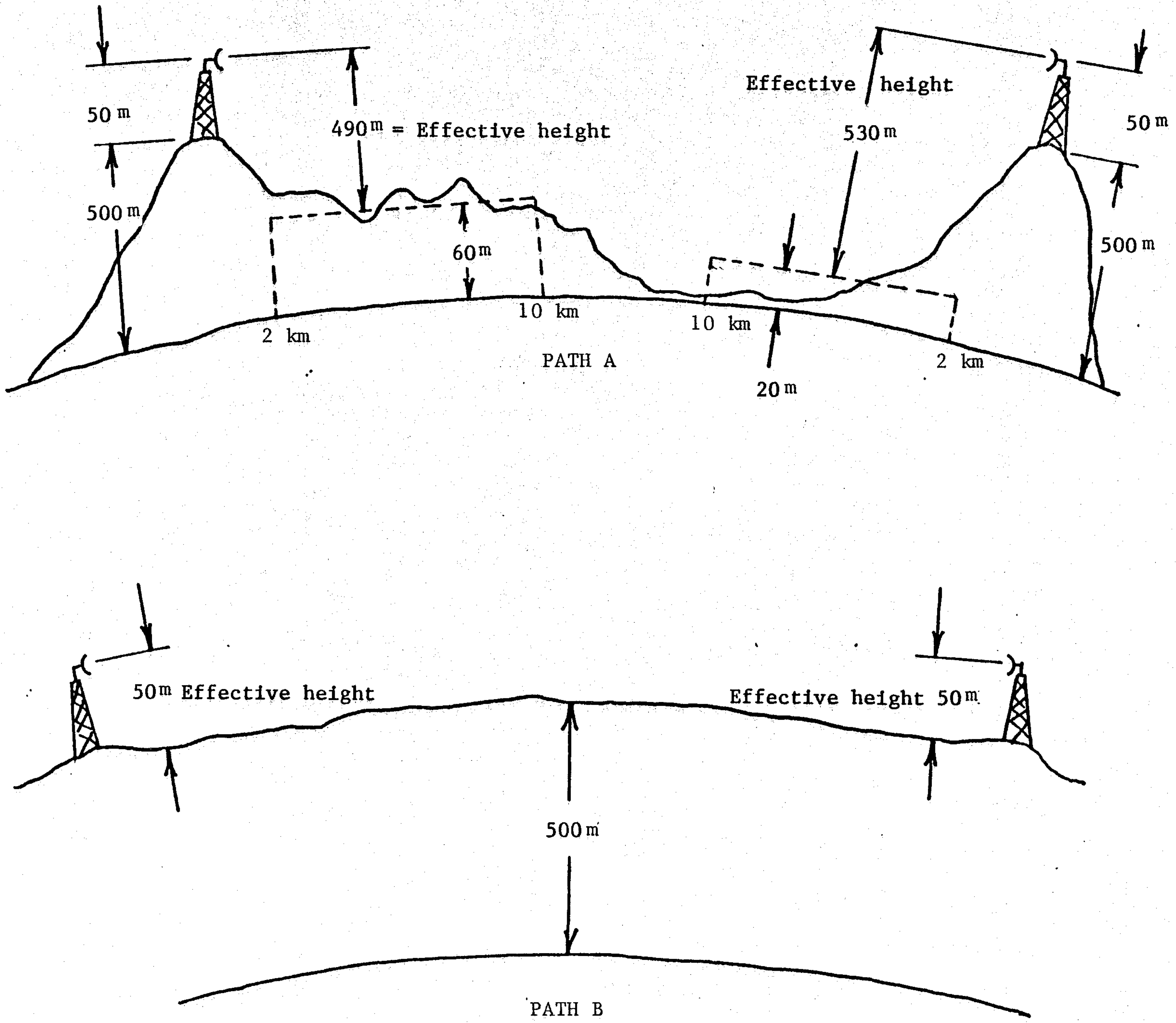

Figure 3. Example of different effective antenna heights for the same structural antenna heights.

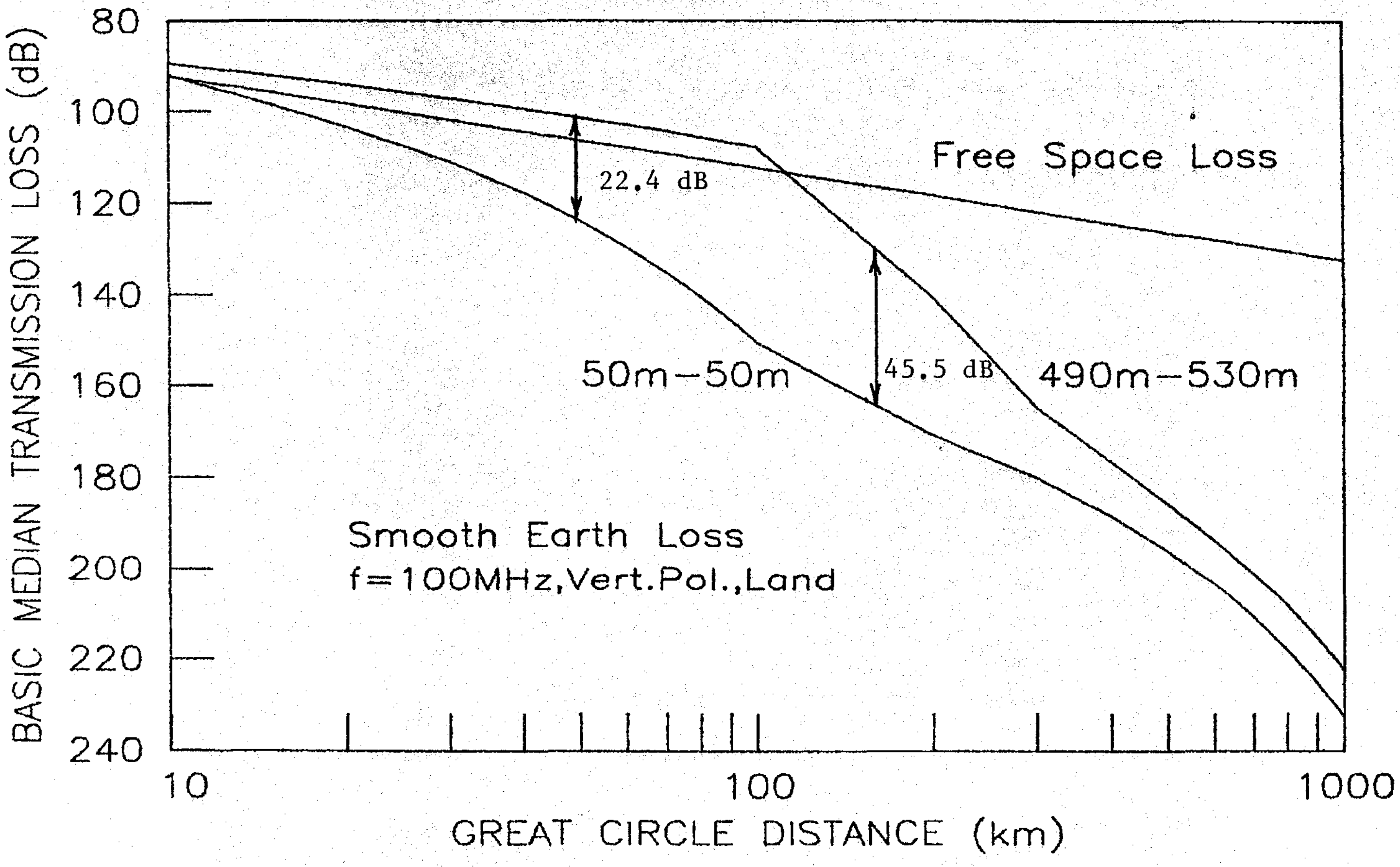

Figure 4. Transmission loss for different effective antenna heights.

although both have structural antenna heights of 50 meters at each end of the path. Path A has the 50-meter structural antennas located on local terrain elevations of 500 meters, while the average terrain elevation along the path for the left antenna site is 60 meters, and for the right antenna, the average elevation is 20 meters. For this example, these average terrain elevations of 60 km and 20 km are determined for the terrain along the path from 2 km to 10 km from each antenna. For the left antenna, the center of radiation is 550 meters above sea level and 490 meters above the average terrain at that end of the path. Similarly, the right antenna height is 550 meters above sea level and 530 meters above the average terrain elevation at that end of the path. The effective antenna heights for the upper path are thus, 490 meters and 530 meters.

Path B has the same 50-meter structural antennas located on a smooth earth surface (plateau) that is 500 meters above sea level. For this path, no terrain adjustments are necessary, since the structural antenna heights are the effective antenna heights. This is because the average terrain elevation along the path is equal to each site elevation. Thus, for Path B, the transmission loss will be the same as if the 50-meter antennas were placed at sea level (assuming atmospheric refractivity changes are negligible).

Figure 4 has transmission loss curves that correspond to Path A and Path B shown in Figure 3. The Path A curve is for effective antenna heights of 490 meters and 530 meters, and the Path B curve is for effective heights of 50 meters and 50 meters. The loss differences between the two curves on Figure 4 are solely due to the differences in the effective antenna heights used in the IPS smooth earth model. As shown in Figure 4, for a transmission path distance of 50 km, the transmission loss difference between the curves is 22.4 dB. At a distance of 150 km, the loss difference is 45.5 dB. The 22.4 dB and 45.5 dB differences represent the prediction error that would result for the paths in Figure 3 if the effective antenna heights used in the IPS computer model do not represent the path geometry.

SECTION 2

APPLICATIONS

GENERAL

Transmission loss is only one parameter in the equation to determine received signal level in, and system performance of, a telecommunication link. It is important to know the relationship of transmission loss to other parameters such as, transmitter power, antenna gains, and interference criteria. To demonstrate this relationship, a summary of the system coupling equation and the important parameters are given in the following section for simple system models. A sample problem is given to illustrate the application of the transmission loss curves in the solution of an interference problem.

The simplest system model for evaluating electromagnetic compatibility (EMC) is one that represents standard deterministic prediction equations for the desired and undesired signals at the receiver input (CCIR, 1983). The desired signal at the receiver input is determined by Equation 1.

$$S_{IN}(\mathrm{dBm}) = S_T(\mathrm{dBm}) + G_T(\mathrm{dBi}) + G_R(\mathrm{dBi}) - L(\mathrm{dB}) \qquad (1)$$

where:

S_{IN} = desired signal at the receiver input
S_T = desired signal from the transmitter
G_T = desired transmitter antenna gain (typically mainbeam gain)
G_R = receiver antenna gain
L = basic transmission loss for desired signal path (the median loss (50%) should be used here).

A simple evaluation would be to compute S_{IN} and compare this value with a performance threshold. If the level of S_{IN} exceeds the threshold, then a level of acceptable desired signal performance is available. The signal could also be readily converted to a signal-to-noise ratio (S/N) since, in Equation 2:

$$(S/N)_{IN}(dB) = S_{IN}(dBm) - N_{IN}(dBm) \quad (2)$$

where:

$(S/N)_{IN}$ = signal-to-noise ratio at the receiver input

N_{IN} = equivalent input noise power

and all other terms are previously defined. An identical analysis can also be performed for the interfering signal in terms of the input power or the input interference-to-noise ratio (I/N). The evaluation of I/N is often employed in EMC analyses.

The undesired signal at the receiver input is given similarly by Equation 3.

$$I_{IN}(dBm) = I_T(dBm) + G_{T1}(dBi) + G_{R1}(dBi) - L_I(dB) \quad (3)$$

where:

I_{IN} = undesired receiver input power

I_T = undesired transmitter signal power

G_{T1} = undesired transmitter antenna gain (mainbeam or sidelobes)

G_{R1} = receiver antenna gain in direction of interference

L_I = basic transmission loss for undesired signal path, (a 10% to 50% loss should be used here)

The next logical step in increasing the complexity of the calculations would be to compute $(S/I)_{IN}$ and compare this to a performance threshold to determine if the level of performance is acceptable or not acceptable. The $(S/I)_{IN}$ is given by Equation 4.

$$(S/I)_{IN}(dB) = S_{IN}(dBm) - I_{IN}(dBm) \qquad (4)$$

and the criteria are:

$(S/I)_{IN}$ (dB) > $(S/I)_{TH}$ (dB) acceptable performance

$(S/I)_{IN}$ (dB) < $(S/I)_{TH}$ (dB) unacceptable performance

where:

$(S/I)_{TH}$ = desired-to-undesired performance threshold criteria (see CCIR Report 526 for typical performance criteria)

and all other terms are previously defined.

Example Problem

To demonstrate application of the transmission loss curves in this handbook, the curves are used in the solution of an example telecommunications problem. This example problem involves a mobile station receiving two cochannel virtually polarized FM signals simultaneously; one desired signal and one undesired signal. The objective is to determine whether the interference to the mobile station receiver is acceptable. The following parameters are known for the telecommunications systems.

Parameter	Base Station (desired signal transmitter)
S_T = 100 watts	Base station transmitter output power
h_T = 10 meters	Base station effective antenna height
G_T = 8 dBi	Base station antenna gain
	Mobile Station (desired signal receiver)
h_R = 1 meter	Mobile station effective antenna height
G_R = 0 dBi	Mobile station antenna gain
N_{IN} = -128 dBm	Mobile station input noise level
$(S/N)_{IN}$ = 15 dB	Mobile station input signal-to-noise ratio
$(S/I)_{TH}$ = 7 dB	Mobile station criteria for FM to FM marginal performance
	Interfering Station (undesired signal transmitter)
I_T = 15 watts	Interfering station's transmitter output power
h_I = 50 meters	Interfering station's effective antenna height
G_{T1} = 7 dBi	Interfering station's antenna gain

The distance between the base station and a specific location of the mobile station is known to be 60 km over a land path. Since the terrain is smooth along the path, the smooth-earth transmission loss curves in APPENDIX A may be used to estimate the propagation loss. The basic median transmission loss between the base station and the mobile station is determined, using the curve for land in Figure A-127, to be L(b) = 171 dB for $h_R = h_1 = 1$ m, $h_T = h_2 = 10$ m, and f = 100 MHz at a distance of 60 km. The level of desired signal at the input to the mobile station can now be determined using Equation 1.

$$\begin{aligned} S_{IN}(\text{dBm}) &= S_T(\text{dBm}) + G_T(\text{dBi}) + G_R(\text{dBi}) - L(\text{dB}) \\ S_{IN}(\text{dBm}) &= 50 + 8 + 0 - 171 \\ S_{IN}(\text{dBm}) &= -113 \end{aligned}$$

The $(S/N)_{IN}$ at the mobile receiver is determined using Equation 2.

$$\begin{aligned} (S/N)_{IN}(\text{dB}) &= S_{IN}(\text{dBm}) - N_{IN}(\text{dBm}) \\ &= -113 - (-128) \\ (S/N)_{IN}(\text{dB}) &= 15 \end{aligned}$$

The distance between an interfering station and the specific location of the mobile station is known to be 53 km over a smooth land path. The propagation loss between the interfering station and the mobile station is thus determined, using the curve for land in Figure A-128, to be $L_I(\text{dB}) = 153$ dB for $h_R = h_1 = 1$ m, $h_I = h_2 = 50$ m, and f = 100 MHz at a distance of 53 km.

The level of the undesired signal at the input to the mobile station is determined using Equation 3.

$$\begin{aligned} I_{IN}(\text{dBm}) &= I_T(\text{dBm}) + G_{T1}(\text{dBi}) + G_{R1}(\text{dBi}) - L_I(\text{dB}) \\ &= 42 + 7 + 0 - 153 \\ I_{IN}(\text{dBm}) &= -104 \end{aligned}$$

The desired-signal-to-interference-signal ratio at the mobile receiver input is determined using Equation 4.

$$\begin{aligned} (S/I)_{IN}(\text{dB}) &= S_{IN}(\text{dBm}) - I_{IN}(\text{dBm}) \\ &= -113 - (-104) \\ (S/I)_{IN}(\text{dB}) &= -9 \end{aligned}$$

The calculated value of $(S/I)_{IN}(dB) = -9$ is compared to the desired-to-undesired performance threshold criteria $(S/I)_{TH} = +7$.

$$(S/I)_{IN}(dB) = -9 < +7 = (S/I)_{TH}(dB)$$

Since the calculated value of $(S/I)_{IN}$ is less than the threshold value of $(S/I)_{TH}$, an unacceptable interference situation exists between the interfering station and the mobile station.

PROPAGATION EQUATIONS AND CONVERSIONS

Equations are given to compute the power density and field strength produced by a transmitter in free space (i.e., a region in which there are no substances to reflect, absorb, refract, or otherwise affect the radio waves). Then the equation is given for computing the power available at the terminals of a receiving antenna that is illuminated by the transmitting antenna. The parameter "basic free-space transmission loss" (L_{bfs}) is introduced to allow this received power to be computed with a compact formula (CCIR, 1982b).

These equations are followed by expressions that can be used when the path between the transmitter and receiver (or observation point) is not in free space. The parameter "basic transmission loss" (L_b) is introduced to allow convenient calculations for these general-environment problems.

FREE SPACE EQUATIONS

Power Density in Free Space

Assume that p(watts) is input to an antenna that is 100 percent efficient and radiates isotropically. Consider observation points at a distance of r(meters) from the transmitter. The power density at these points is now the power per unit area flowing through a spherical shell of radius r with a center at the transmitting antenna. At any point on this sphere, the power density $P_d(W/m^2)$, is determined by Equation 5.

$$P_d(W/m^2) = \frac{P_t(W)}{4\pi r^2(m)} \qquad (5)$$

where:

P_d = power density
P_t = the power delivered to the transmitting antenna
r = distance

and, where r is in statute miles (there are 1609 meters in one statute mile):

$$P_d(W/m^2) = \frac{P_t(W)}{r^2(mi)} \times 30.73 \times 10^{-9} \qquad (5a)$$

If the problem input parameters remain as now stated, but the desired output is in dB above 1 mW/m^2 (i.e., dBm/m^2), then:

$$P_d(dBm/m^2) = 10 \log\left[\frac{P_d(mW/m^2)}{r^2(m)}\right] \qquad (5b)$$

or, for statute miles:

$$= 10 \log\left[\frac{P_t(W)}{r^2(mi)} \times 30.73 \times 10^{-9} \times 10^{3}\right]$$

$$= 10 \log P_t(W) - 20 \log r(mi) + 10 \log (30.73 \times 10^{-6})$$
$$= 10 \log P_t(W) - 20 \log r(mi) - 45.12$$

and, the transmitted power is expressed in dBm (i.e., dB above 1 mW):

$$P_t(dBm) = 10 \log P_t(mW) = 10 \log P_t(W) + 30 \qquad (5c)$$

so that:

$$P_d(\text{dBm/m}^2) = P_t(\text{dBm}) - 20 \log r(\text{mi}) - 75.12 \qquad (5d)$$

but generally:

$$P_d(\text{dBm/m}^2) = P_t(\text{dBm}) - 20 \log r \text{ (units)} - K_1 \qquad (5e)$$

where:

K = a constant dependent on the unit of measurement used to express r (see TABLE 2) and all other terms are previously defined.

TABLE 2

CONSTANTS FOR EQUATIONS

Units of r	K_1	K_2
Statute miles	75.12	36.58
Nautical miles	76.34	37.80
Kilometers	70.99	32.45
Feet	0.67	-37.87
Meters	10.99	-27.55

Received Power in Free Space

The effective aperture (A_e) of an antenna is defined by:

$$A_e(\text{m}) = \frac{P_r(\text{W})}{P_d(\text{W/m}^2)} \qquad (6)$$

where:

P_r =the power delivered to a matched load at the terminals of the receiving antenna

This aperture is computed by:

$$A_e(m) = \frac{g \text{ (numeric)} \lambda(m)^2}{4\pi} \qquad (6a)$$

where:

g = the power gain of the antenna expressed as a ratio relative to the gain of an isotropic antenna that is 100 percent efficient

λ= the wavelength of the radiation

For an isotropic antenna that is 100 percent efficient, g = 1 and:

$$A_e(m) = \frac{\lambda(m)^2}{4\pi} \qquad (6b)$$

and all terms are previously defined. A formula for the power received by such an antenna in free space can be obtained by adding Equations 5 and 6b to Equation 6. The result is:

$$P_r(W) = P_d(W/m)^2 A_e(m)^2 = P_t(W)\left[\frac{\lambda(m)}{4\pi r(m)}\right]^2 \qquad (7)$$

Here, λ and r have the same units, and P_r and P_t have the same nonlogarithmic units (e.g., watts, milliwatts, etc.). If the problem is specified in terms of frequency (f) rather than wavelength, then one can substitute:

$$\lambda(\text{meters}) = \frac{300}{f(\text{MHz})} \qquad (7)$$

into the preceding equation and obtain:

$$P_r = \frac{569.9P_t}{(f(\text{MHz}) \times r(\text{meters}))^2} \qquad (8)$$

where P_r and P_t are in the same nonlogarithmic units.

If the transmitted power and received power are expressed in the same logarithmic units (e.g., dBm or dBW), then the proper equation can be obtained by taking the logarithm (base 10) of each side of this equation and multiplying the results by 10. Thus:

$$P_r = P_t - 20 \log f(\text{MHz}) - 20 \log r(\text{meters}) + 27.55 \qquad (8a)$$

This can be adapted to other units (e.g., when r is in statute miles):

$$P_r = P_t - 20 \log f(\text{MHz}) - 20 \log r(\text{miles}) - 36.58 \qquad (8b)$$

Equation 8b is frequently written as:

$$P_r = P_t - L_{bfs} \qquad (9)$$

where the basic free space transmission loss (L_{bfs}) is given by:

$$L_{bfs} = 20 \log r(\text{units}) + 20 \log f(\text{MHz}) + K_2, \qquad (10)$$

where values for K_2 appear in TABLE 2 for different units of r, the slant range (CCIR, 1982c).

The preceding equations for received power are for lossless (i.e., 100 percent efficient) isotropic antennas at both ends of the link. If the transmitting antenna is not like this, then the power density (P_d) in front of the receiving antenna changes to:

$$P_d = \frac{P_t G_t}{4\pi r^2} \qquad (11)$$

where G_t and G_r are the transmitter and receiver antenna gains, respectively, relative to a lossless isotropic antenna (dimensionless units). If the receiving antenna is not lossless or isotropic, its effective aperture is given by Equation 6a. Inserting Equations 11 and 6a into Equation 6 yields:

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi r}\right)^2 \qquad (12)$$

In logarithmic units (and allowing use of f instead of λ):

$$P_r(\mathrm{dBW}) = P_t(\mathrm{dBW}) + G_t(\mathrm{dBi}) + G_r(\mathrm{dBi}) - 20 \log r(\mathrm{miles}) - 20 \log f(\mathrm{MHz}) - 36.58 \qquad (13)$$

where

$G_t(\mathrm{dBi}) = 10 \log G_t$

$G_r(\mathrm{dBi}) = 10 \log G_r$

dBi = decibels above the gain of lossless (100 percent efficient) isotropic antenna.

NOTE: Some manufacturers specify gain relative to a lossless 1/2 λ dipole, rather than relative to an isotropic antenna. In this case, add 2.15 dB to the manufacturers' values before using them in Equation 13.

Combining Equations 10 and 13 yields the equation for power available at the terminals of the receiving antenna when the transmission medium is free space:

$$P_r(\mathrm{dBw}) = P_t(\mathrm{dBw}) + G_t(\mathrm{dBi}) + G_r(\mathrm{dBi}) - L_{bfs}(\mathrm{dB}) \qquad (14)$$

EQUATIONS USED WHEN THE ANTENNAS ARE NOT IN FREE SPACE

A General Equation for Received Power

Equation 14 accounts for the $1/(4\pi r^2)$ spreading loss in free space, a region free from reflecting, absorbing or refracting materials. The terms G_r and G_t are receiver and transmitter antenna gains, respectively, in dBi. These terms also account for losses within the antennas due to the lack of 100 percent radiation efficiency.

There may be other losses between the outputs of the transmitter and the transmitting antenna. These can be ohmic losses (e.g., in transmission lines, wave guides or antenna couplers). Mismatch losses can also occur. Similar losses may exist between the receiving antenna and the input to the receiver. Also, there may be differences in the polarization of transmitting and receiving antennas. To account for these losses when calculating the power at the input terminals of the reciever (P_r), Equation 14 should be modified to read:

$$P_r = P_t + G_t + G_r - L_{bfs} - (\text{OTHER LOSSES}) \qquad (15)$$

where P_t is the power available at the output of the transmitter.

In many cases, the space between the two antennas will contain atmospheric effects (e.g., rain) or irregular earth obstructions (e.g., hills and mountains). Thus, the basic free space transmission loss (L_{bfs}) will frequently not be appropriate. Instead, the more general basic transmission loss (L_b) is needed. The received power equation becomes:

$$P_r = P_t + G_t + G_r - L_b - (\text{OTHER LOSSES}) \qquad (16)$$

A General Equation for Power Density

An equation for predicting power density in a non-free space environment can be obtained by entering Equations 16 and 6a into Equation 6 and solving for P_d. The result is:

$$\begin{aligned} P_d(\text{dBm/m}^2) = {} & P_t(\text{dBm}) + G_t - L_b + 20 \log (f(\text{MHz})) \\ & - 38.54 - (\text{Losses between the transmitter} \\ & \text{output and the transmitting antenna}). \end{aligned} \qquad (17)$$

COMPUTING THE ELECTRIC FIELD STRENGTH

If the engineer/analyst needs to know the electric field strength at a point in space, it may be computed from the power density. In the far field of the transmitting antenna, these quantities are related by:

$$P_d(\text{W/m2, avg}) = \frac{E^2(\text{V/m, rms})}{\eta} \qquad (18)$$

where:

E = electric field strength

η = the impedance of free space = $120\pi\Omega$ or $\approx 377\Omega$

rms = root mean square.

TABLE 3 is a set of conversion equations for a variety of units.

TABLE 3

CONVERSION OF POWER DENSITY TO ELECTRIC FIELD STRENGTH

$E_{rms} = 19.42\ (P_{avg})^{1/2}$	E_{rms} in V/m, P_{avg} in W/m^2
$E_{rms} = .61 \times 10^{P_{avg}/20}$	E_{rms} in V/m, P_{avg} in dBm/m^2
$E_{rms} = P_{avg} + 115.8$	E_{rms} in dBμV/m, P_{avg} in dBm/m^2
$P_{avg} = \frac{(E_{rms})^2}{376.99}$	P_{avg} in W/m^2, E_{rms} in V/m
$P_{avg} = 20 \log E_{rms} + 4.24$	P_{avg} in dBm/m^2, E_{rms} in V/m
$P_{avg} = E_{rms} - 115.8$	P_{avg} in dBm/m^2, E_{rms} in dBμV/m

where:

E_{rms} = rms electric field strength,

P_{avg} = average power density.

NOTES: 1) Transmitter duty cycle effects must be taken into account independently, as must all nonsinusoidal waveforms.

2) All relations apply only in the far field.

SECTION 3

TERMINOLOGY

SUPPLEMENTARY DEFINITIONS

In using some references, analysts come across other terms that are used in the calculation of received power. To aid in correlating these with the terms used in this section, some of the more common terms are defined below.

Antenna Factor. This is 10 log of the square of the ratio of the electric field intensity (V/m) at the antenna to the terminal voltage (V). Antenna gain can be computed from the antenna factor using Equation 19.

$$G = 20 \log f - A_f - 30 \qquad (19)$$

where G is the gain in dB, and A_f is the antenna factor in dB.

Transmission Loss. This is 10 $\log_{10}$ of the ratio of the power input to the transmitting antenna to the power available from the receiving antenna. If it is designated as loss (L) in dB, it can be related to L_b through:

$$L = L_b - G_t - G_r \qquad (20)$$

MODIFICATIONS TO THE SMOOTH-EARTH MEDIAN TRANSMISSION LOSS

Modifications of the smooth-earth transmission loss from terrain roughness, mixed path surface, foliage, rain, and long-term time-dependent power fading must be determined from other sources and added to the smooth-earth transmission loss predictions obtained using the methods in this handbook. Comments on the effects of these phenomena, relative to the smooth-earth transmission loss, are given below along with appropriate references.

Terrain roughness along the transmission path can produce transmission loss variations above and below the median loss. Generally, the loss will increase over rough terrain for beyond-the-horizon paths relative to the same distance over a smooth earth. Line-of-sight transmission over rough terrain can produce short term multiple reflections that are referred to as multipath or fast fading. Multipath is characterized by rapid variations about the median loss from a 3 dB improvement to a deep fade of 30 dB or more of the signal. References for the effects of multipath and rough-earth effects are (Rice, 1966), (Powell, 1983), (NTIS, 1983), (CCIR, 1982d), and (Weissberger, 1982).

Mixed path surface transmission can be significantly different than transmission over a path having uniform electrical characteristics. A typical mixed path would be from a ship at sea to an inland station. Propagation characteristics could change abruptly at the land-sea boundary. This phenomenon is important for low antennas at frequencies below about 160 MHz. References for the effects of mixed path propagation are (Millington, 1949), and (Weissberger, 1982).

Foliage attenuation must be considered when either antenna is very near, or emersed in, trees or other foliage. Determining the effects of foliage on the propagating signal requires detailed knowledge of the environment. Although in some cases, foliage may improve the signal propagation, the usual effect is increased attenuation relative to the median. References for foliage attenuation are (Saxton, 1955), (Kinase, 1969), (J & B, 1966), (Weissberger, 1982), and (CCIR, 1982d).

Rain attenuation becomes important for transmissions at frequencies in the 10-30 GHz range. This phenomenon produces the largest variations in signal phase and amplitude on earth-space line-of-sight paths. References for the effects of rain attenuation are (Crane, 1979), (CCIR, 1982e),and (Weissberger, 1982).

Time-dependent power fading (long term) must be considered for propagation over beyond-the-horizon paths. This phenomenon causes variations relative to the median loss due to large-scale slow changes in the atmosphere. It is a function of time of day, time of year, and geographic location. The transmission loss curves in this handbook provide estimates of the median loss (50%) of log normal distribution of transmission losses. The variation about this median for any other percentile (10%, 90%, etc.) can be estimated using an emperical model for long-term time-dependent power fading given in the references below. As an example, for a given propagation path, the transmission loss for a 10% probability may be 10 to 15 dB less than the median loss (50%). Also, for a 90% probability, the loss may be 30 dB more than the median loss. The method and data to estimate long-term time-dependent power fading are well documented in (Rice, 1966), (Weissberger, 1982), (NTIS, 1983), and (Powell, 1983).

Tropospheric ducting is a significant anomalous propagation mode for frequencies above 100 MHz. The probability of occurrence of tropospheric ducting typically is less than about ten percent of the time. The ducting mode usually is not a reliable or continuous mode of propagation. Ducting occurs as the result of atmospheric stratification that is found typically in coastal regions. Tropospheric ducting can produce unusually high signal levels relative to the median value. Estimates of the worldwide probability of occurence of tropospheric ducting and the resultant signal enhancement from ducting may be determined using (CCIR, 1982a) and (Ortenburger, 1978).

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APPENDIX A

CURVES OF BASIC MEDIAN TRANSMISSION LOSS

This appendix contains curves of Basic Median Transmission Loss in dB for frequencies of 100 MHz, 1,000 MHz, and 10,000 MHz. Estimates of transmission loss for frequencies between 100 MHz and 10,000 MHz may be determined by interpolation between the curves. TABLE A-1 is included to help locate the transmission loss curve for a particular combination of frequency and antenna heights.

TABLE A-1: CURVES OF BASIC MEDIAN TRANSMISSION LOSS

LIST OF TRANSMISSION LOSS FIGURES

f(MHz)	h_2(m) h_1(m)	1	10	50	100	200	500	1K	2K	5K
100	1		A-127	A-128	A-1	A-2	A-3	A-4	A-5	A-6
	10		A-129	A-130	A-131	A-7	A-8	A-9	A-10	A-11
	50			A-12	A-13	A-14	A-15	A-16	A-17	A-18
	100				A-19	A-20	A-21	A-22	A-23	A-24
	200					A-25	A-26	A-27	A-28	A-29
	500						A-30	A-31	A-32	A-33
	1K							A-34	A-35	A-36
	2K								A-37	A-38
	5K									A-39
1000	1		A-132	A-40	A-41	A-42	A-43	A-44	A-45	A-46
	10		A-47	A-48	A-49	A-50	A-51	A-52	A-53	A-54
	50			A-55	A-56	A-57	A-58	A-59	A-60	A-61
	100				A-62	A-63	A-64	A-65	A-66	A-67
	200					A-68	A-69	A-70	A-71	A-72
	500						A-73	A-74	A-75	A-76
	1K							A-77	A-78	A-79
	2K								A-80	A-81
	5K									A-82
10000	1		A-83	A-84	A-85	A-86	A-87	A-88	A-89	A-90
	10		A-91	A-92	A-93	A-94	A-95	A-96	A-97	A-98
	50			A-99	A-100	A-101	A-102	A-103	A-104	A-105
	100				A-106	A-107	A-108	A-109	A-110	A-111
	200					A-112	A-113	A-114	A-115	A-116
	500						A-117	A-118	A-119	A-120
	1K							A-121	A-122	A-123
	2K								A-124	A-125
	5K									A-126

Example: f(MHz) = h_1(m) = 200 meters, h_2(m) = 1K meters, curves in Figure A-27.

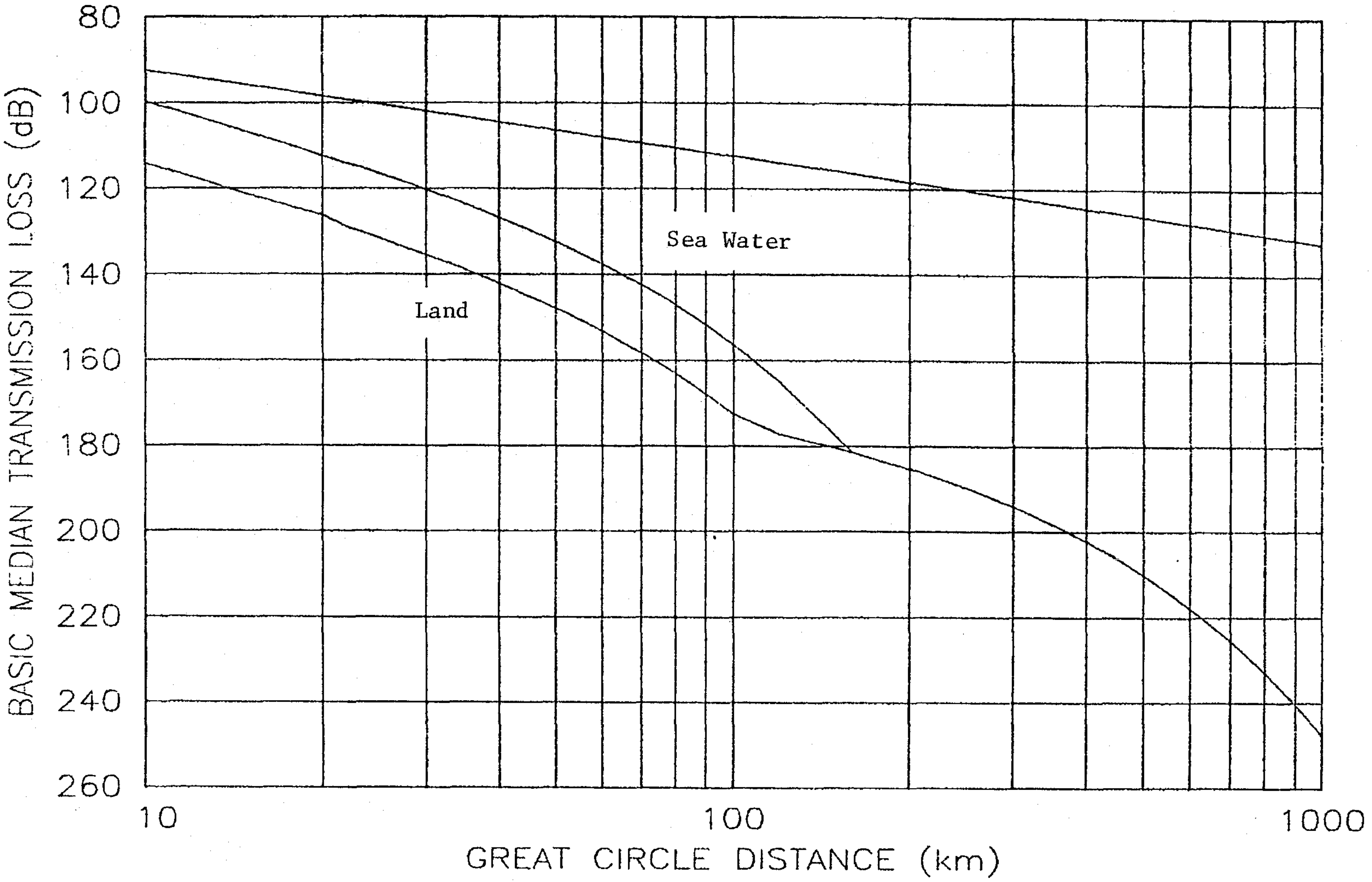

FIGURE A-1. f=100MHz,h_1=1m,h_2=100m,V.P.,Land and Sea Water

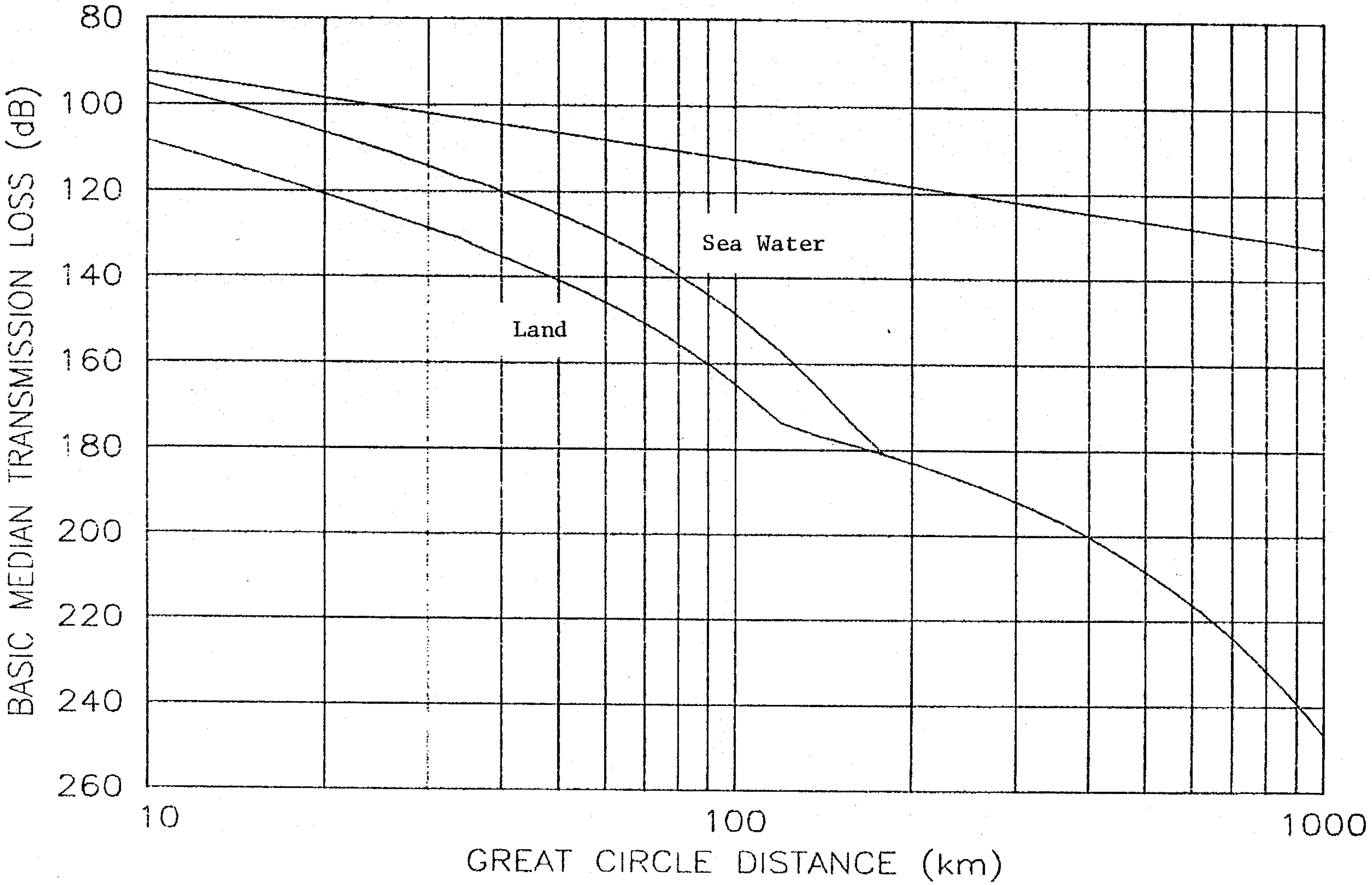

FIGURE A-2. f=100MHz,h_1=1m,h_2=200m,V.P.,Land and Sea Water

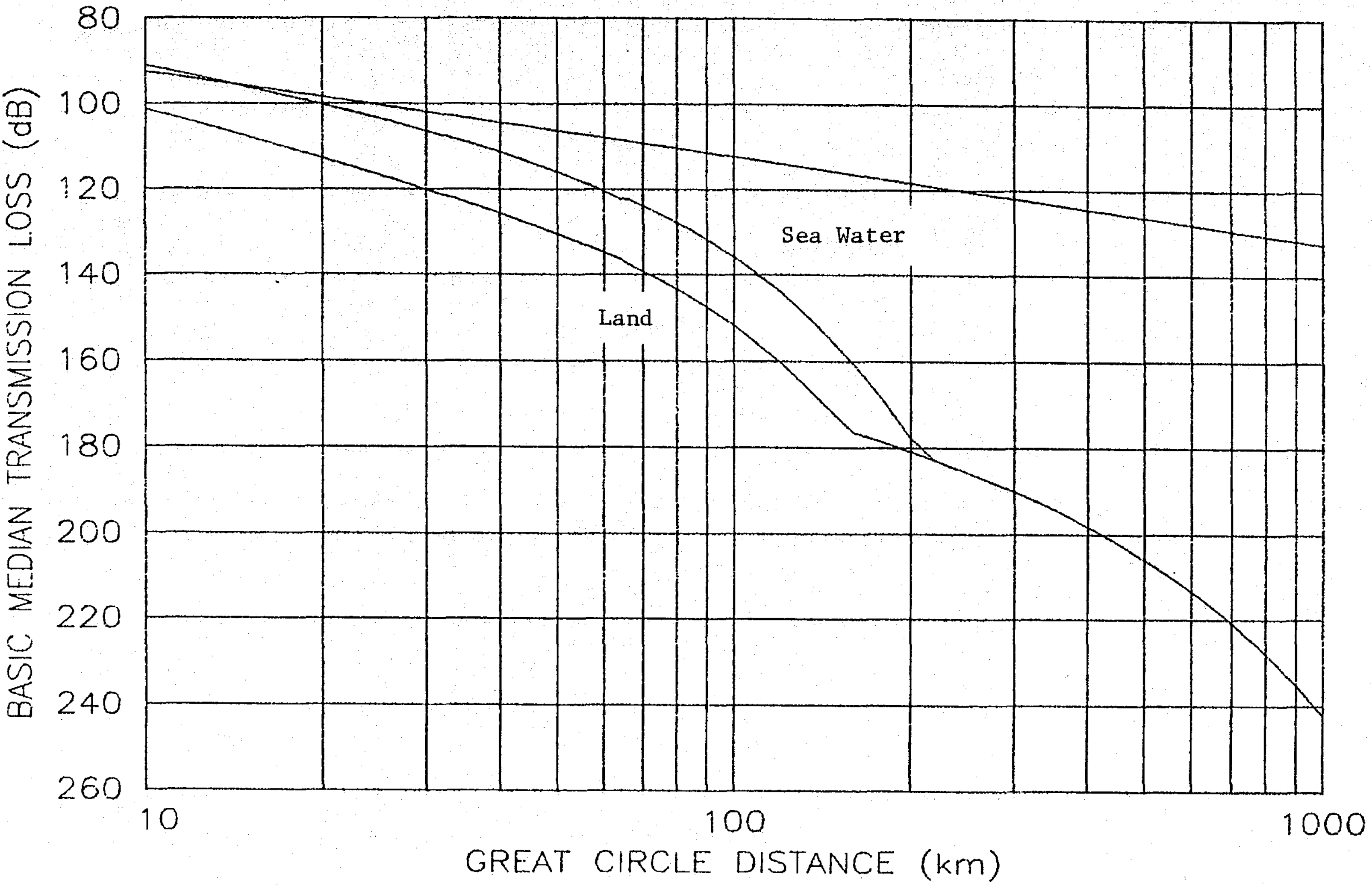

FIGURE A-3. f=100MHz,h_1=1m,h_2=500m,V.P.,Land and Sea Water

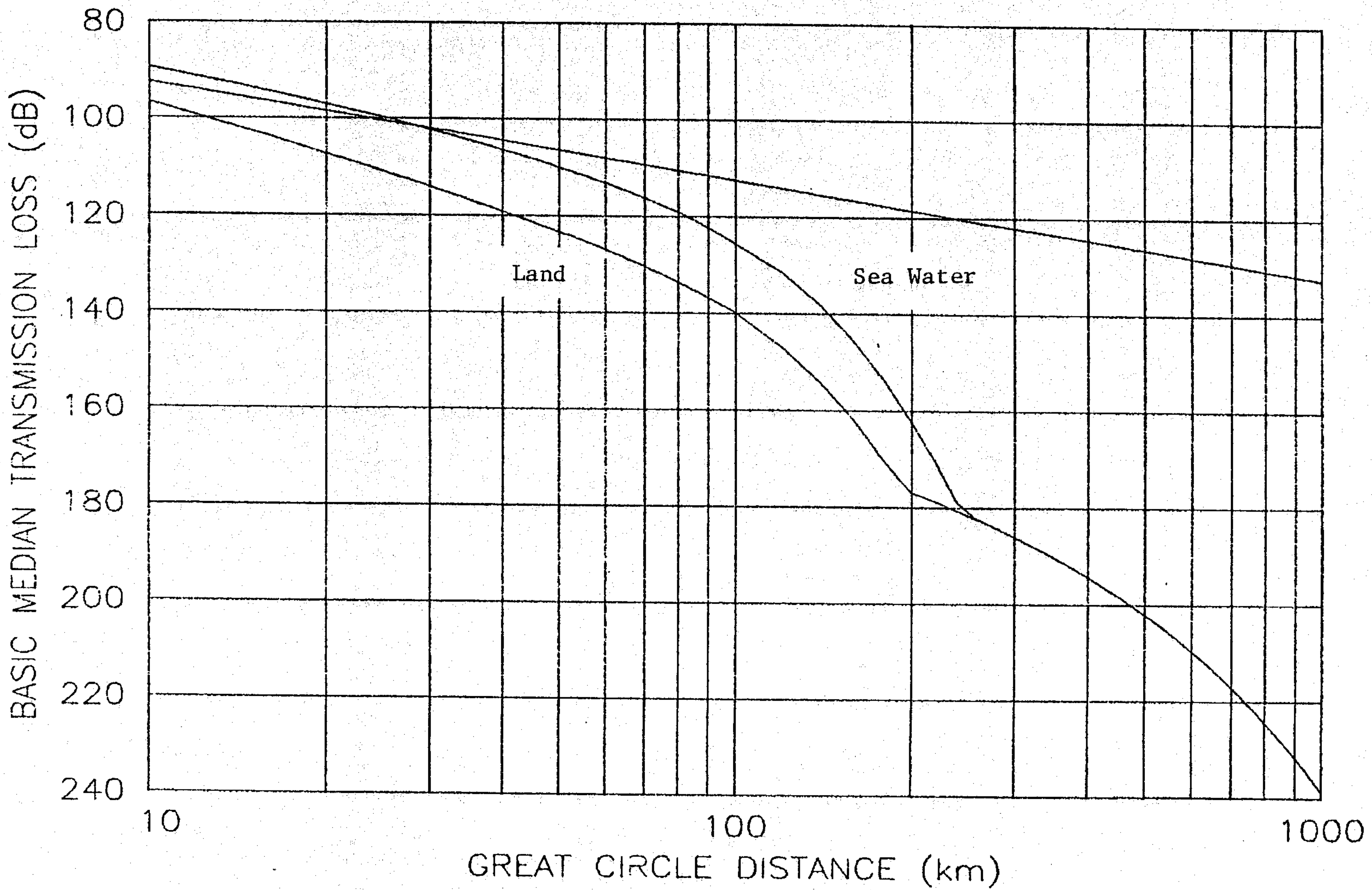

FIGURE A-4. $f=100$MHz, $h_1=1$m, $h_2=1$km, V.P., Land and Sea Water

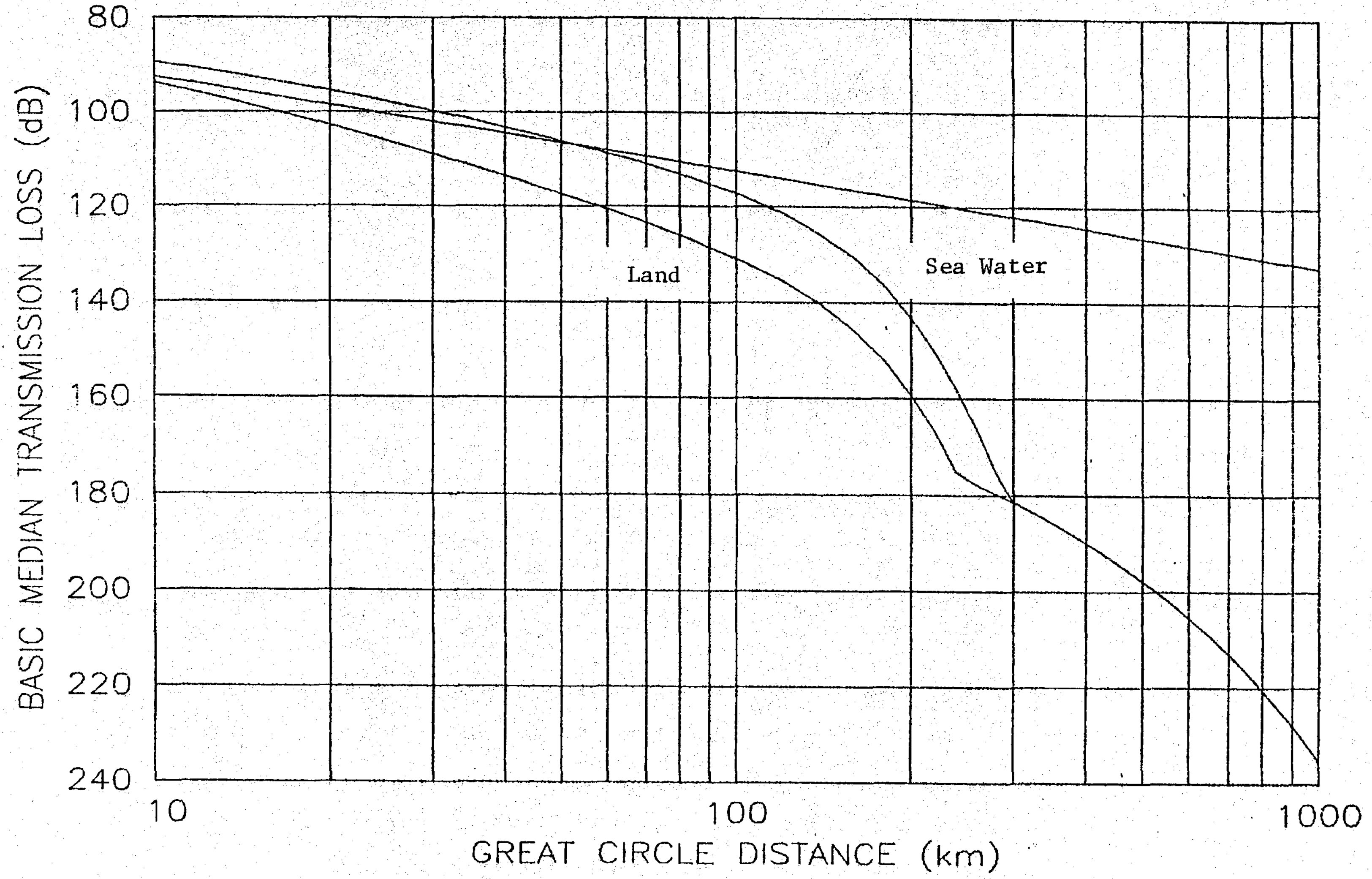

FIGURE A-5. $f=100MHz, h_1=1m, h_2=2km$, V.P., Land and Sea Water

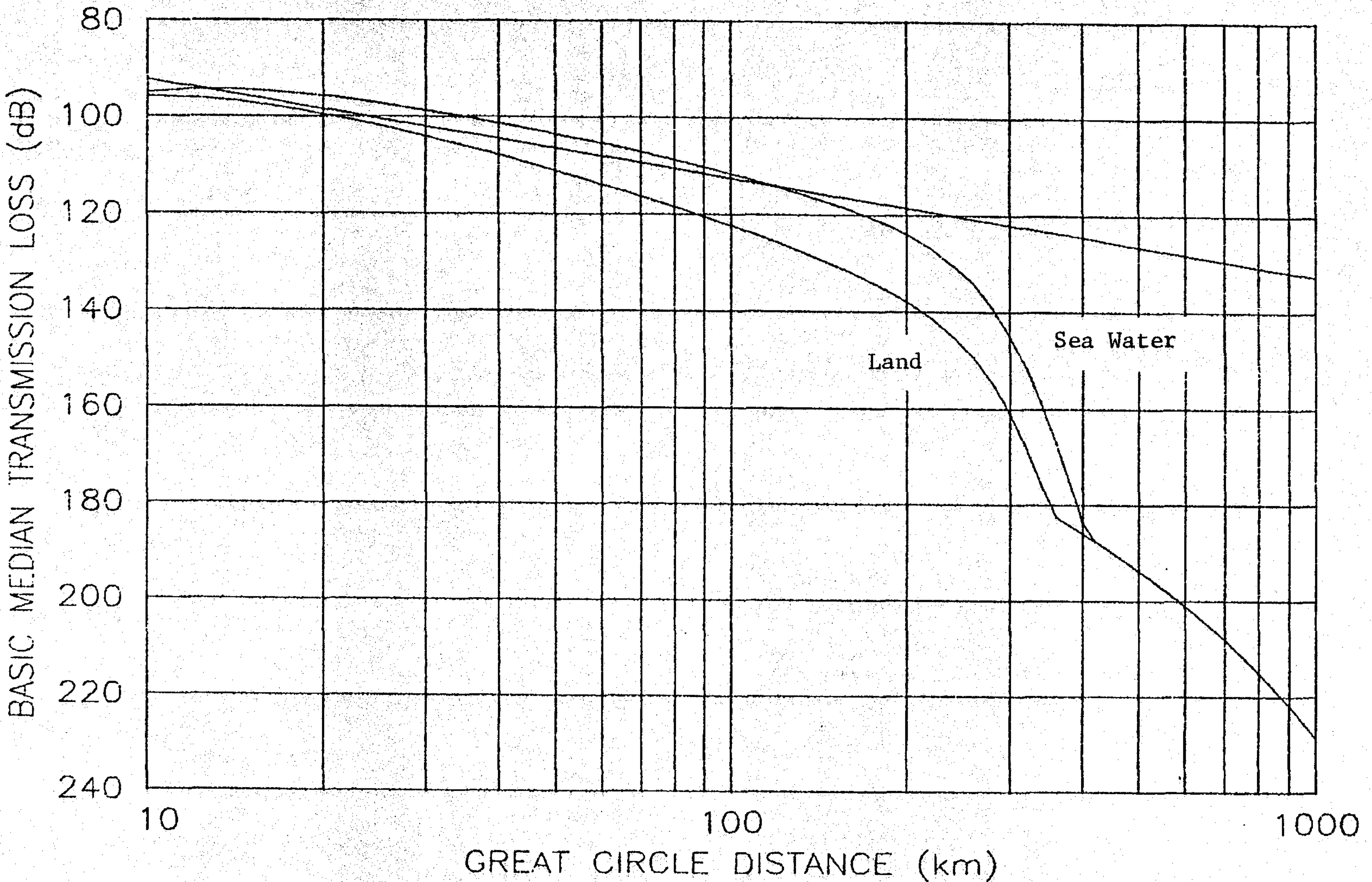

FIGURE A-6. f=100MHz,h_1=1m,h_2=5km,V.P.,Land and Sea Water

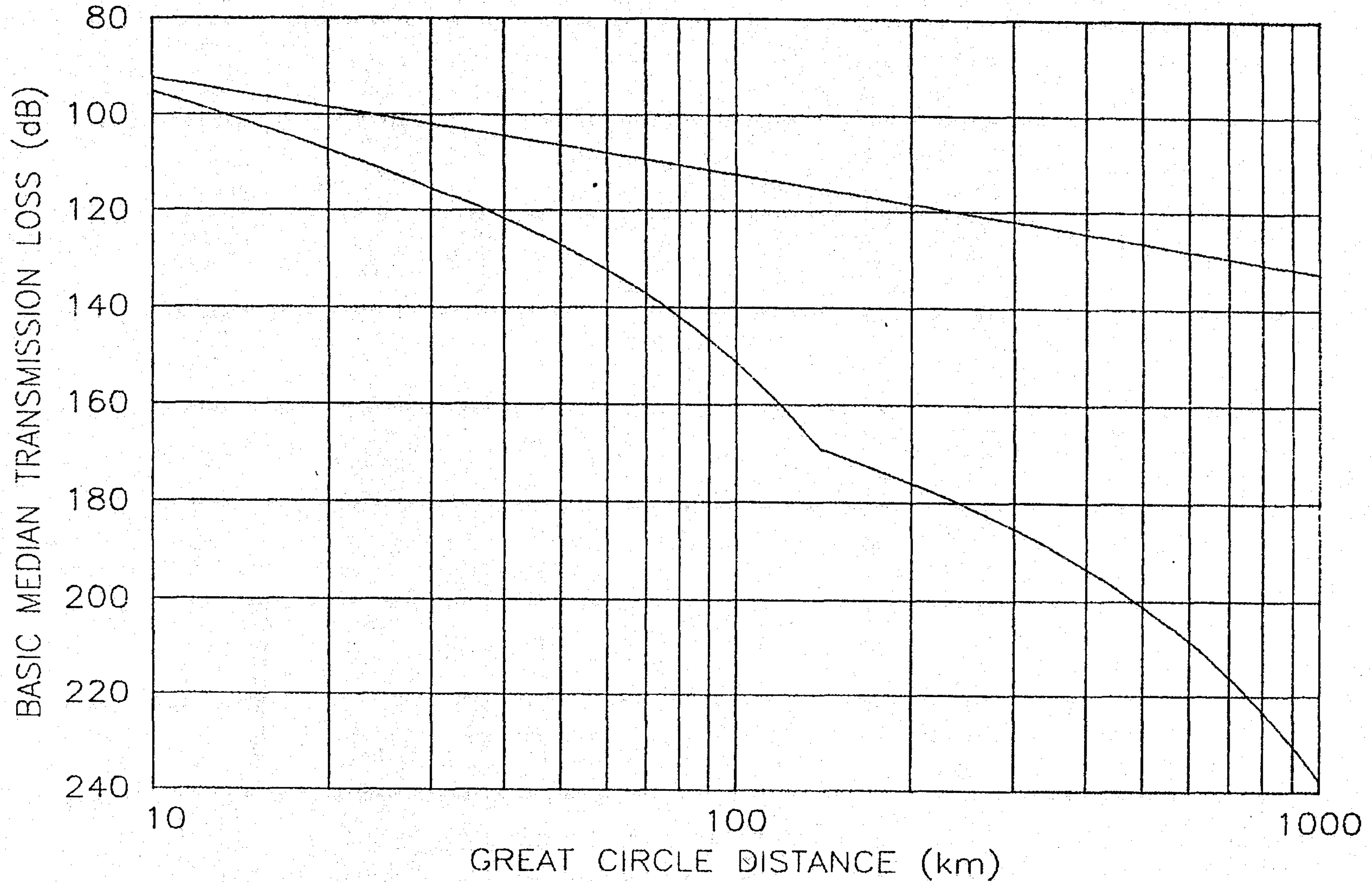

FIGURE A-7. f=100MHz,h_1=10m,h_2=200m,V.P.,Land and Sea Water

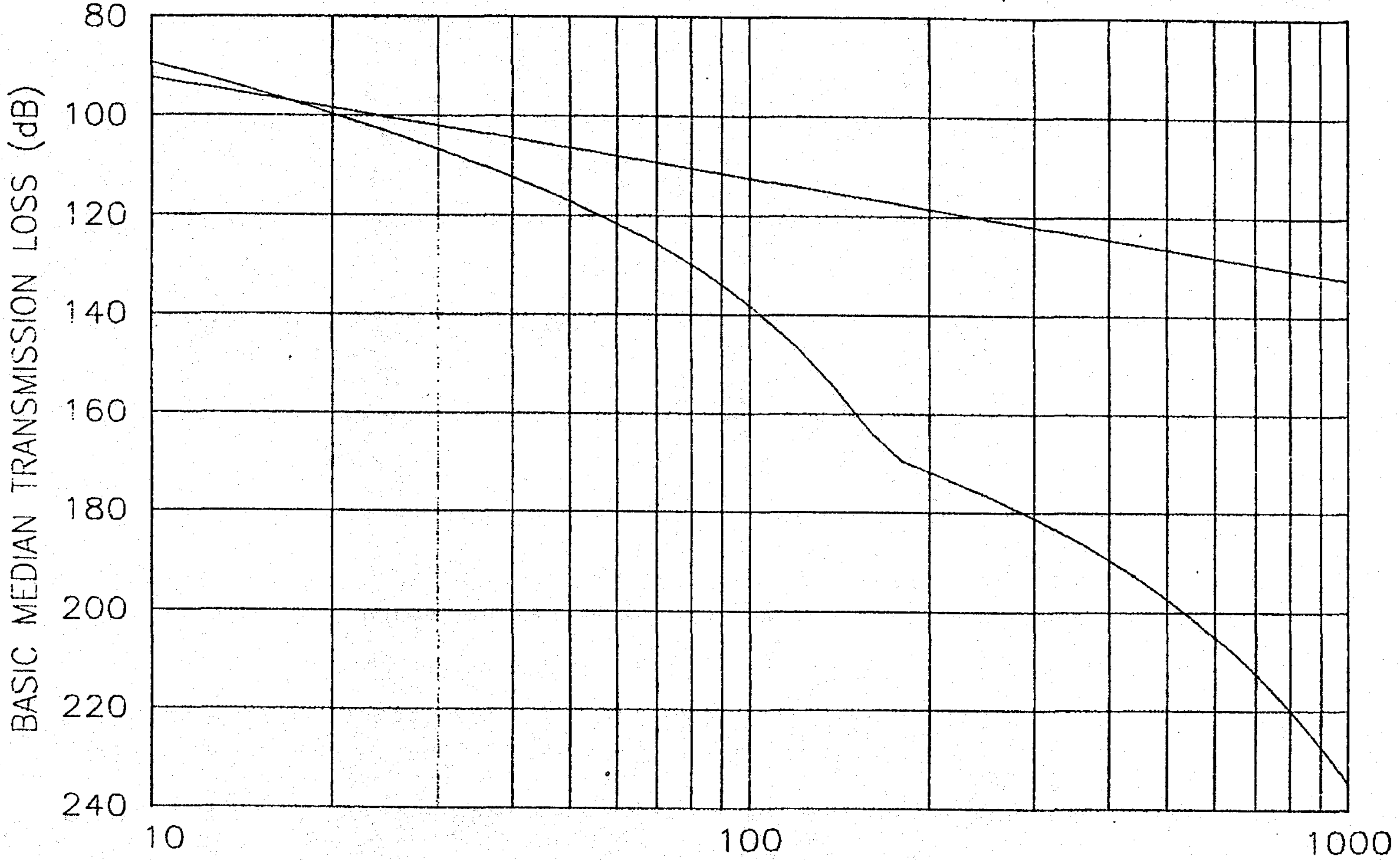

FIGURE A–8. f=100MHz, h_1=10m, h_2=500m, V.P., Land and Sea Water

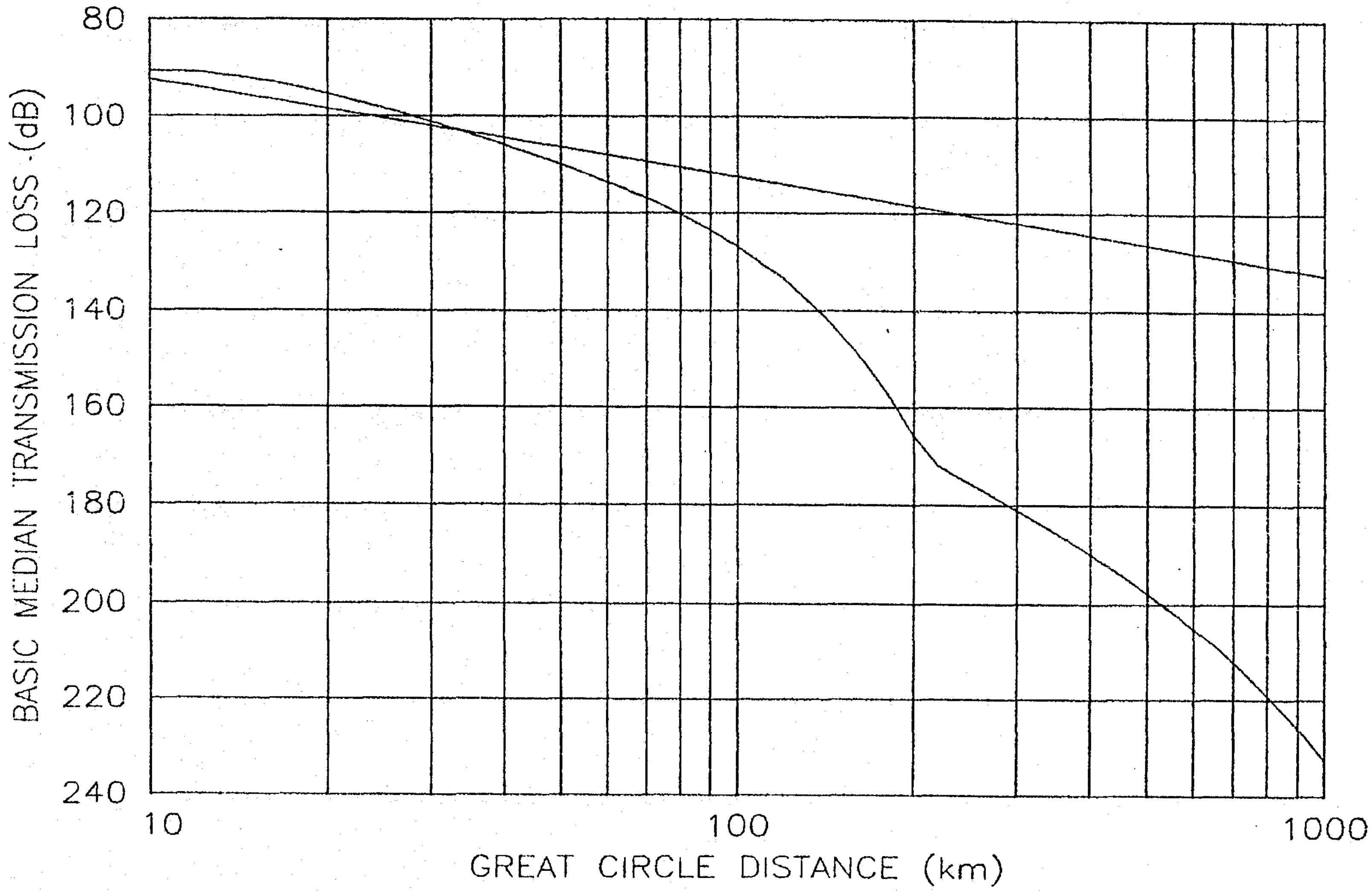

FIGURE A-9. f=100MHz,h_1=10m,h_2=1km,V.P.,Land and Sea Water

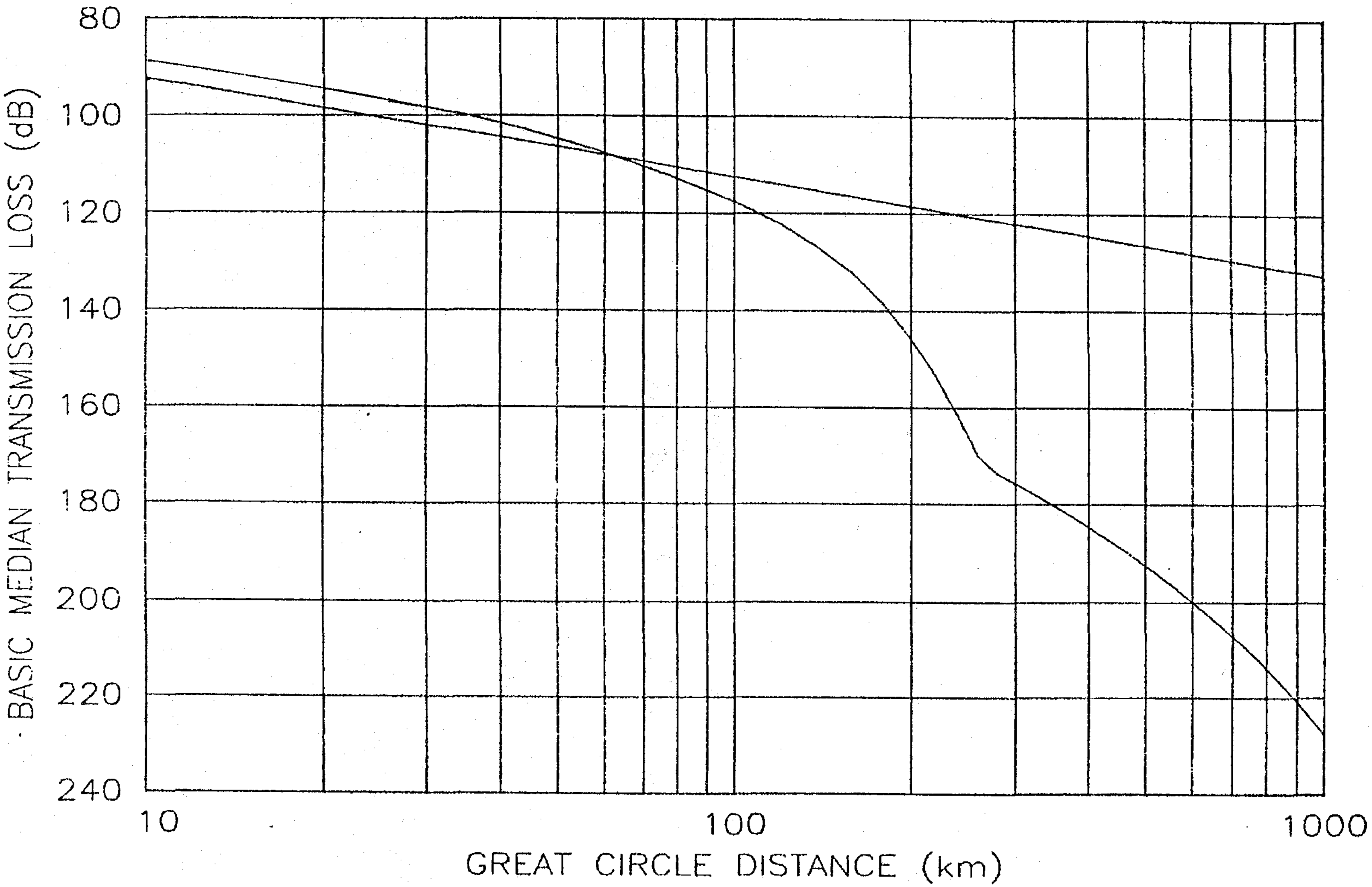

FIGURE A-10. $f=100\text{MHz}, h_1=10\text{m}, h_2=2\text{km}$, V.P., Land and Sea Water

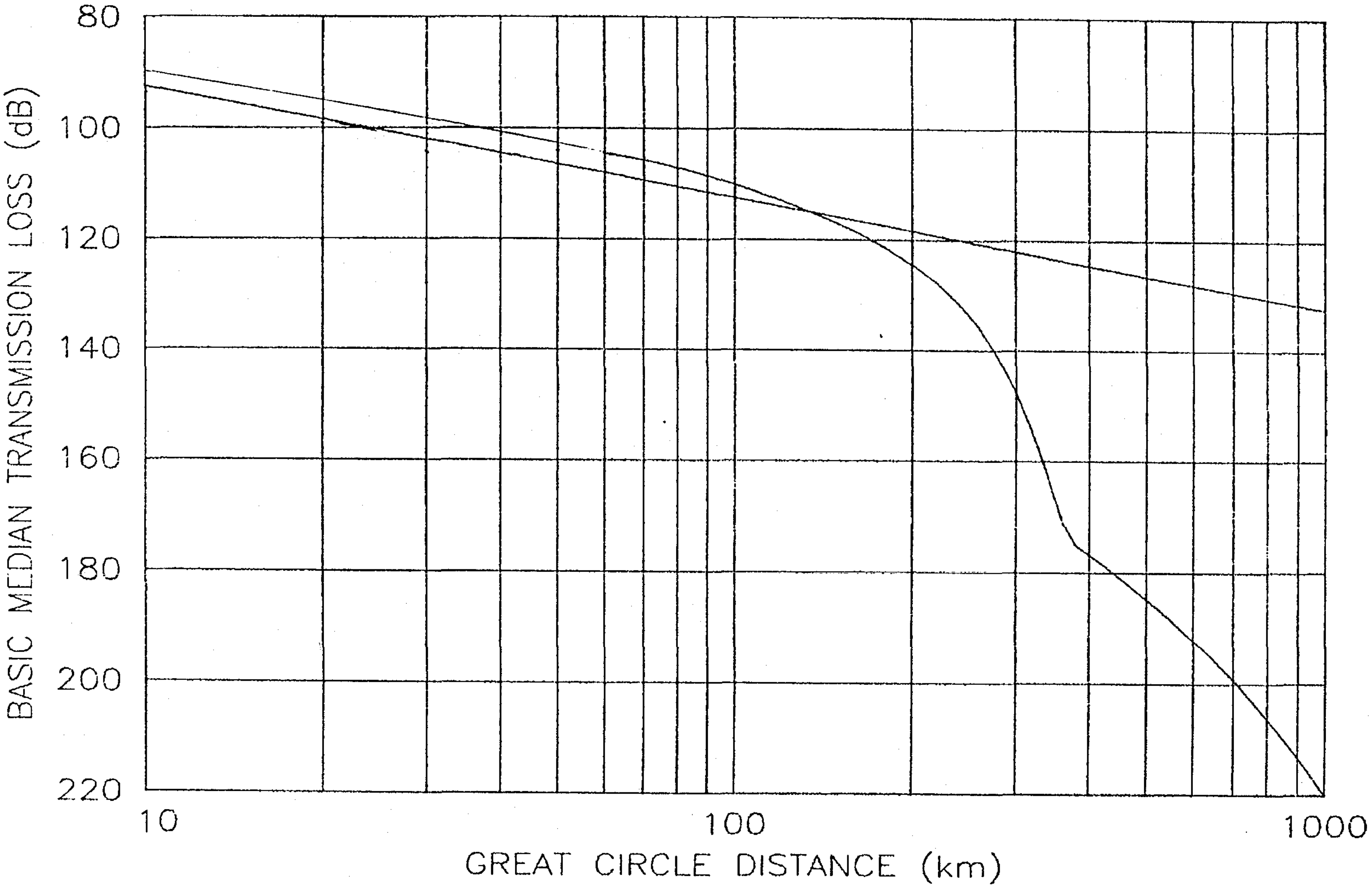

FIGURE A-11. f=100MHz,h_1=10m,h_2=5km,V.P.,Land and Sea Water

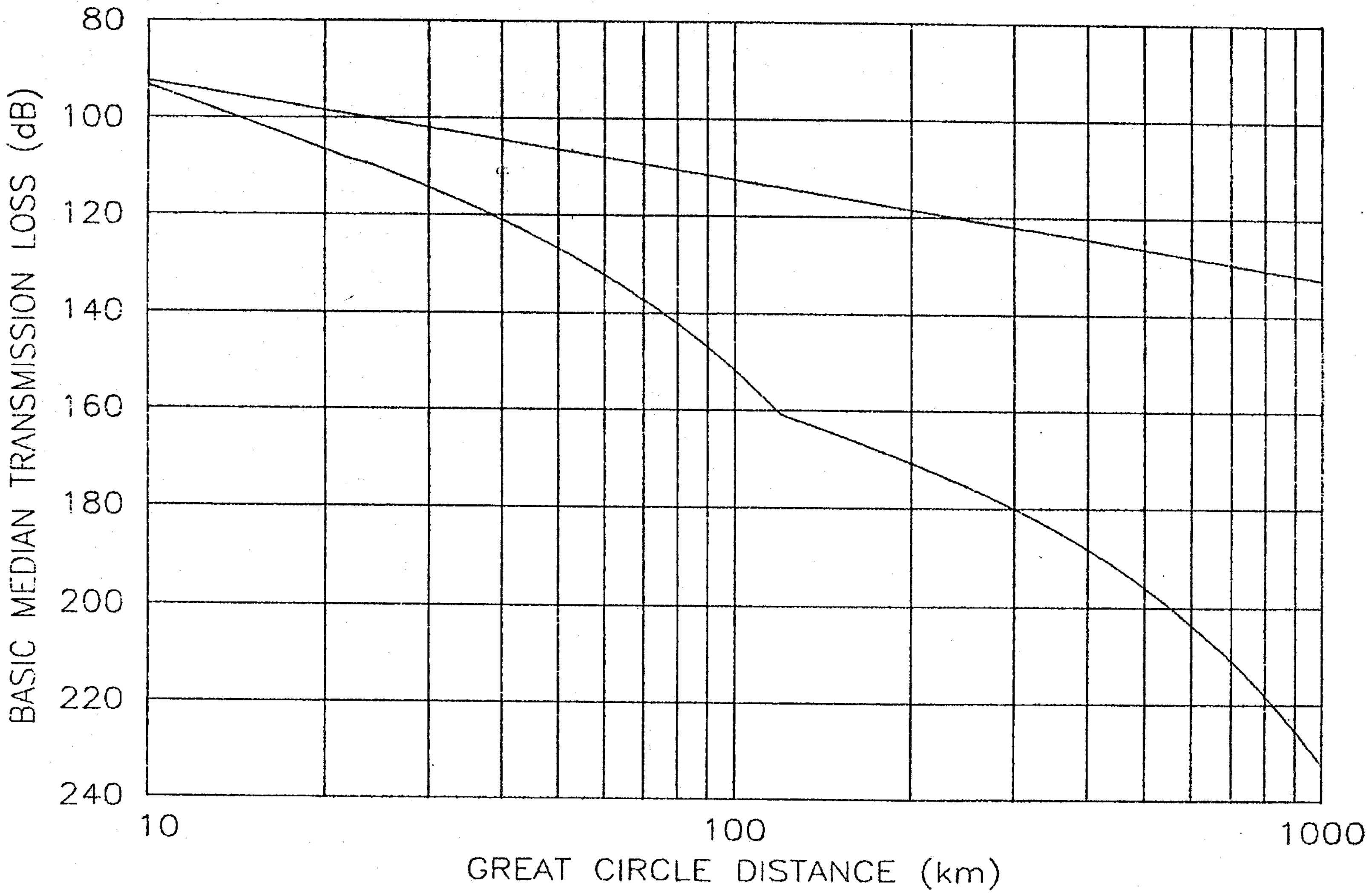

FIGURE A-12. $f=100MHz, h_1=50m, h_2=50m$, V.P., Land and Sea Water

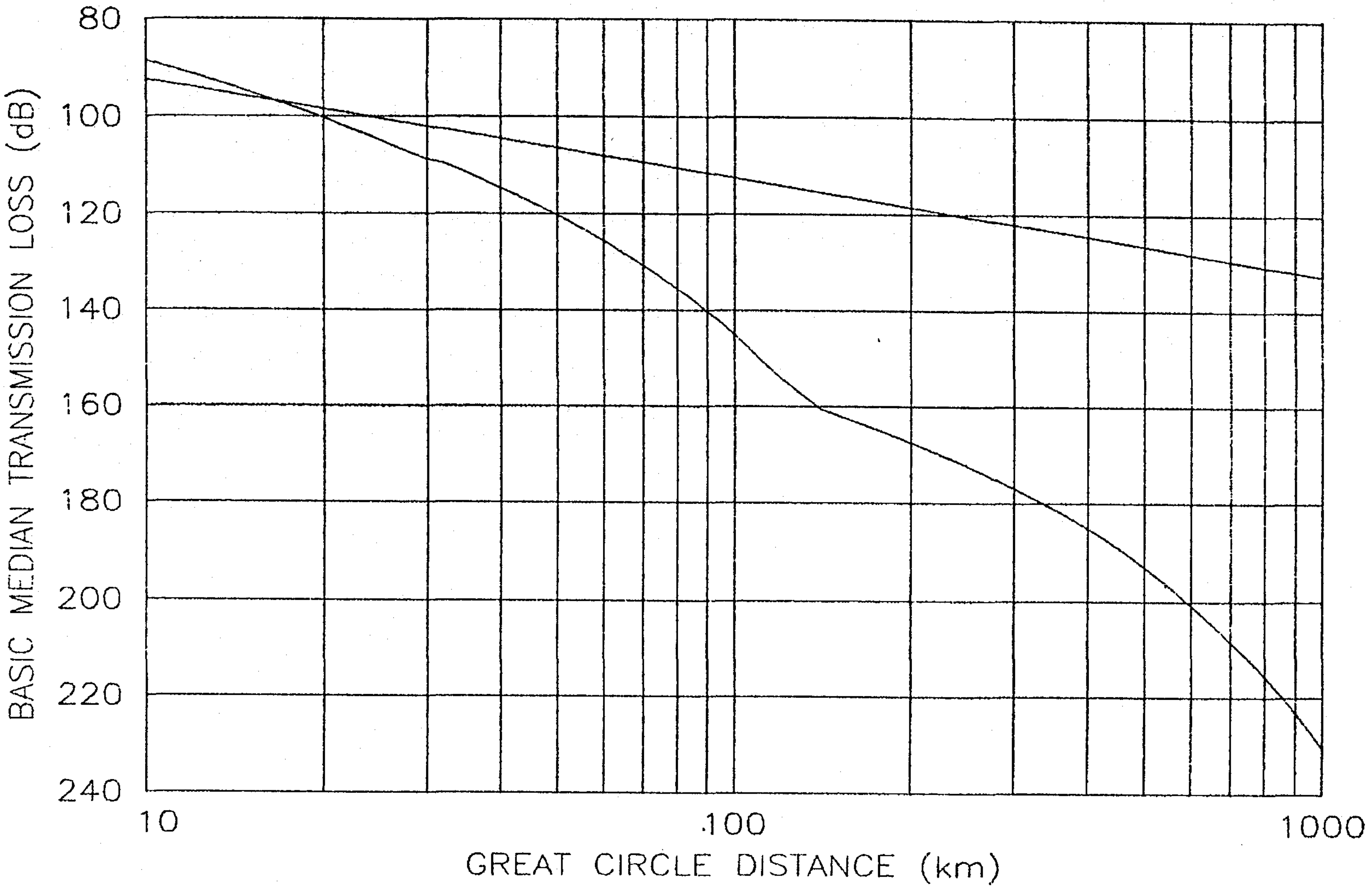

FIGURE A-13. f=100MHz,h_1=50m,h_2=100m,V.P.,Land and Sea Water

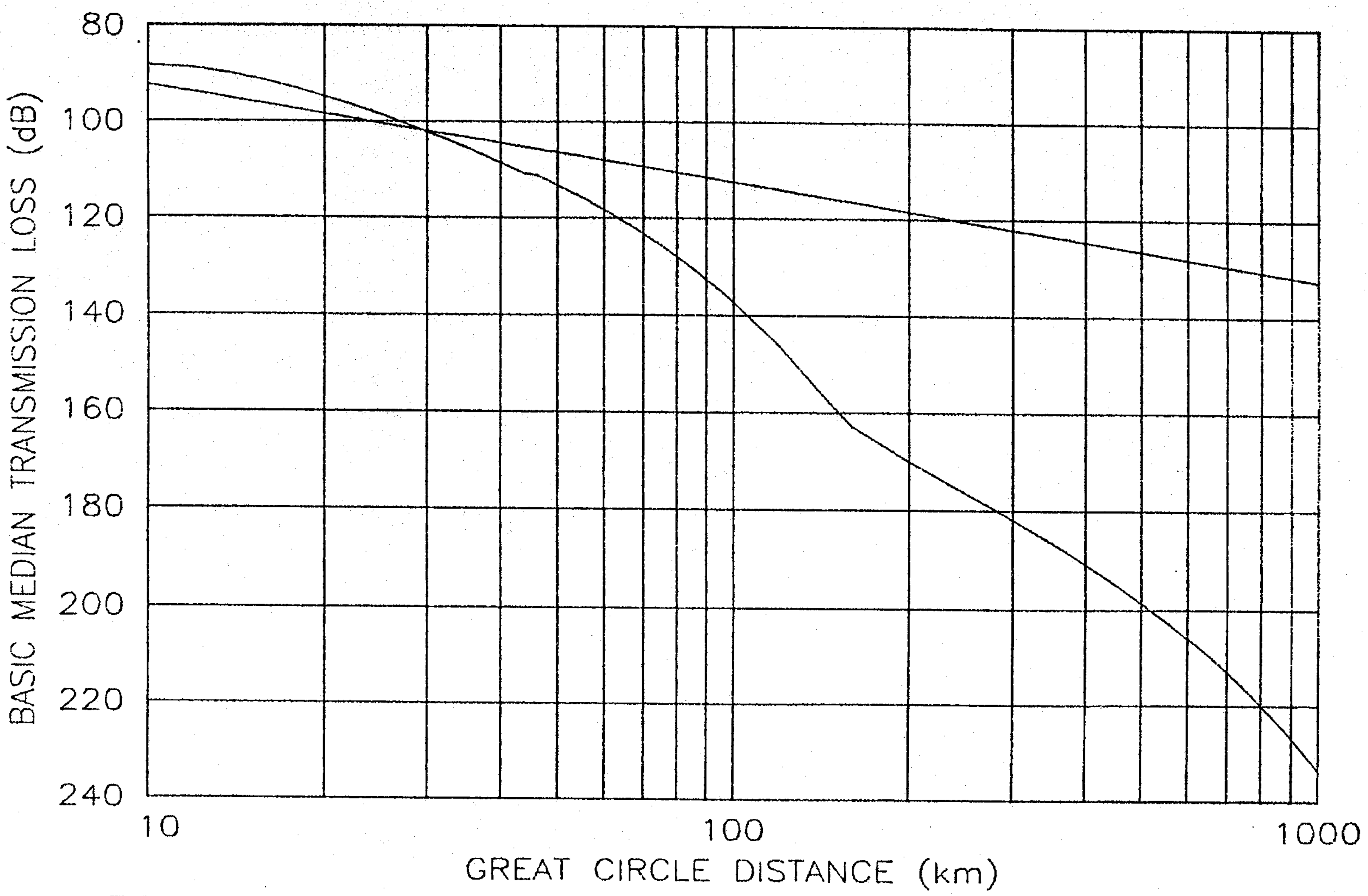

FIGURE A-14. $f=100\text{MHz}, h_1=50\text{m}, h_2=200\text{m}$, V.P., Land and Sea Water

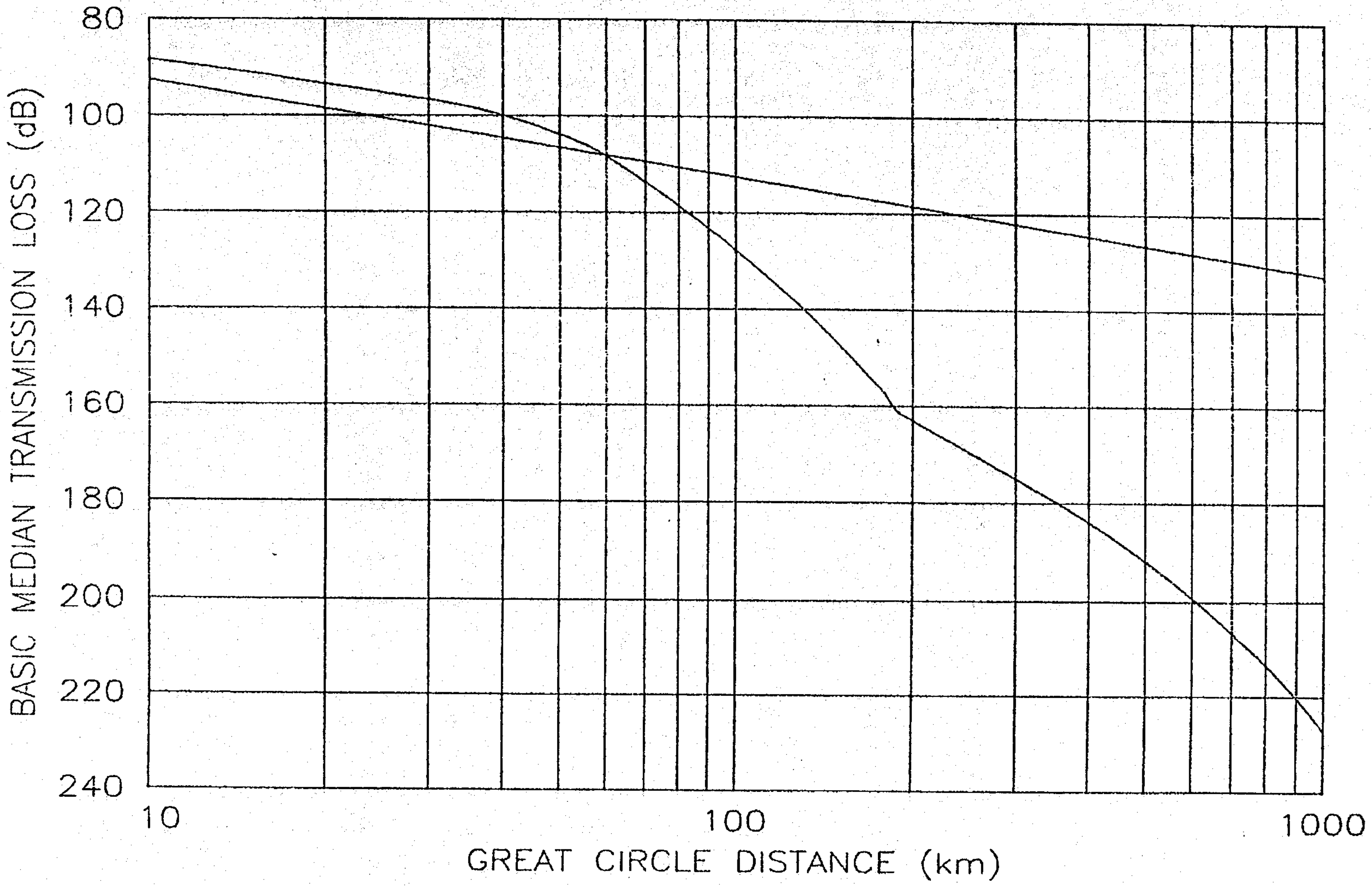

FIGURE A-15. $f=100MHz, h_1=50m, h_2=500m$, V.P., Land and Sea Water

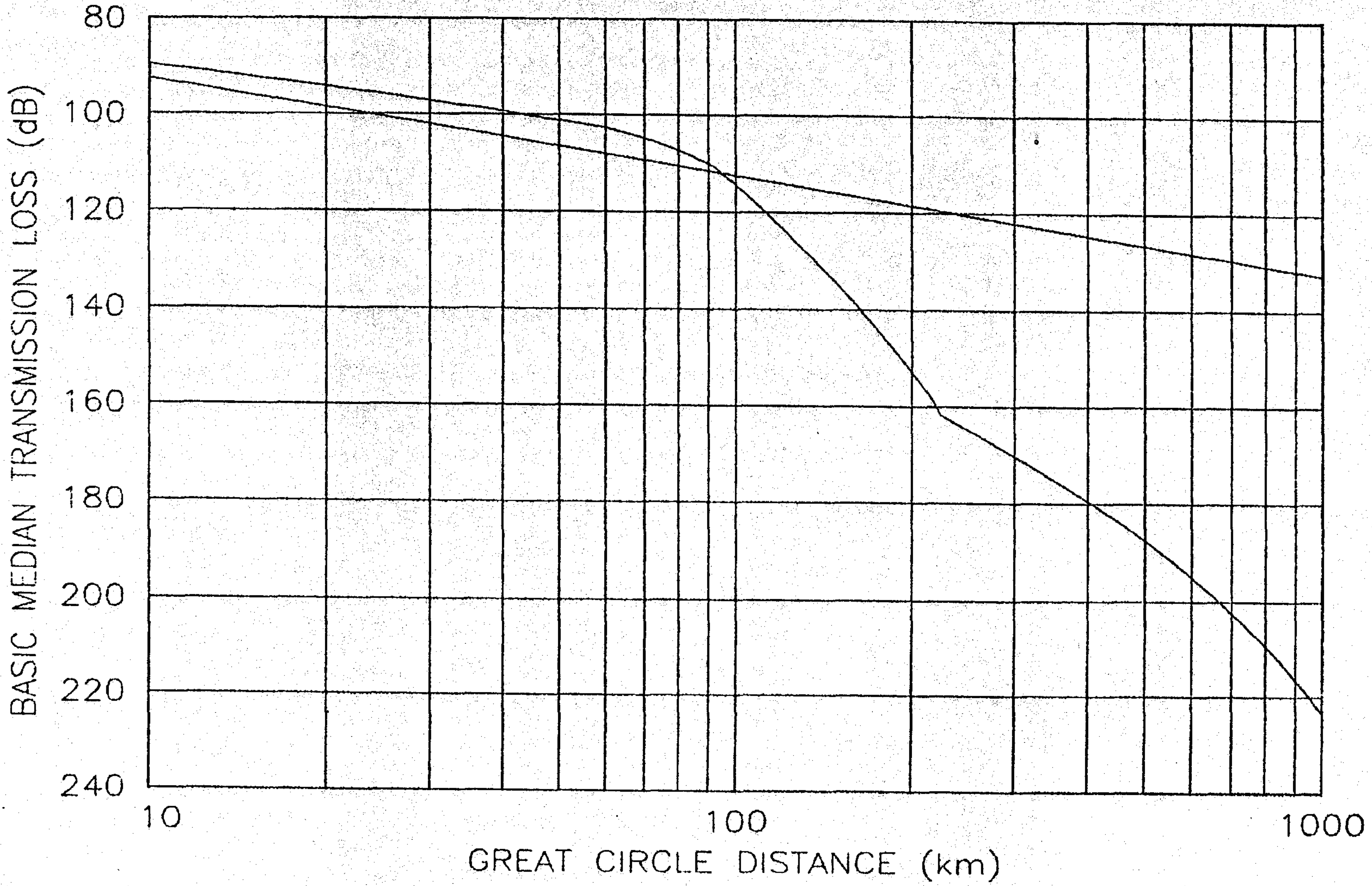

FIGURE A–16. f=100MHz,h_1=50m,h_2=1k,V.P.,Land and Sea Water

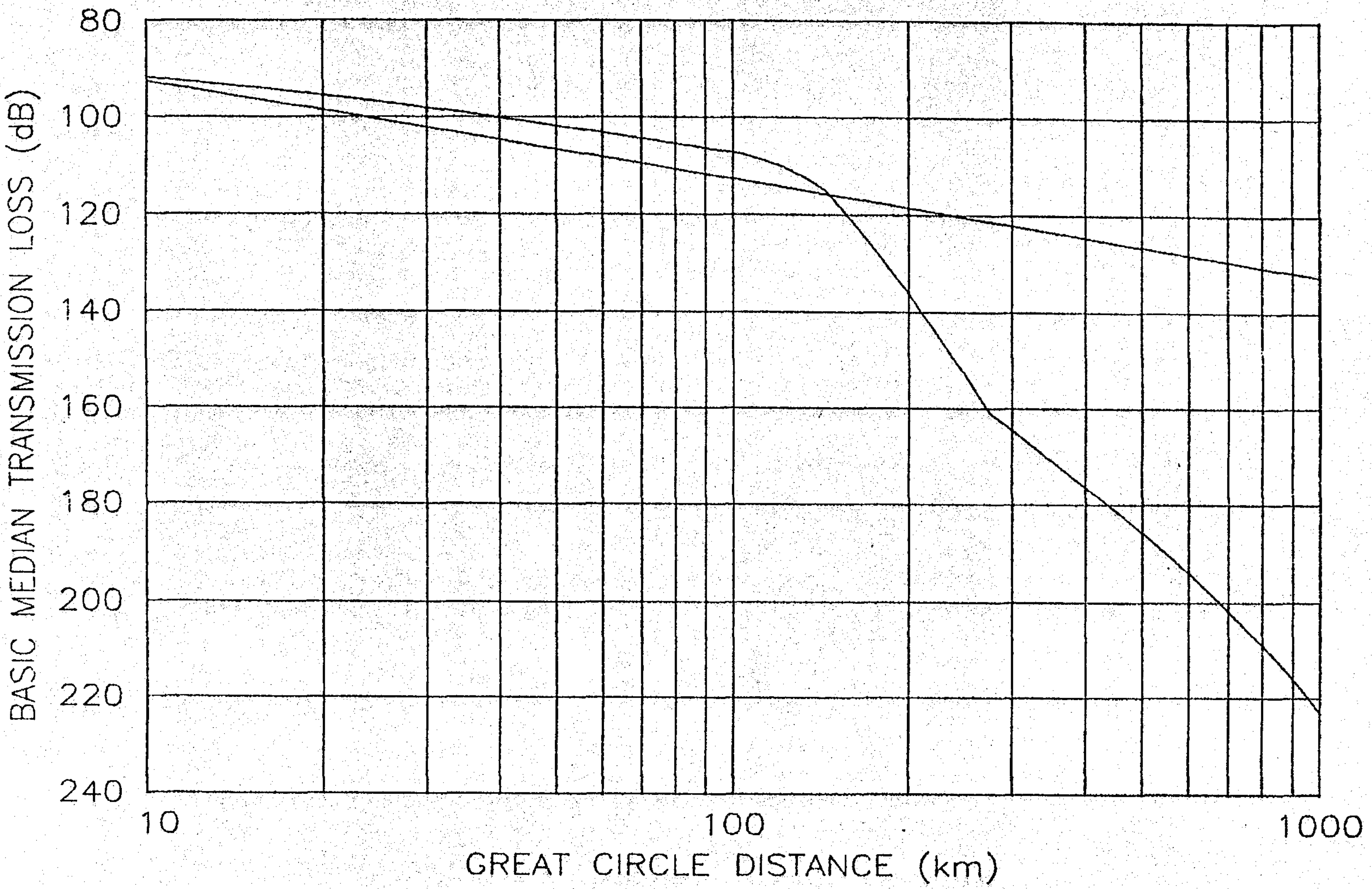

FIGURE A-17. f=100MHz, h_1=50m, h_2=2k, V.P., Land and Sea Water

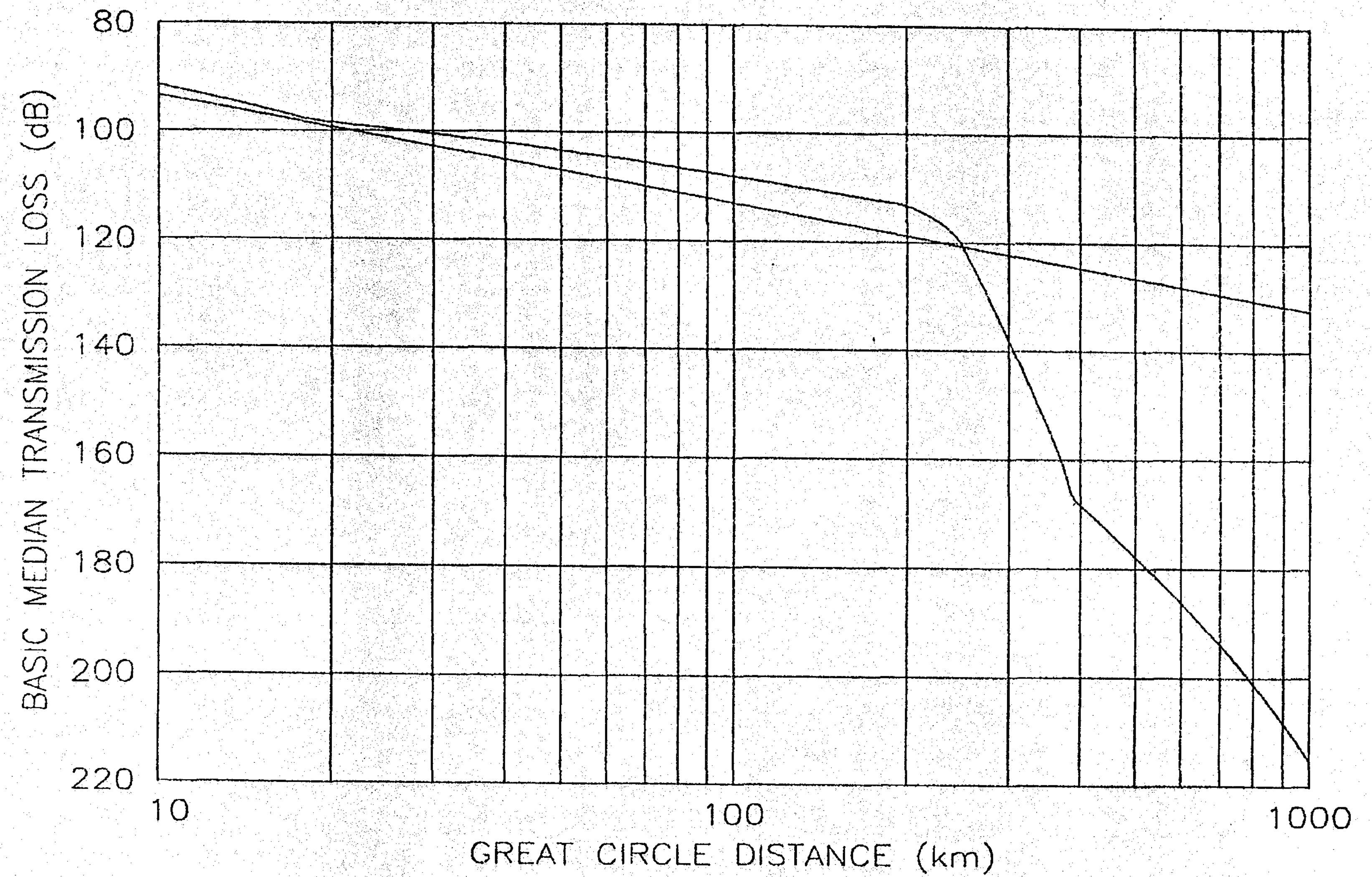

FIGURE A-18. f=100MHz,h_1=50m,h_2=5k,V.P.,Land and Sea Water

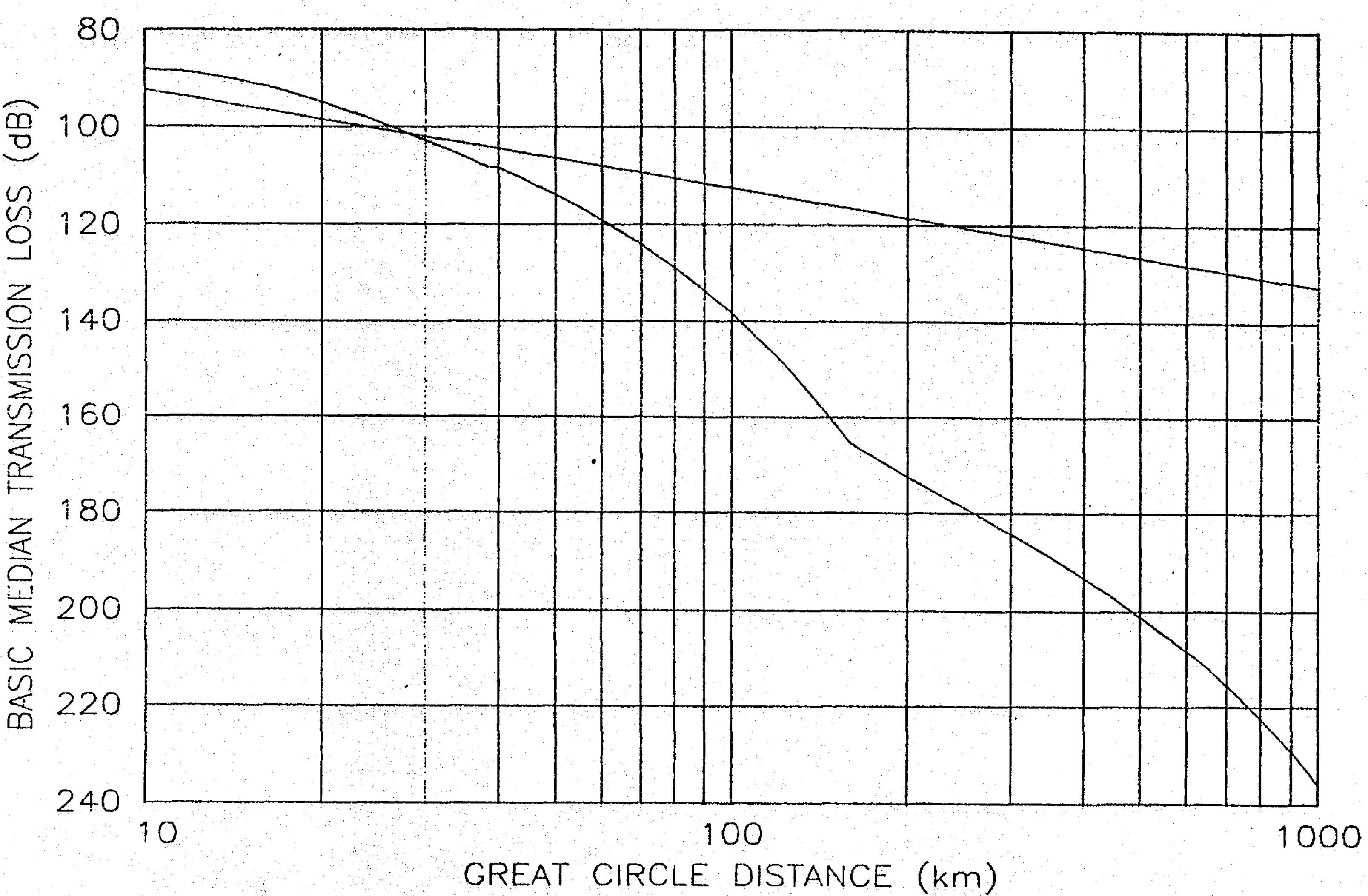

FIGURE A−19. $f=100MHz, h_1=100m, h_2=100m$, V.P., Land and Sea Water

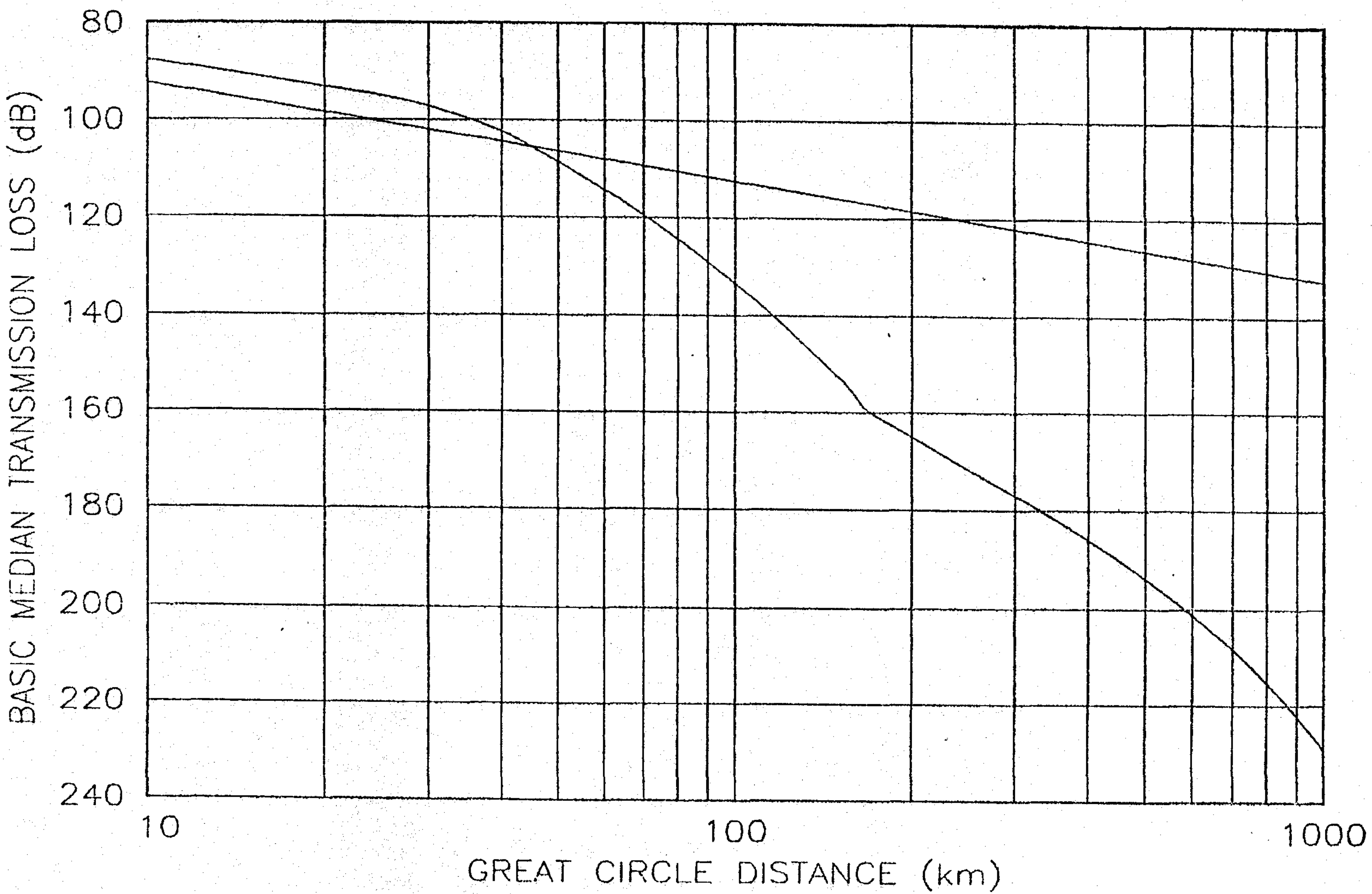

FIGURE A–20. $f=100$MHz,$h_1=100$m,$h_2=200$,V.P.,Land and Sea Water

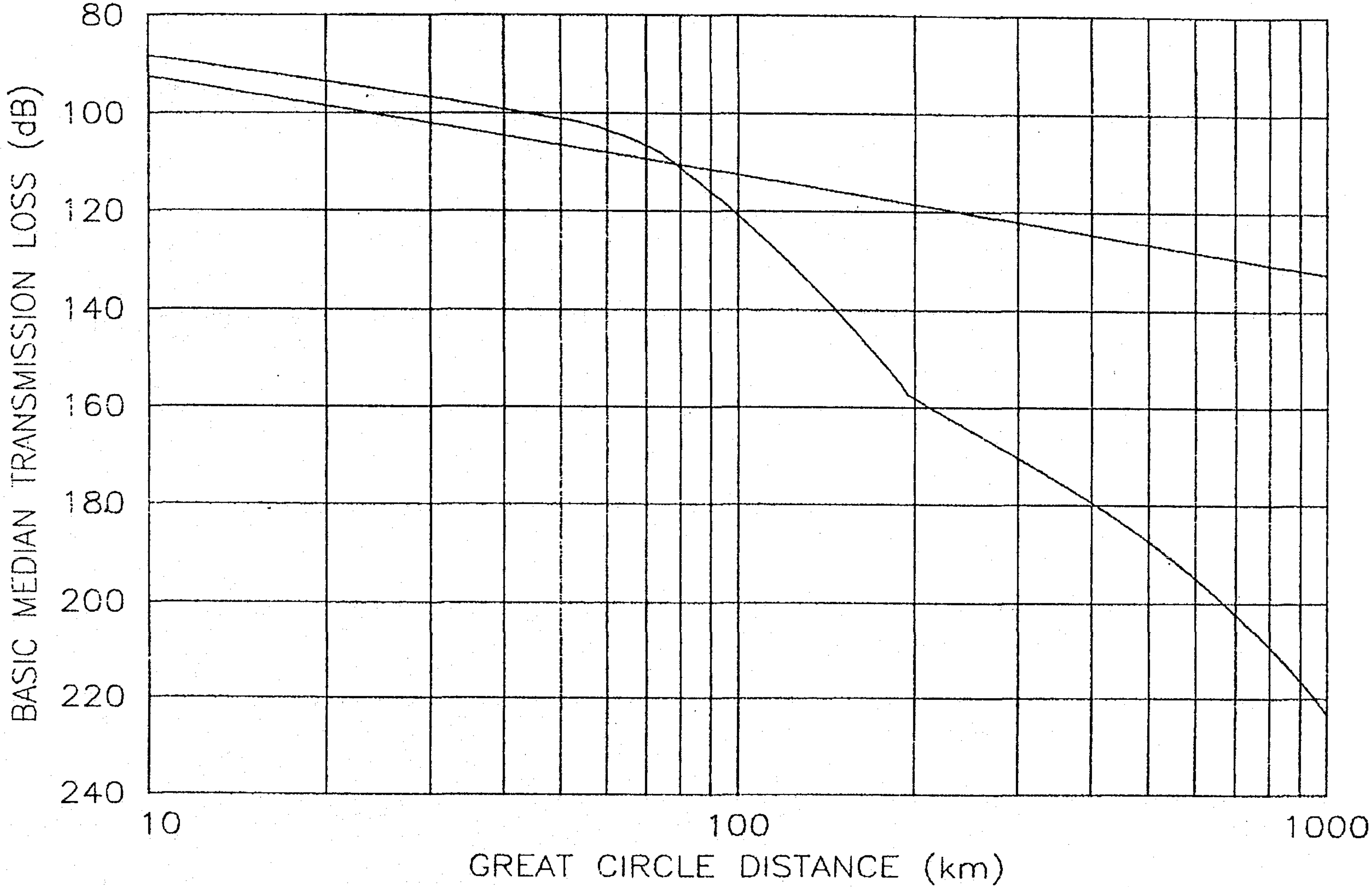

FIGURE A-21. $f=100\text{MHz}, h_1=100\text{m}, h_2=500\text{m}$, V.P., Land and Sea Water

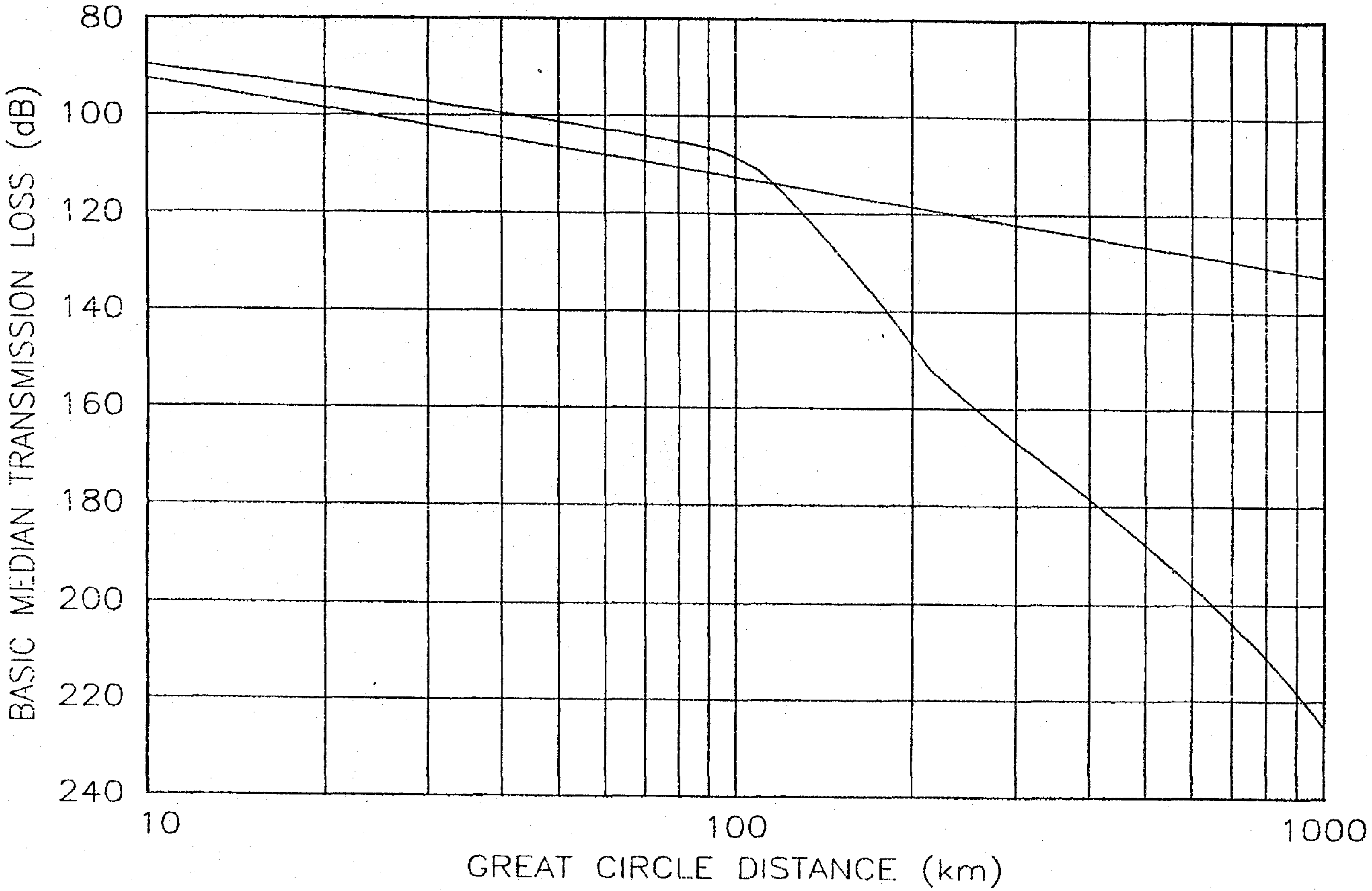

FIGURE A-22. f=100MHz,h_1=100m,h_2=1km,V.P.,Land and Sea Water

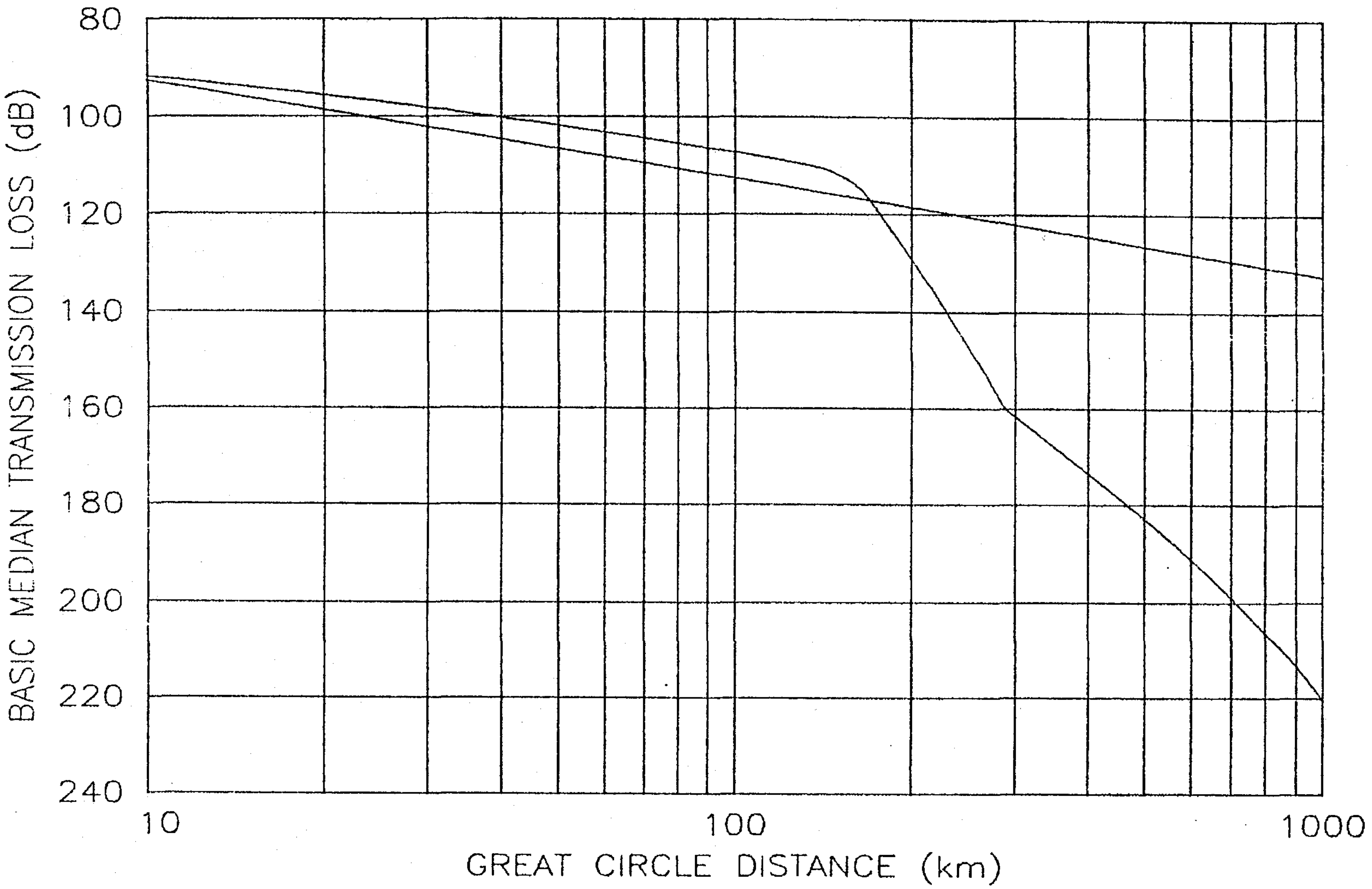

FIGURE A-23. f=100MHz,h_1=100m,h_2=2km,V.P.,Land and Sea Water

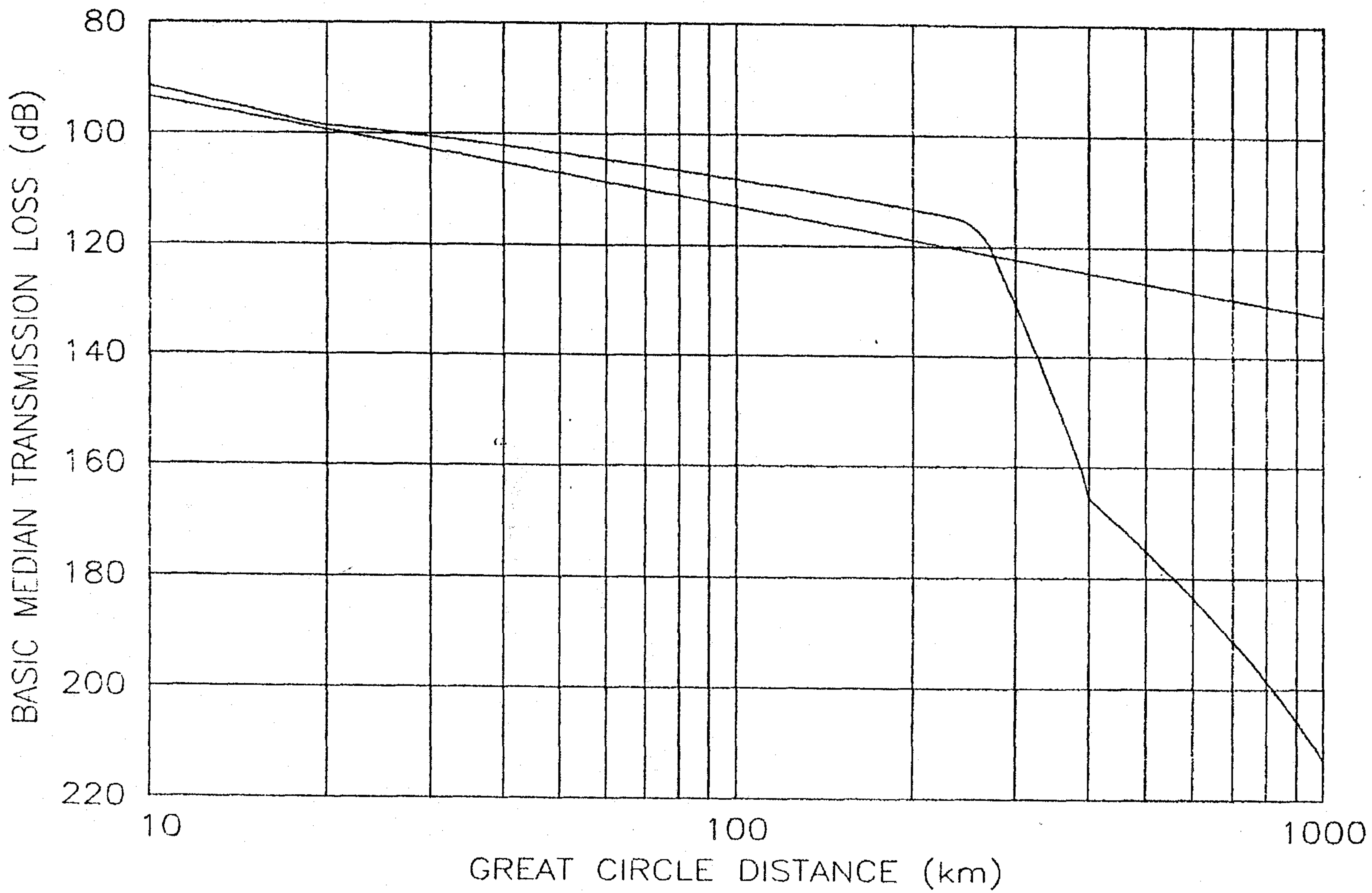

FIGURE A-24. $f=100MHz, h_1=100m, h_2=5km$, V.P., Land and Sea Water

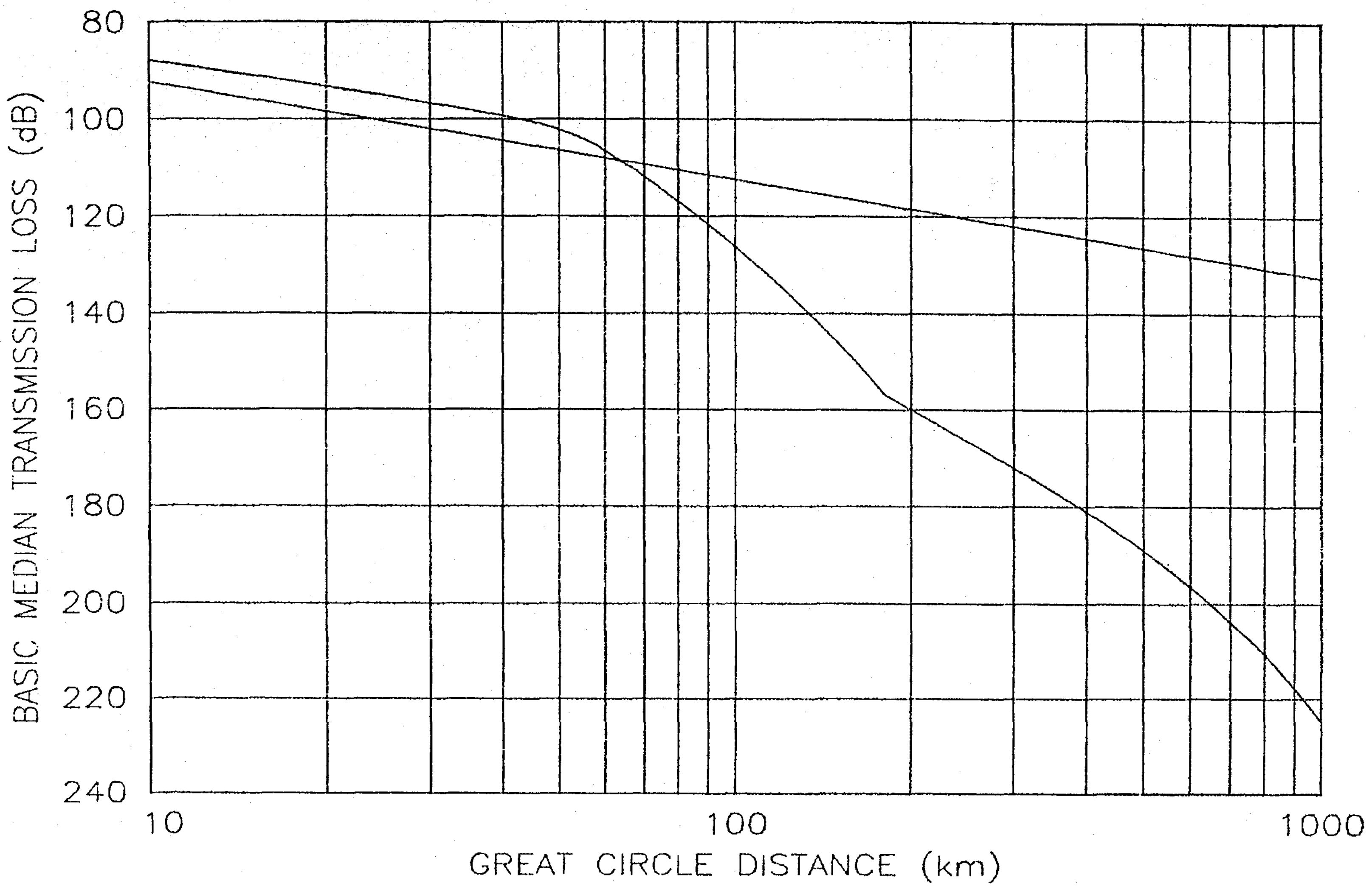

FIGURE A-25. f=100MHz,h_1=200m,h_2=200m,V.P.,Land and Sea Water

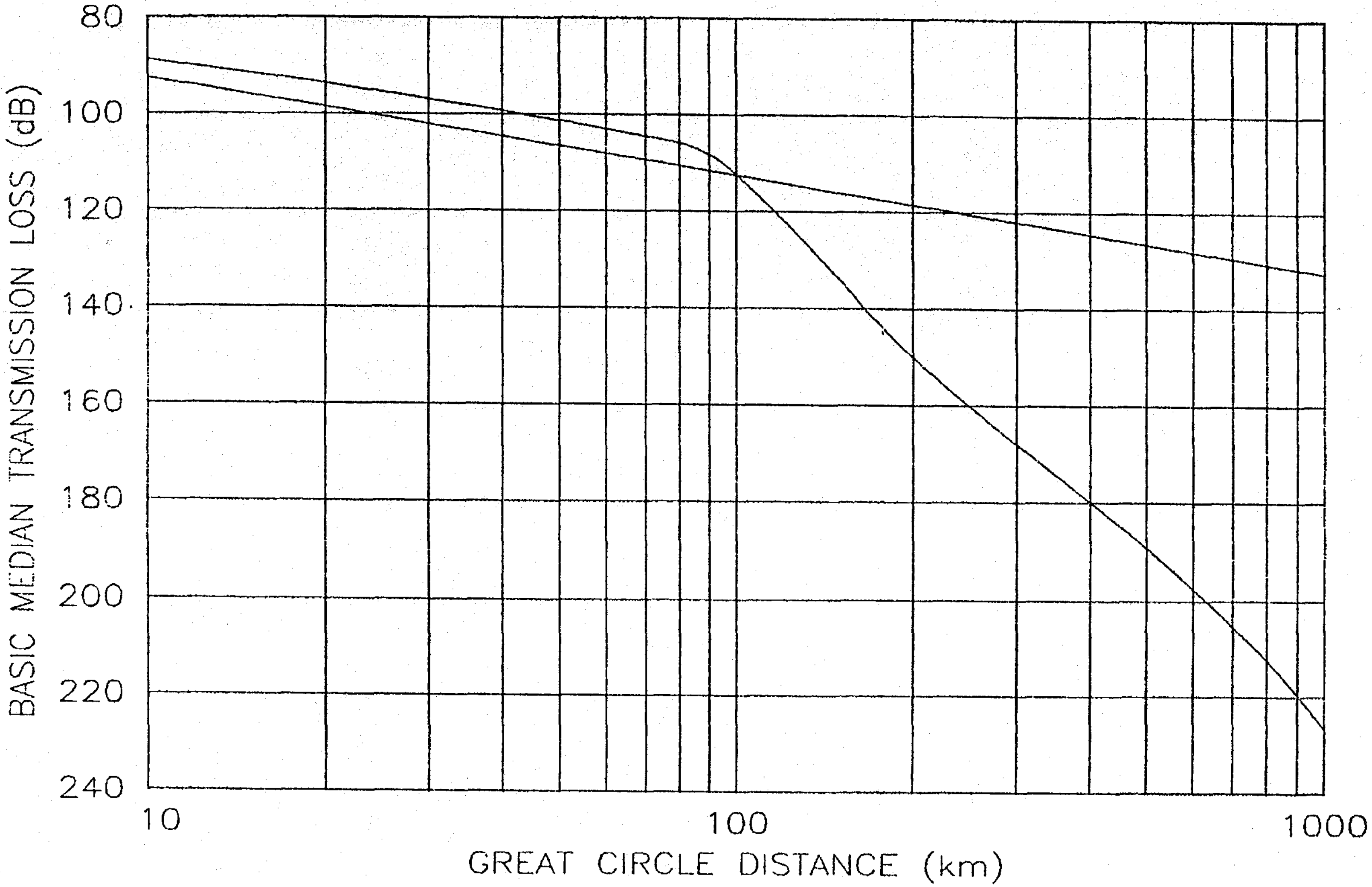

FIGURE A−26. f=100MHz,h_1=200m,h_2=500m,V.P.,Land and Sea Water

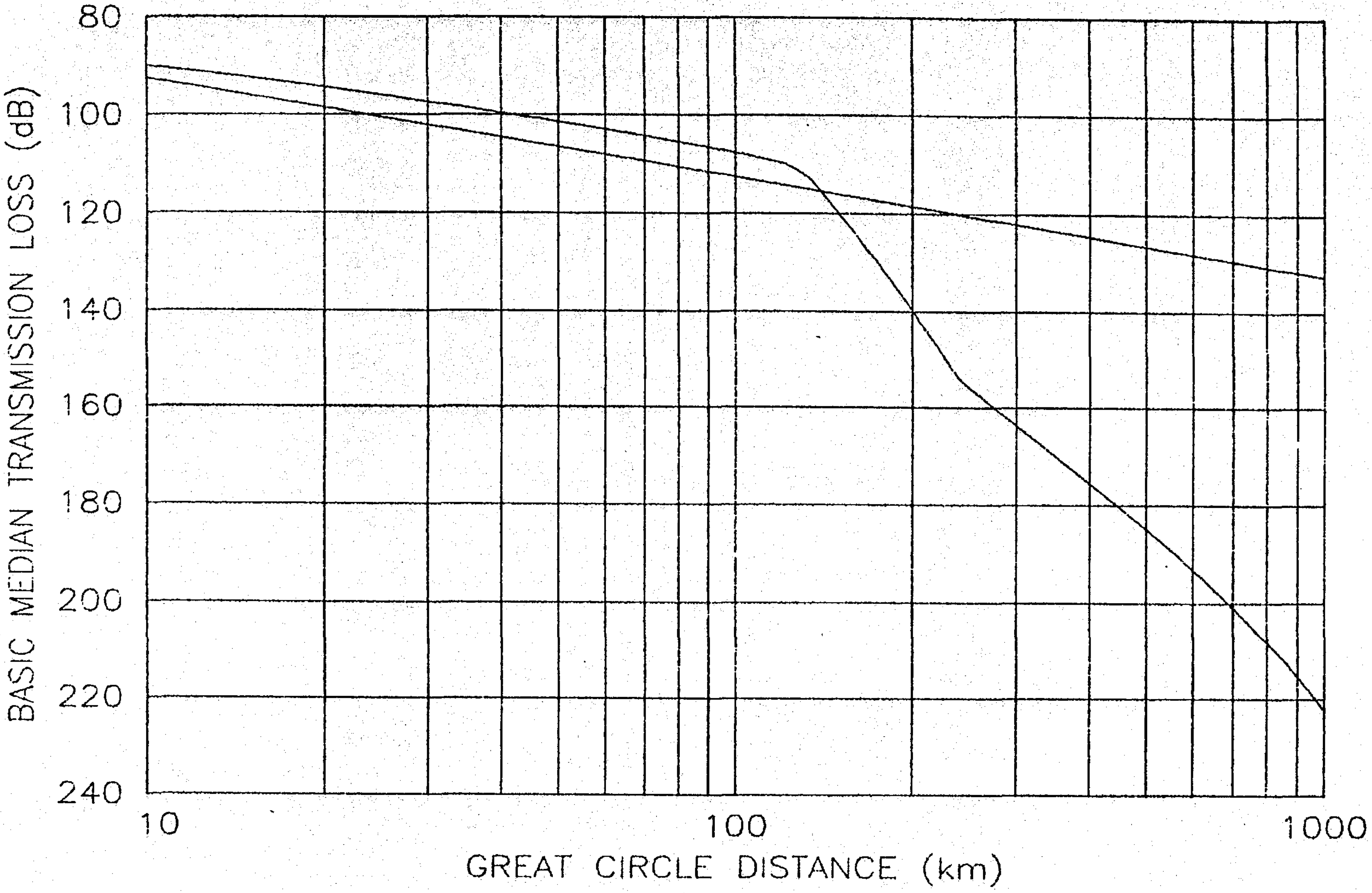

FIGURE A-27. f=100MHz, h_1=200m, h_2=1km, V.P., Land and Sea Water

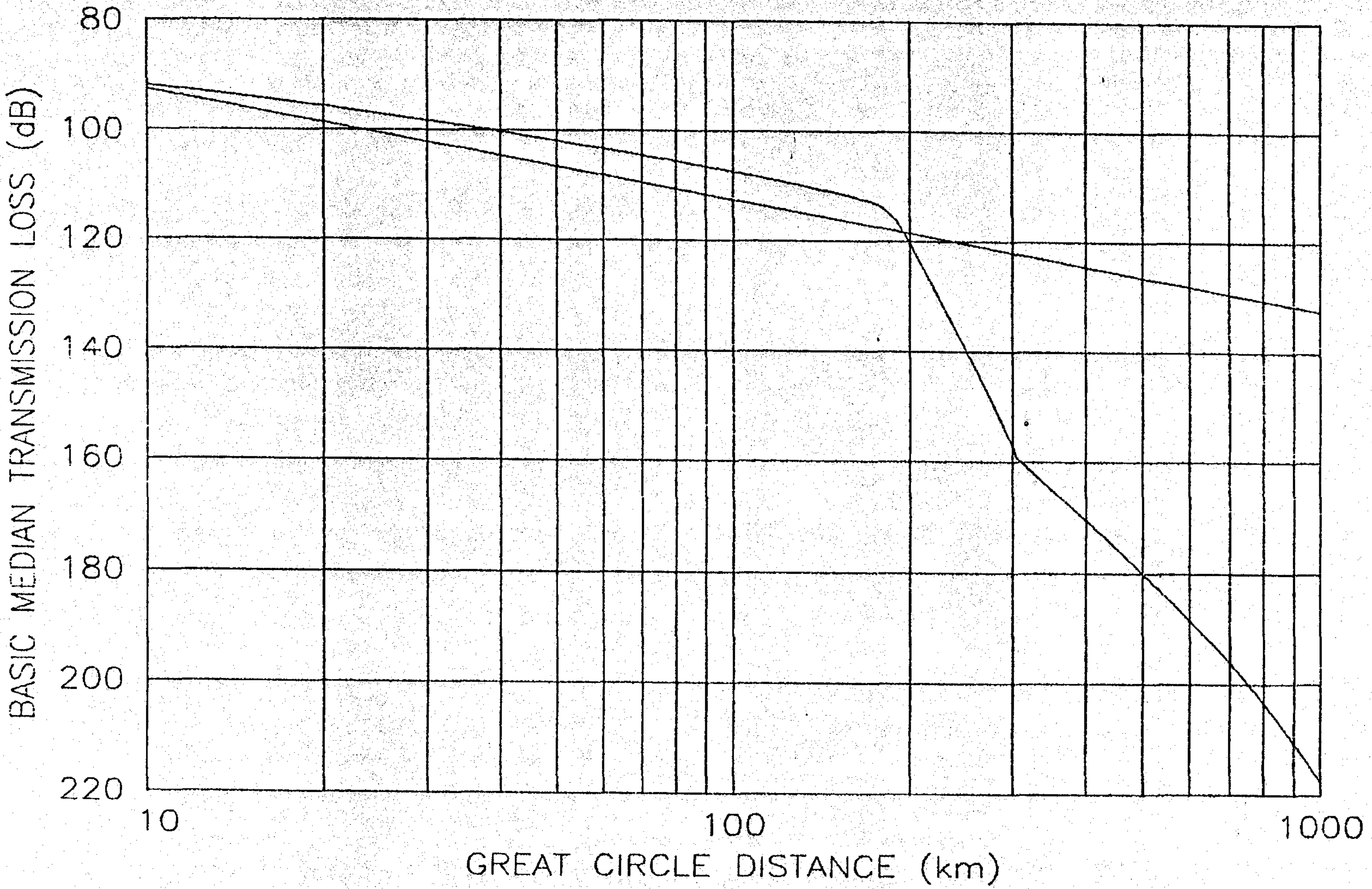

FIGURE A-28. $f=100\text{MHz}, h_1=200\text{m}, h_2=2\text{km}$, V.P., Land and Sea Water

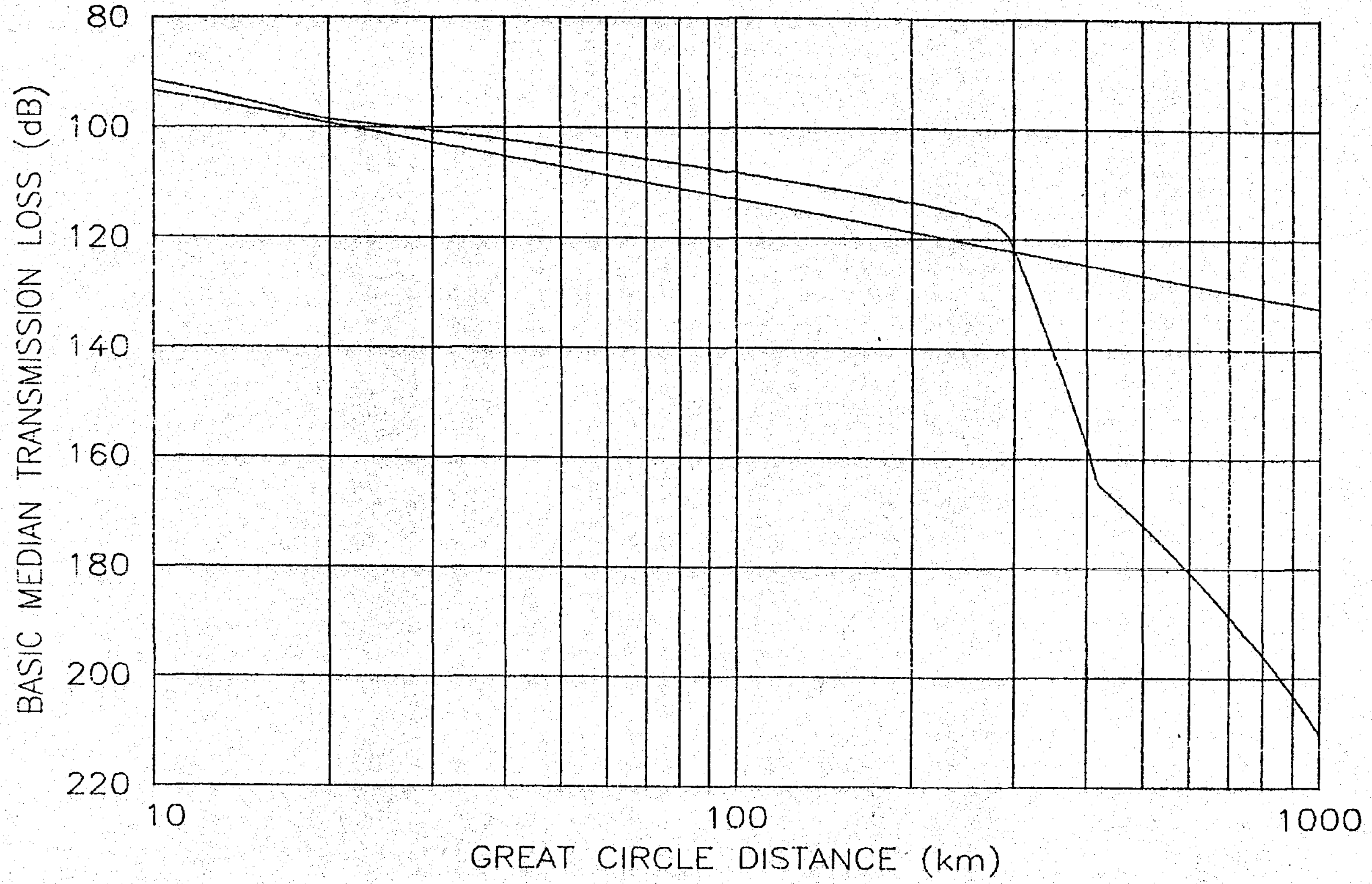

FIGURE A-29. f=100MHz, h_1=200m, h_2=5km, V.P., Land and Sea Water

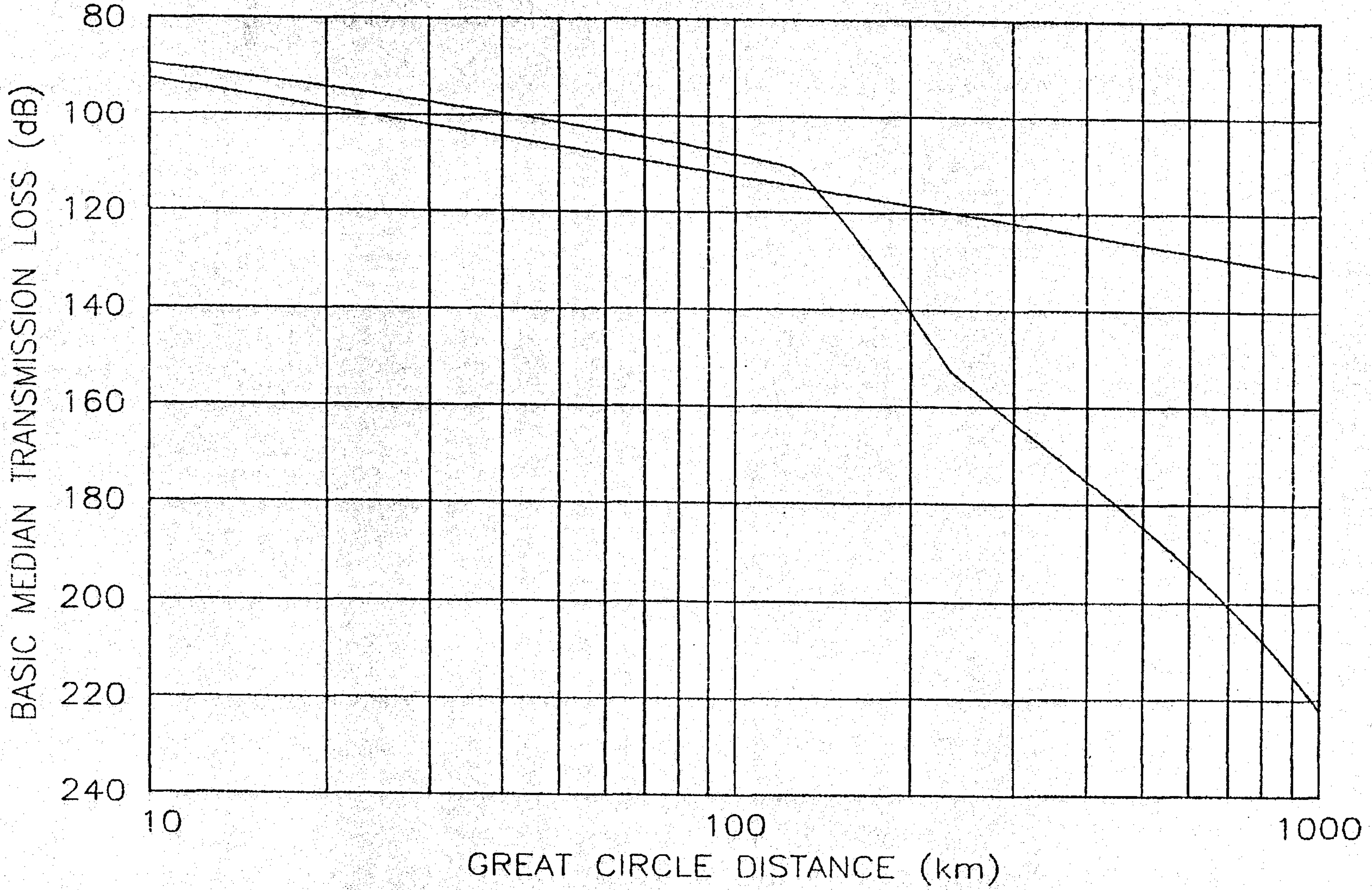

FIGURE A-30. $f=100MHz, h_1=500m, h_2=500m$, V.P., Land and Sea Water

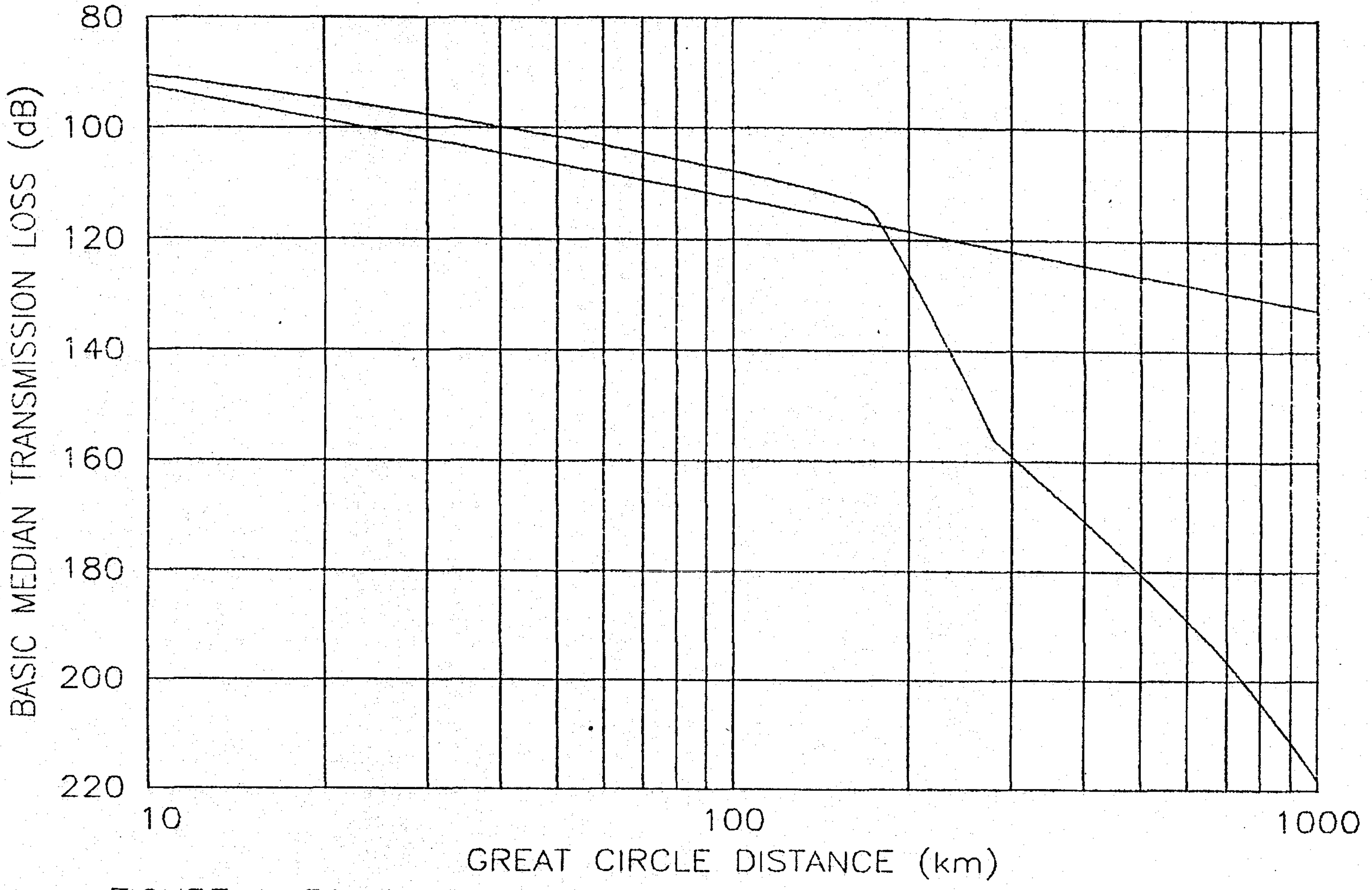

FIGURE A-31. f=100MHz,h_1=500m,h_2=1km,V.P.,Land and Sea Water

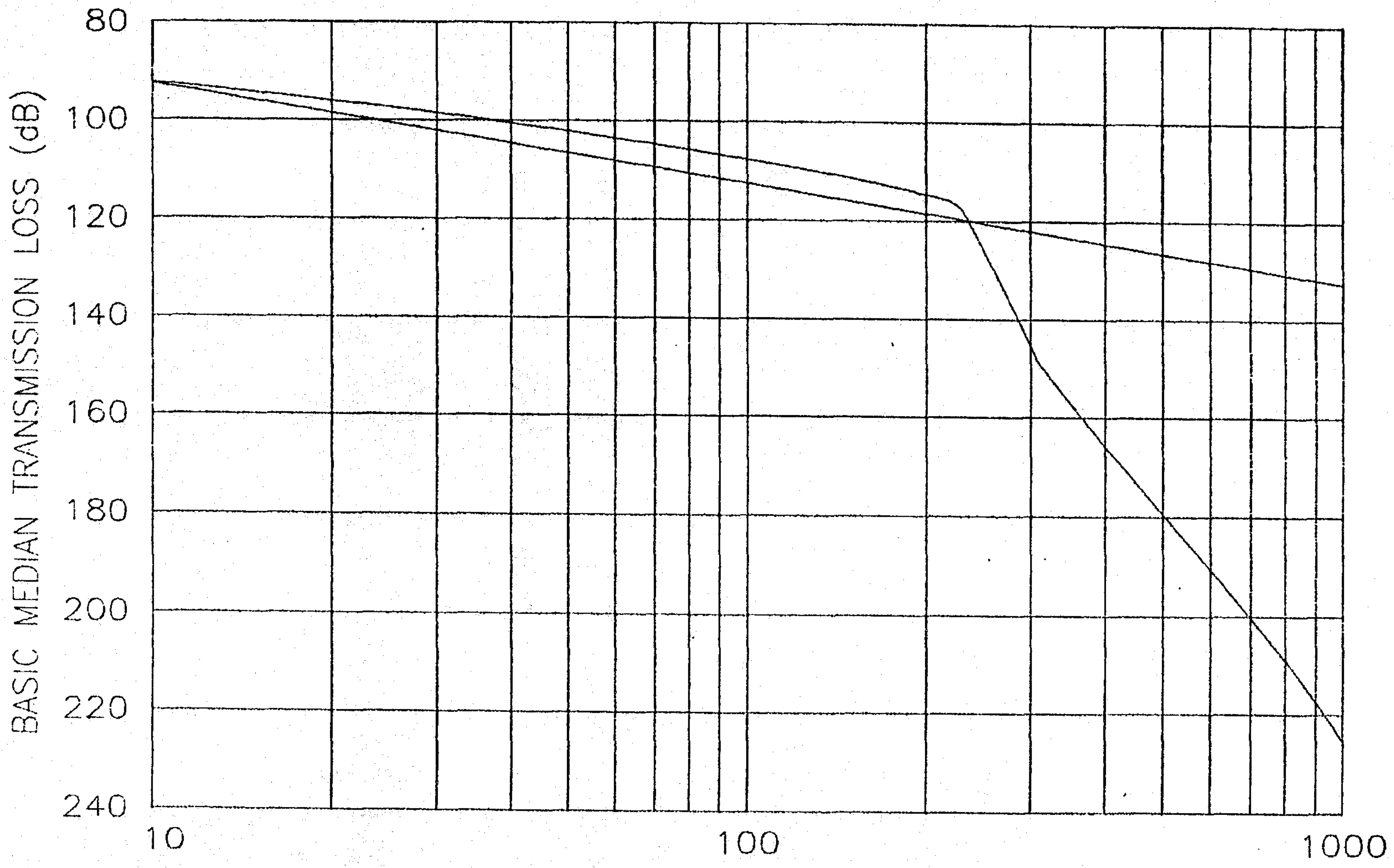

FIGURE A-32. $f=100MHz, h_1=500m, h_2=2km$, V.P., Land and Sea Water

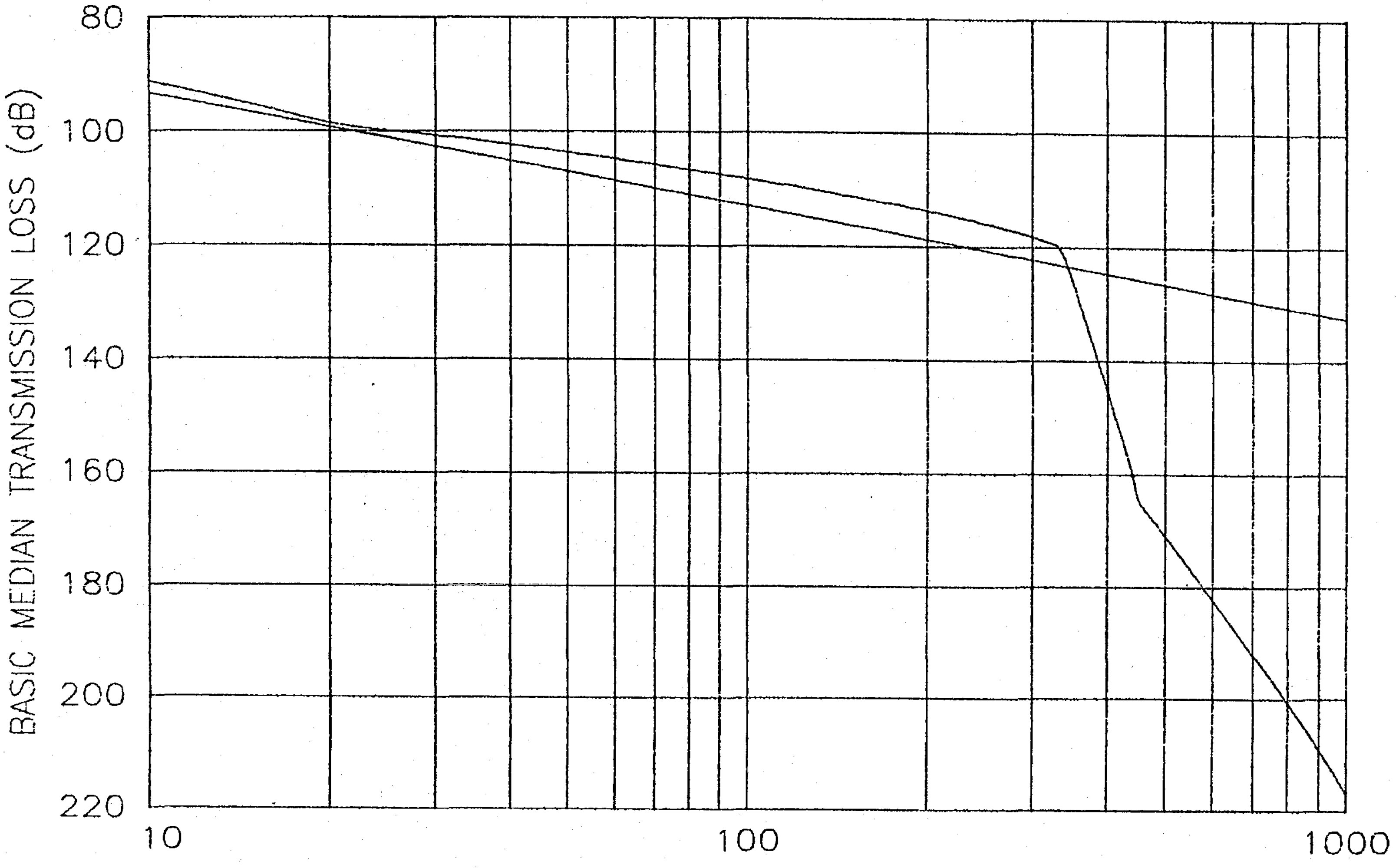

FIGURE A-33. $f=100MHz, h_1=500m, h_2=5km$, V.P., Land and Sea Water

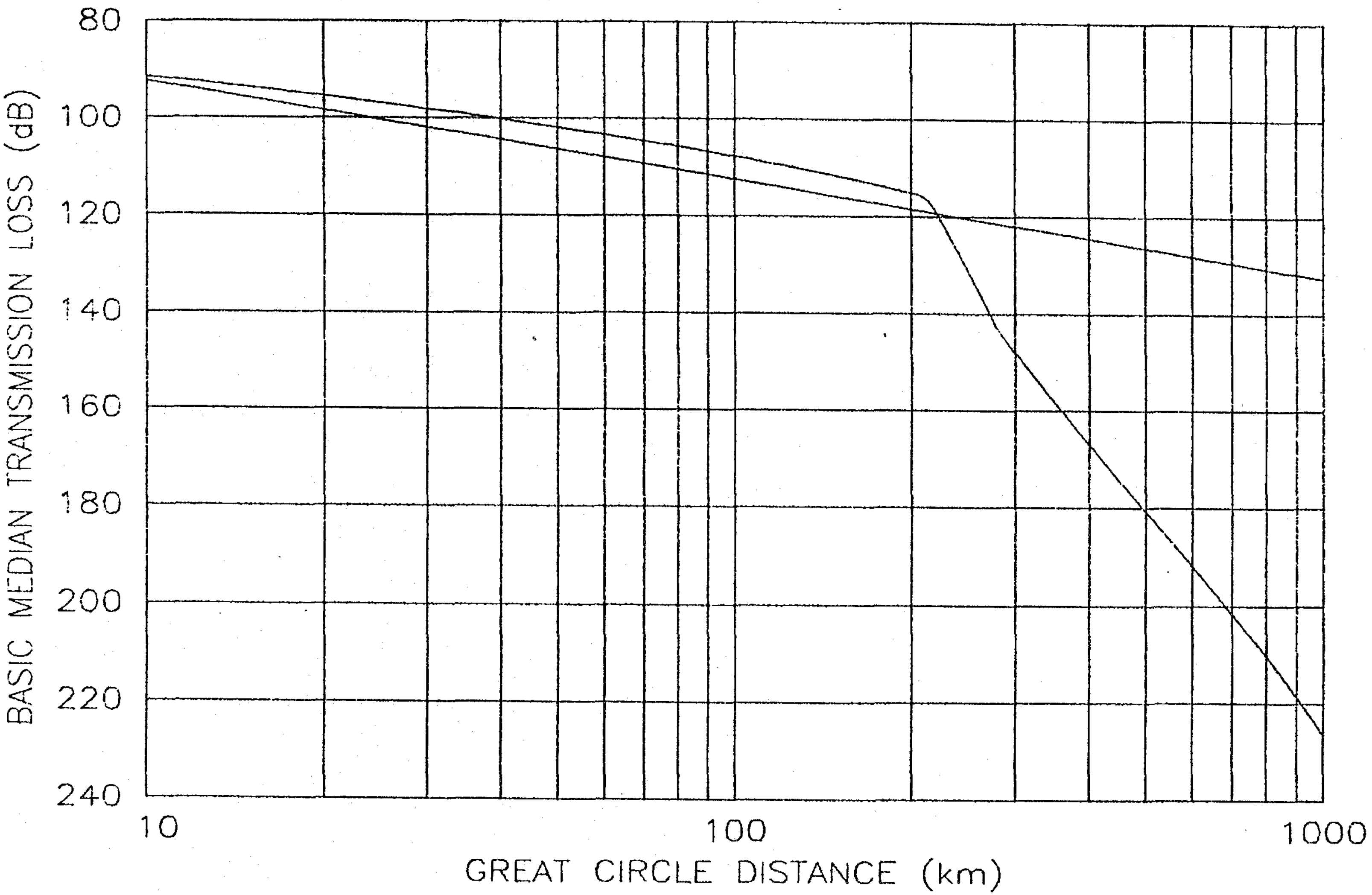

FIGURE A–34. f=100MHz,h_1=1km,h_2=1km,V.P.,Land and Sea Water

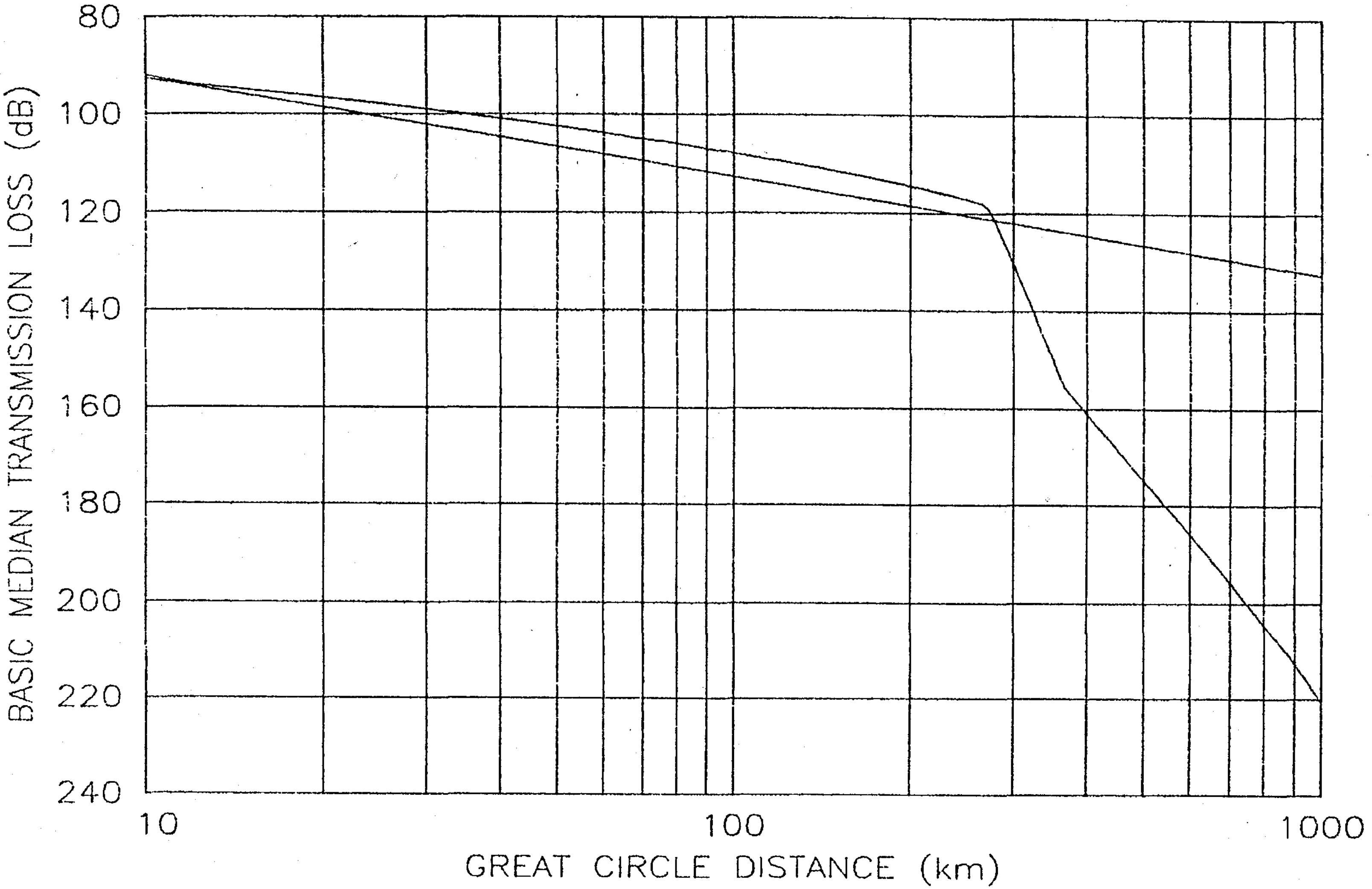

FIGURE A-35. f=100MHz,h_1=1km,h_2=2km,V.P.,Land and Sea Water

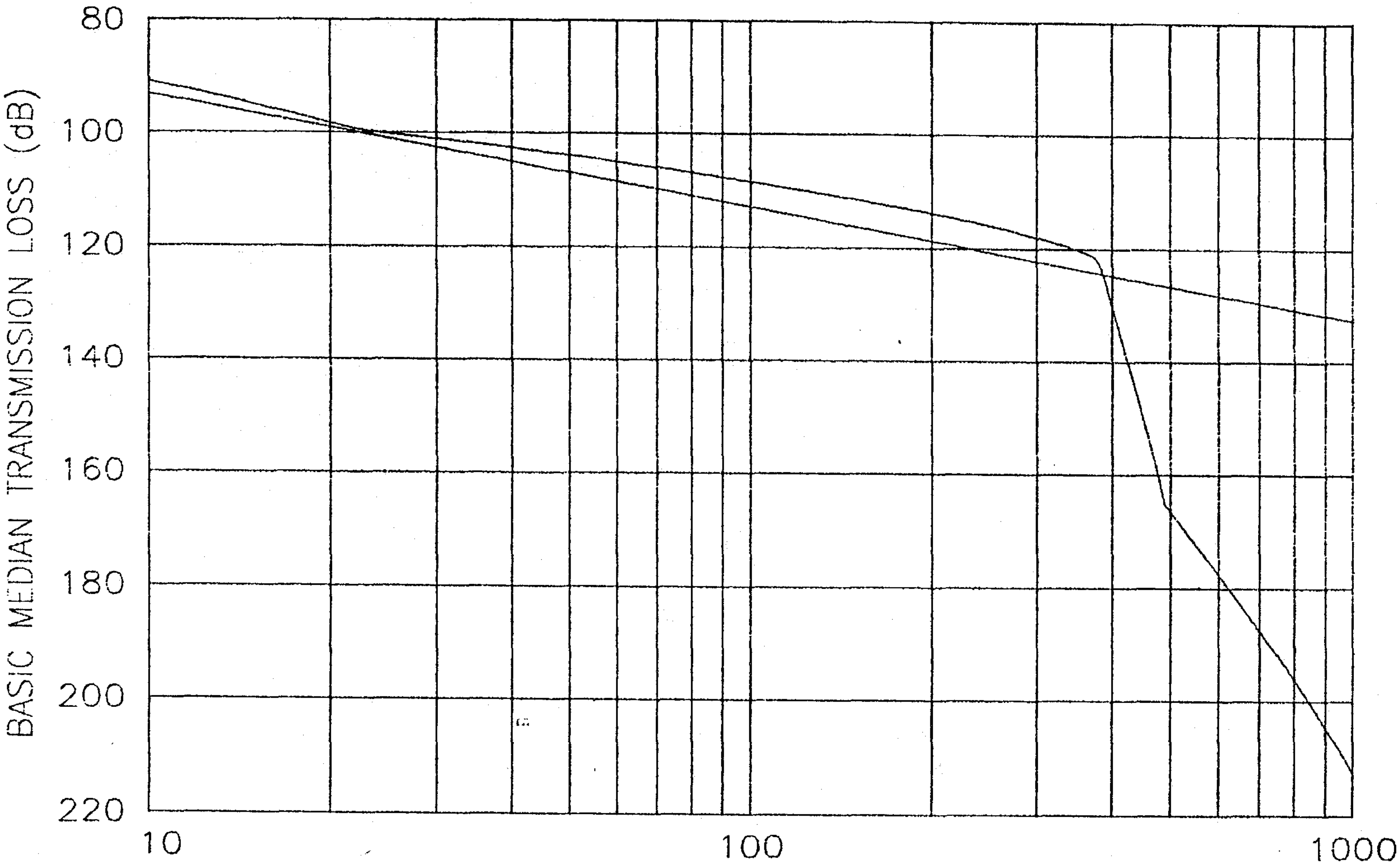

FIGURE A-36. $f=100\text{MHz}, h_1=1\text{km}, h_2=5\text{km}$, V.P., Land and Sea Water

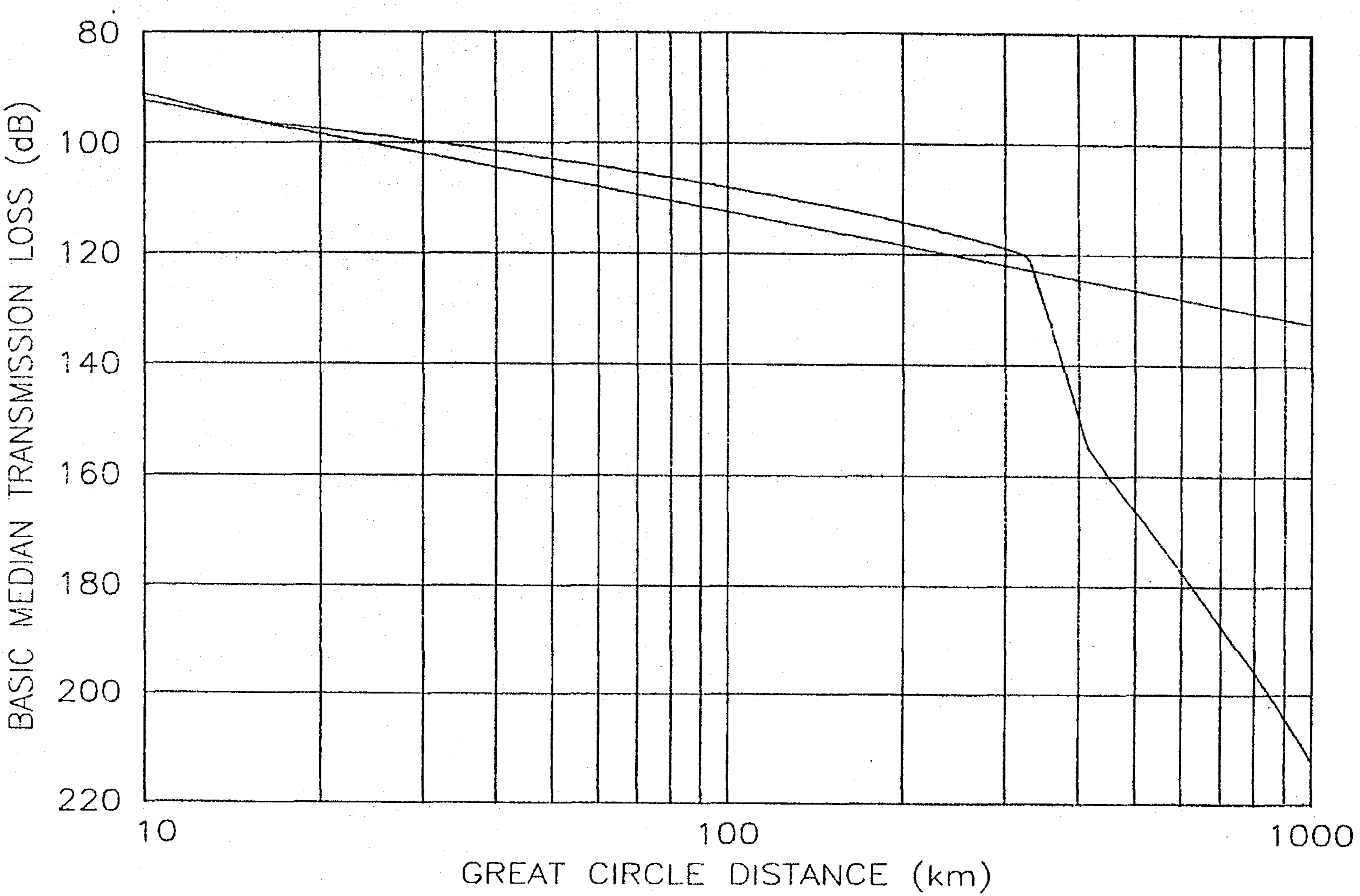

FIGURE A-37. f=100MHz, h_1=2km, h_2=2km, V.P., Land and Sea Water

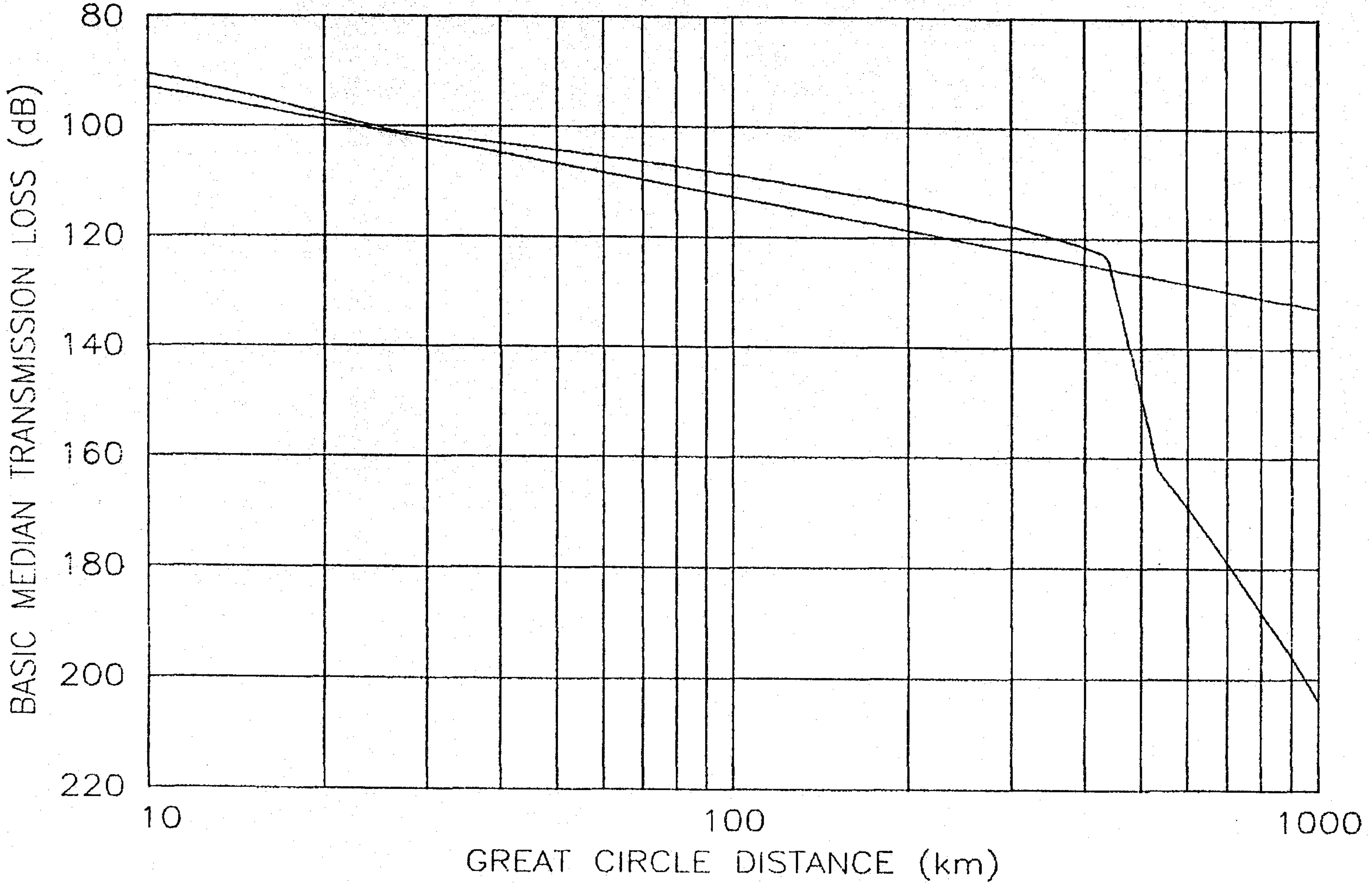

FIGURE A-38. $f=100MHz, h_1=2km, h_2=5km$, V.P., Land and Sea Water

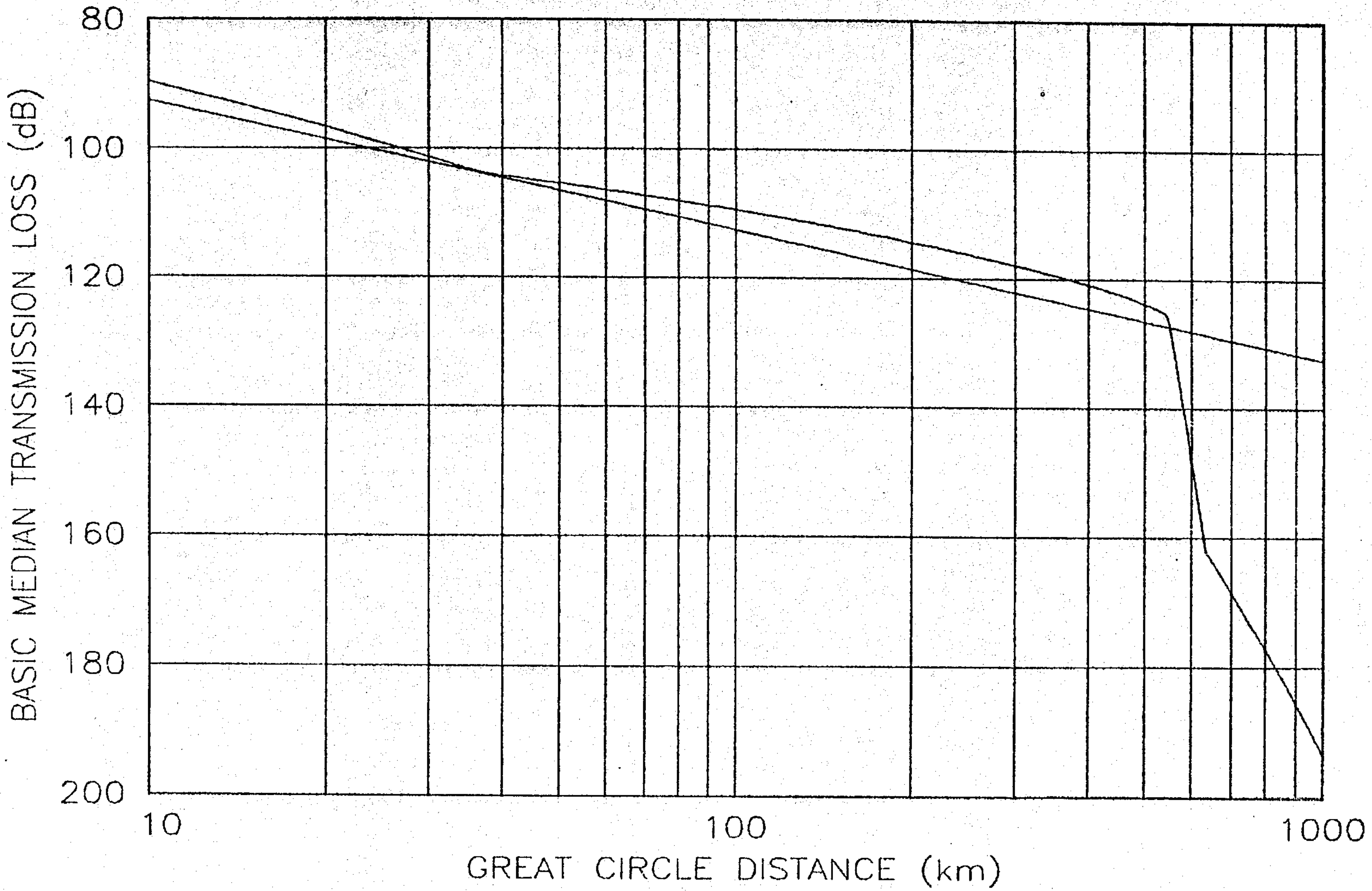

FIGURE A-39. f=100MHz,h_1=5km,h_2=5km,V.P.,Land and Sea Water

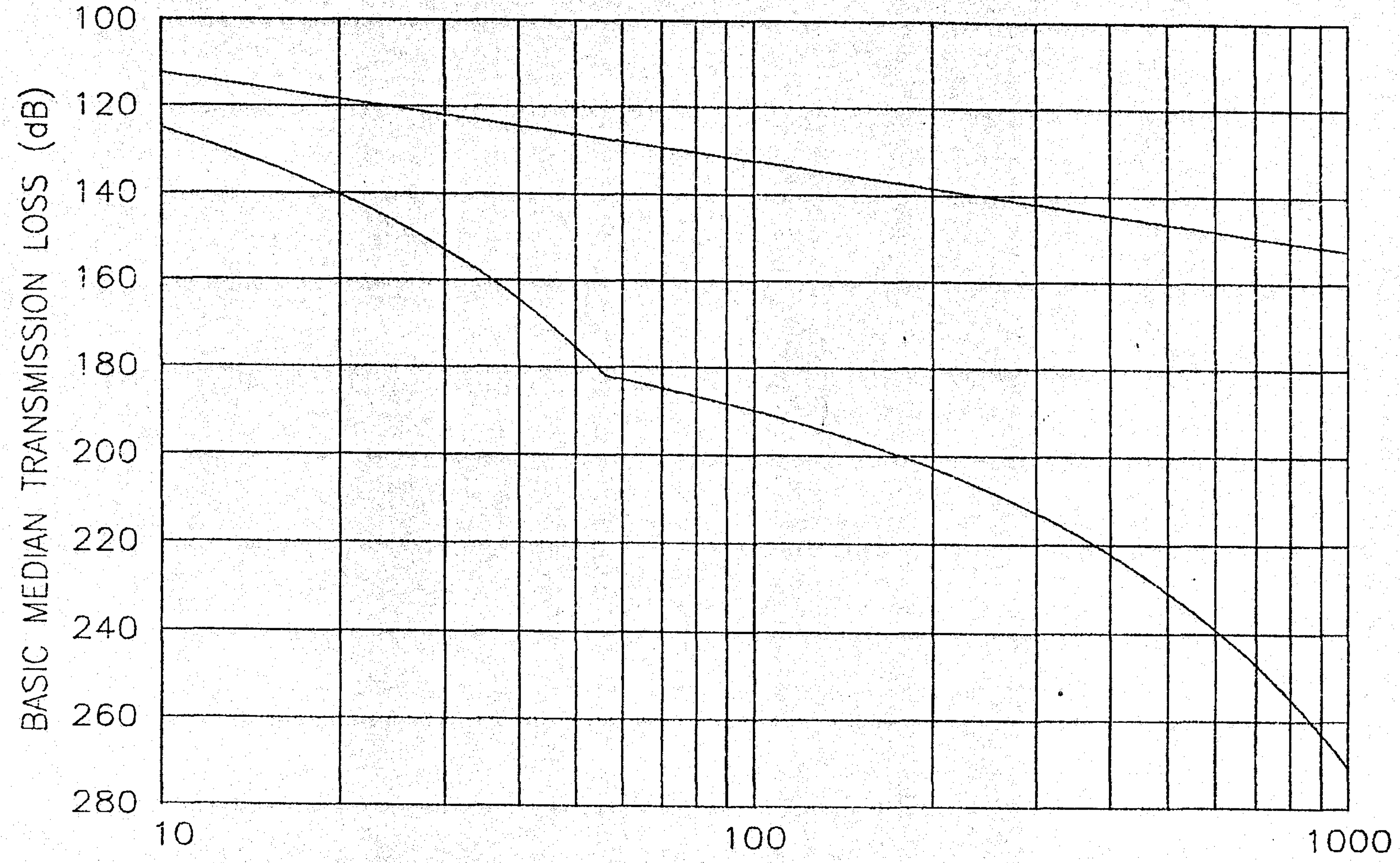

FIGURE A-40. f=1GHz, h_1=1m, h_2=50m, V.P., Land and Sea Water

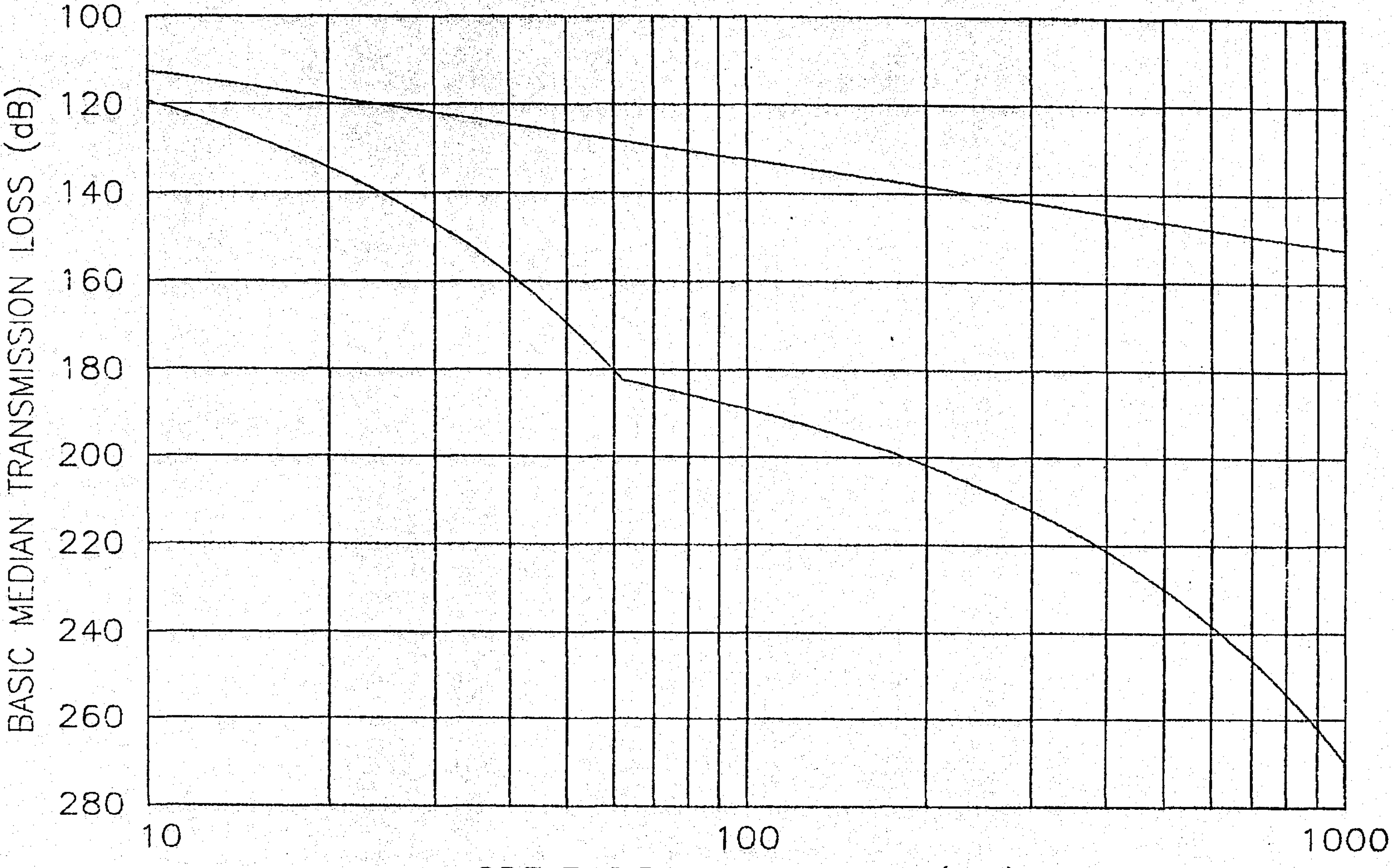

FIGURE A-41. $f=1GHz, h_1=1m, h_2=100m$, V.P., Land and Sea Water

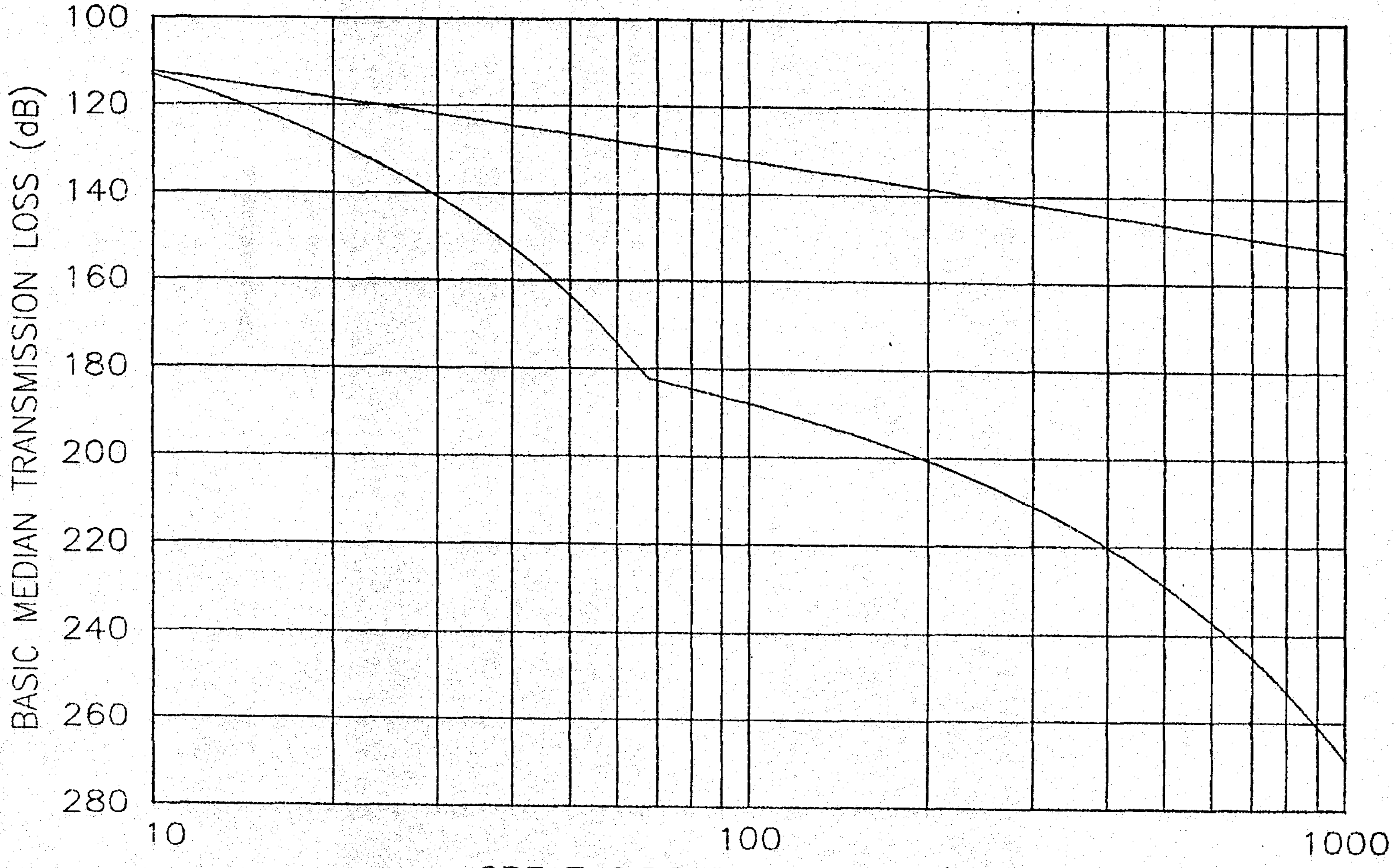

FIGURE A-42. f=1GHz,h_1=1m,h_2=200m,V.P.,Land and Sea Water

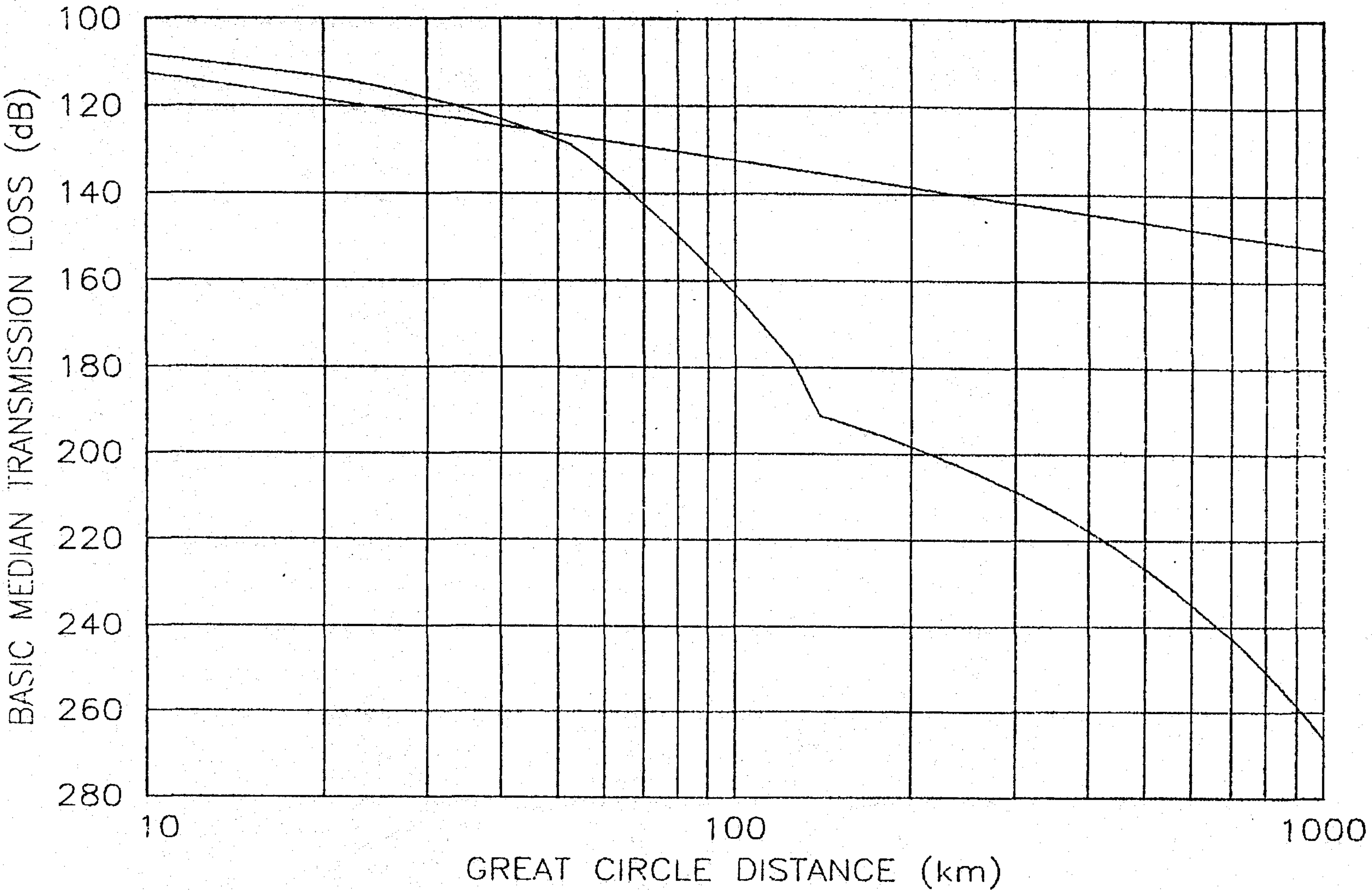

FIGURE A-43. f=1GHz, h_1=1m, h_2=500m, V.P., Land and Sea Water

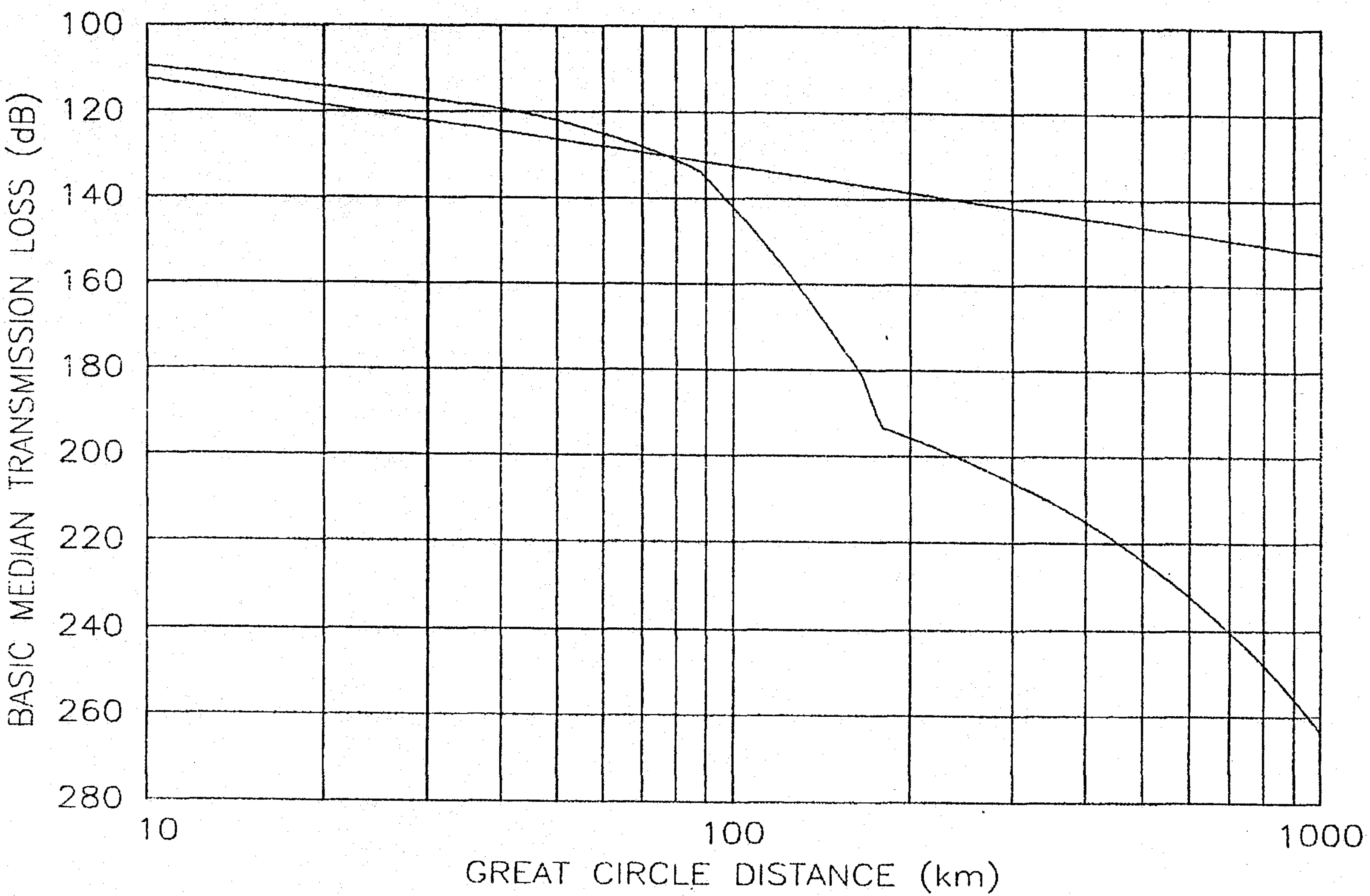

FIGURE A-44. f=1GHz,h_1=1m,h_2=1km,V.P.,Land and Sea Water

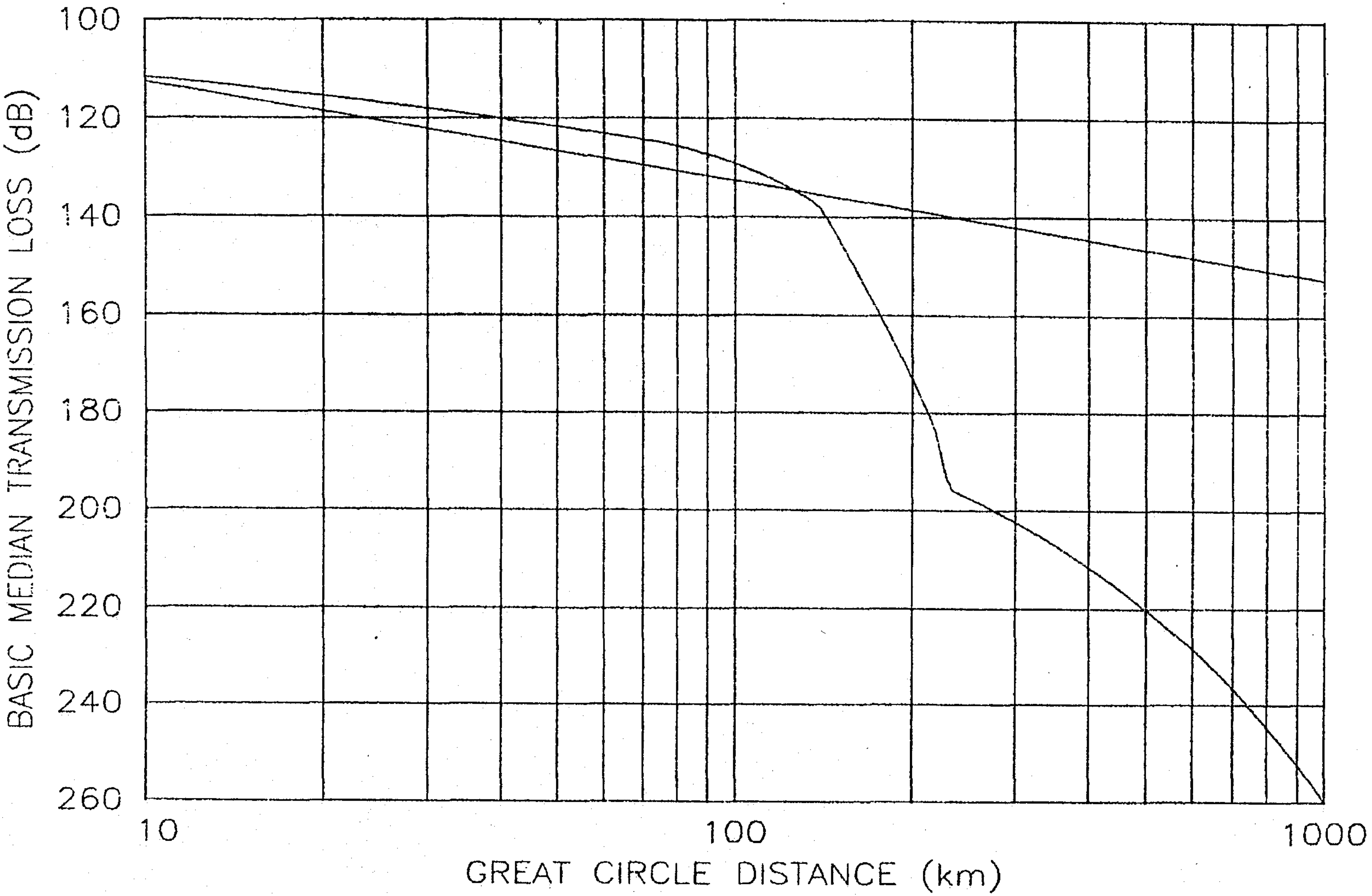

FIGURE A-45. f=1GHz,h_1=1m,h_2=2km,V.P.,Land and Sea Water

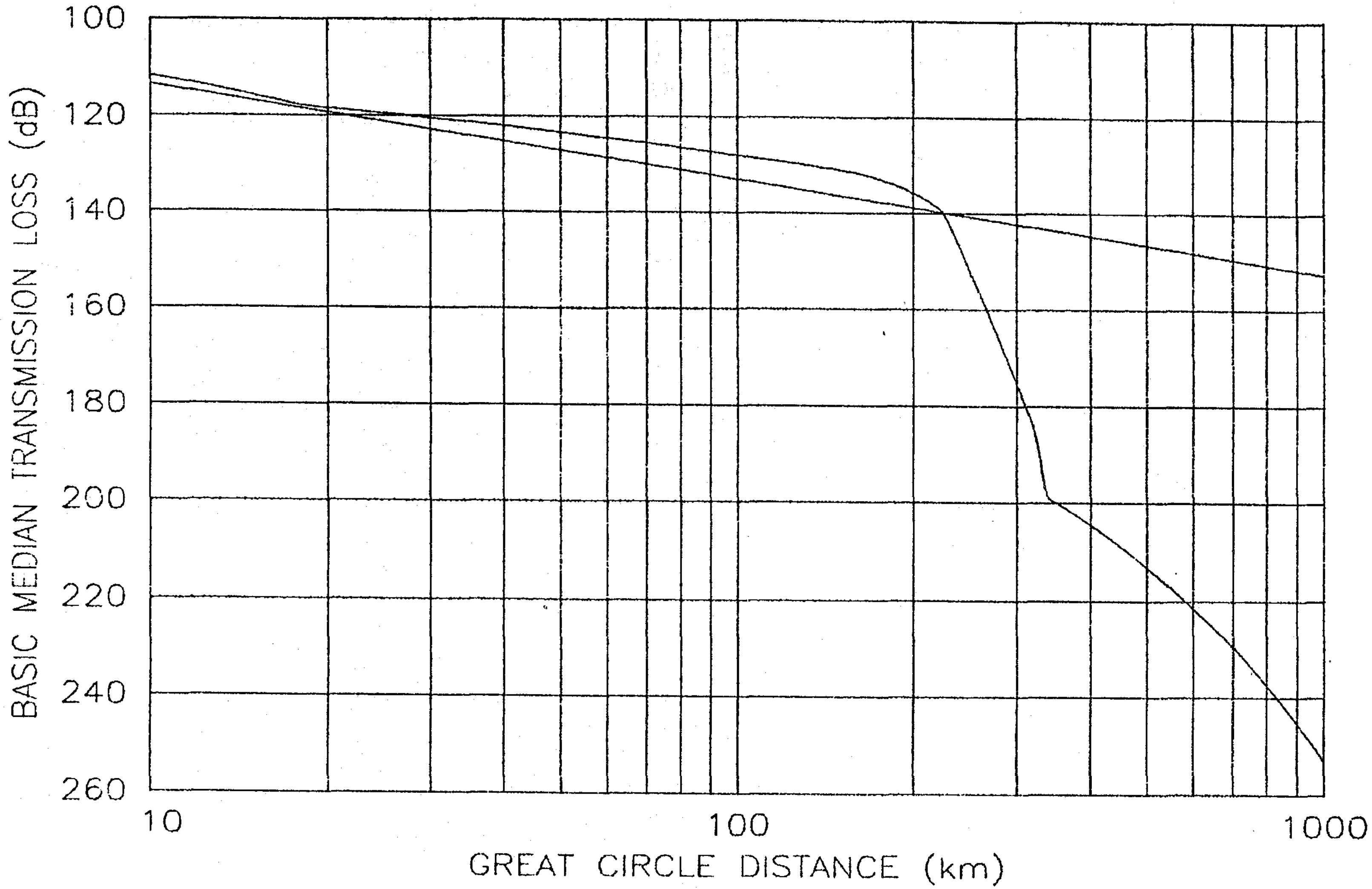

FIGURE A-46. $f=1\text{GHz}, h_1=1\text{m}, h_2=5\text{km}$, V.P., Land and Sea Water

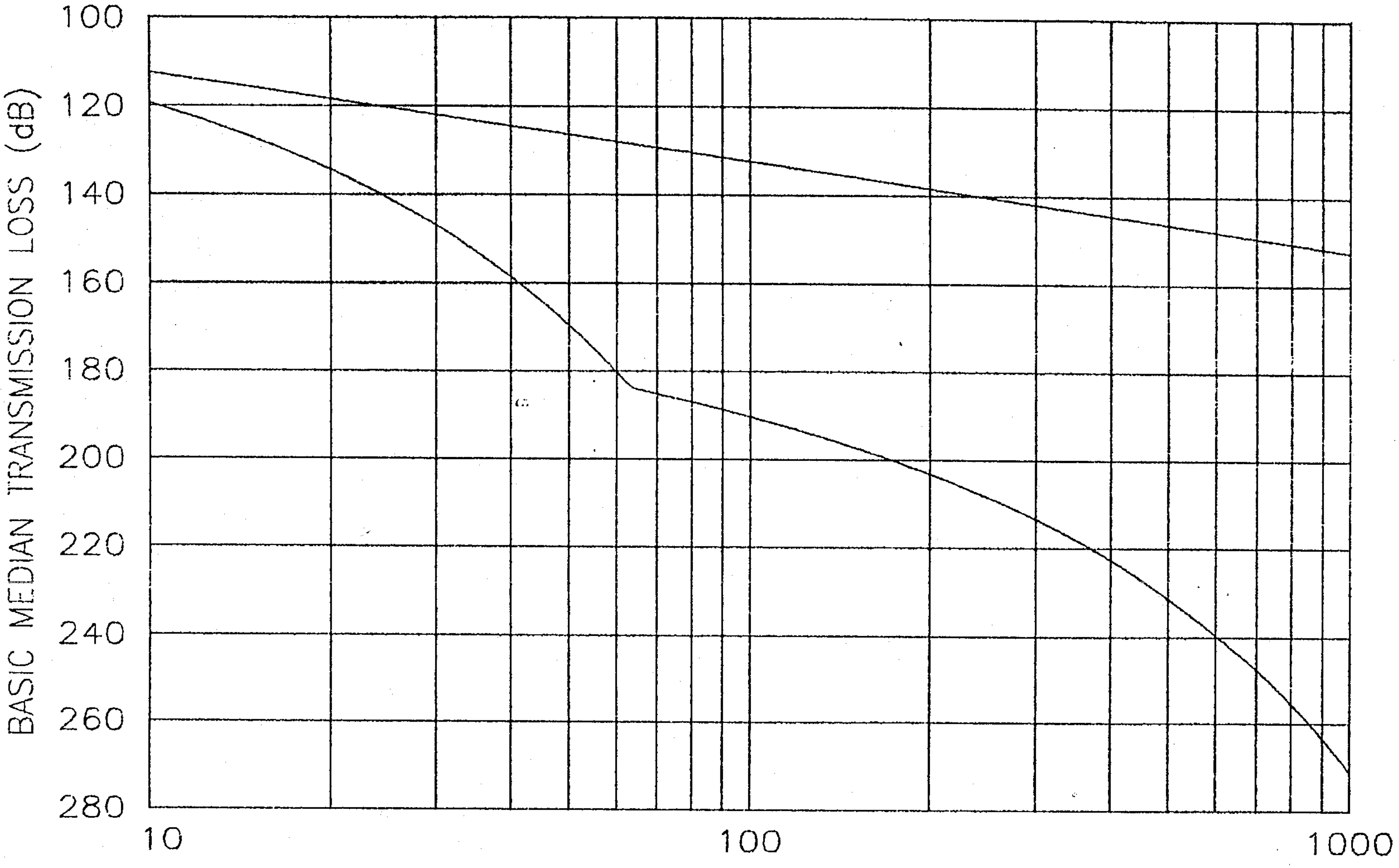

FIGURE A–47. $f=1GHz, h_1=10m, h_2=10m$, V.P., Land and Sea Water

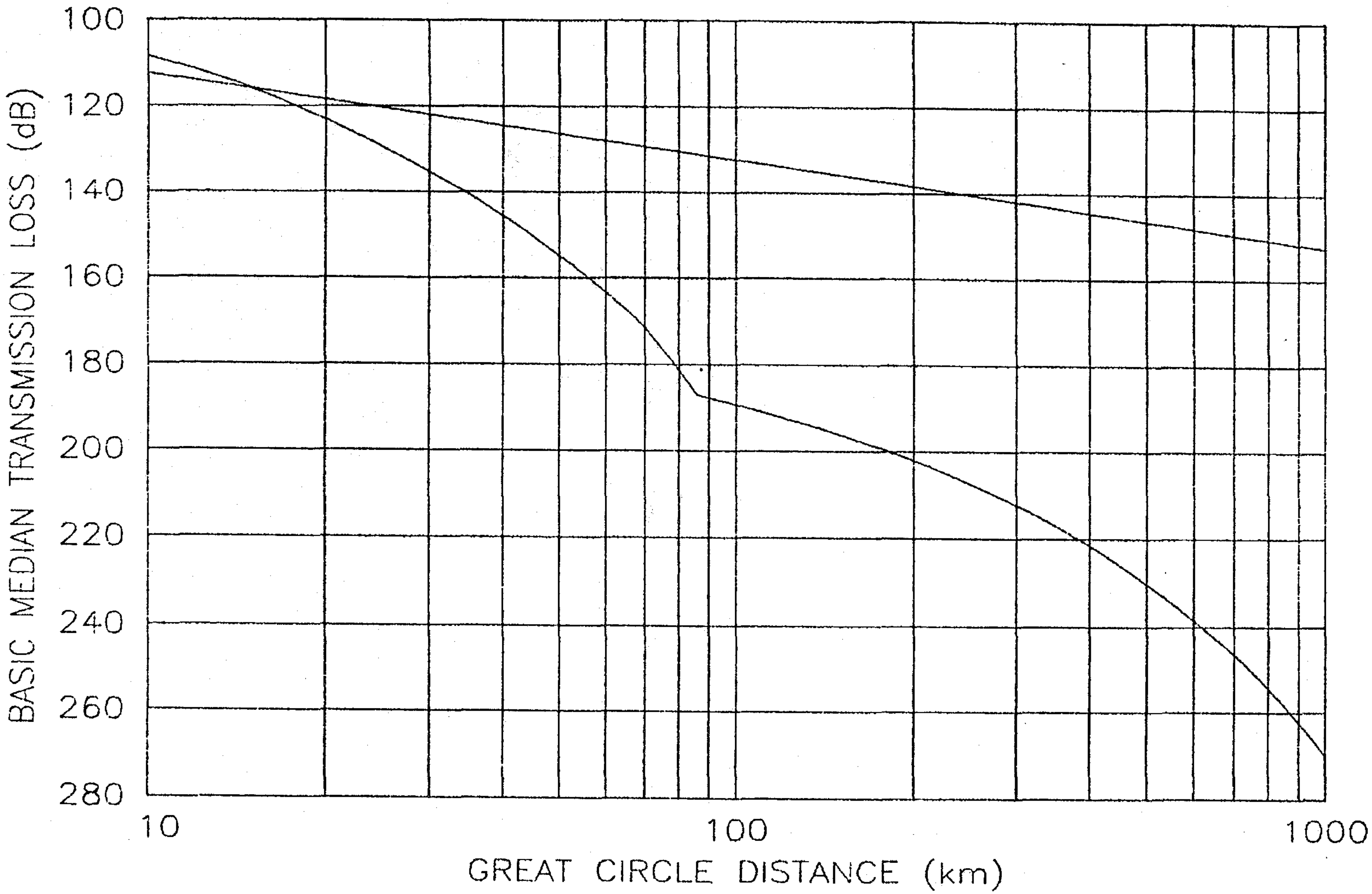

FIGURE A-48. f=1GHz,h_1=10m,h_2=50m,V.P.,Land and Sea Water

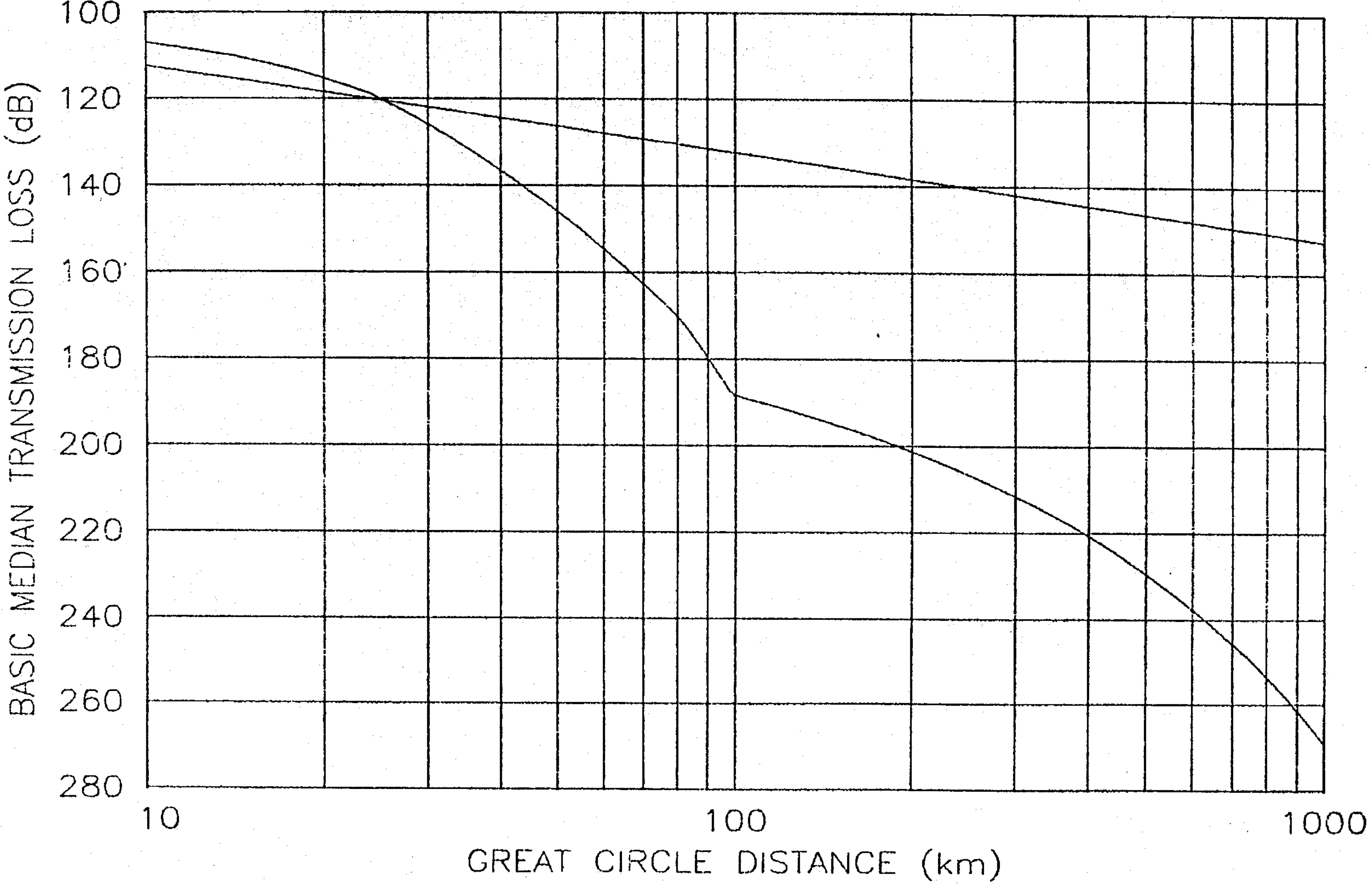

FIGURE A-49. $f=1GHz, h_1=10m, h_2=100m$, V.P., Land and Sea Water

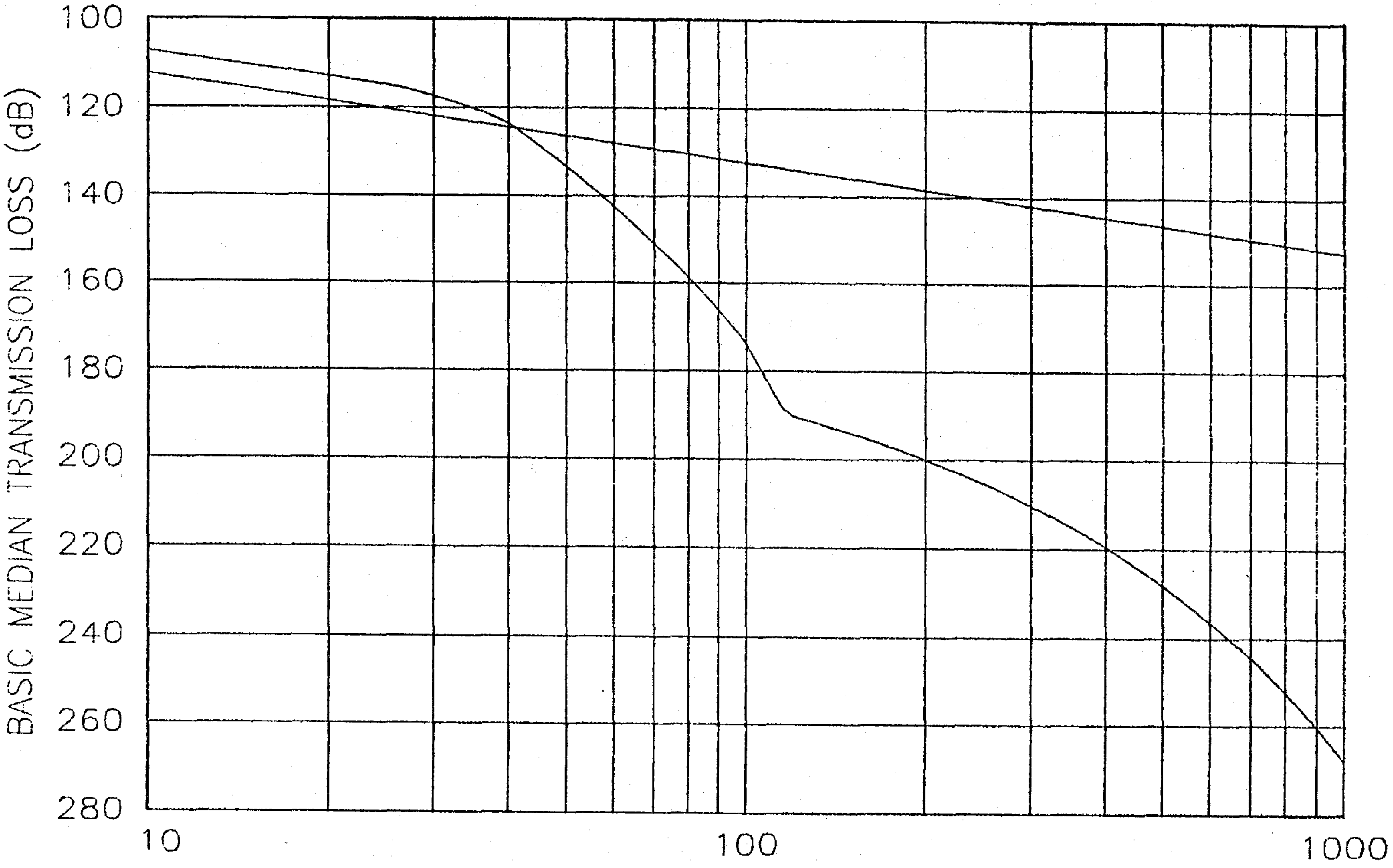

FIGURE A–50. $f=1GHz, h_1=10m, h_2=200m$, V.P., Land and Sea Water

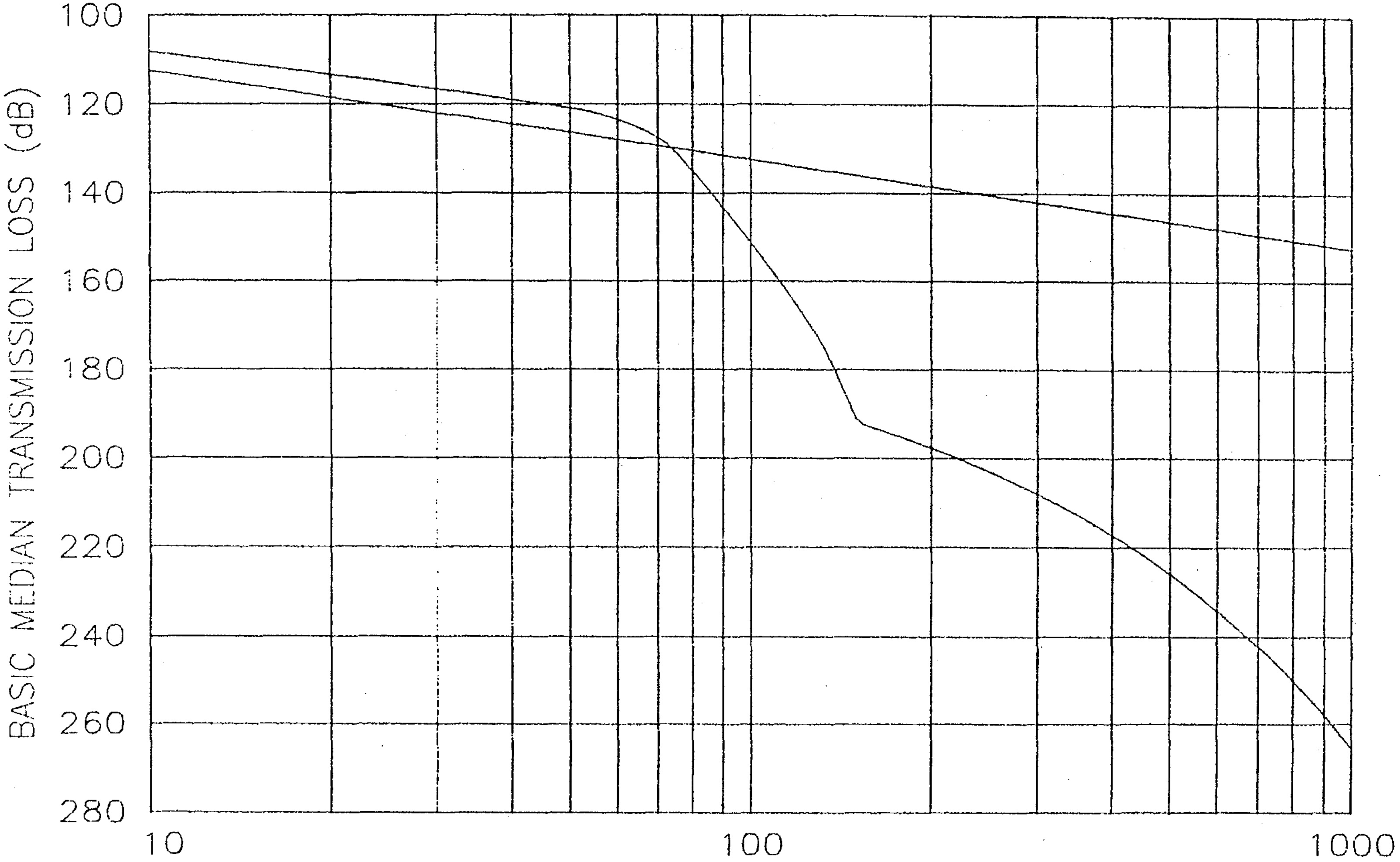

FIGURE A-51. $f=1GHz, h_1=10m, h_2=500m$, V.P., Land and Sea Water

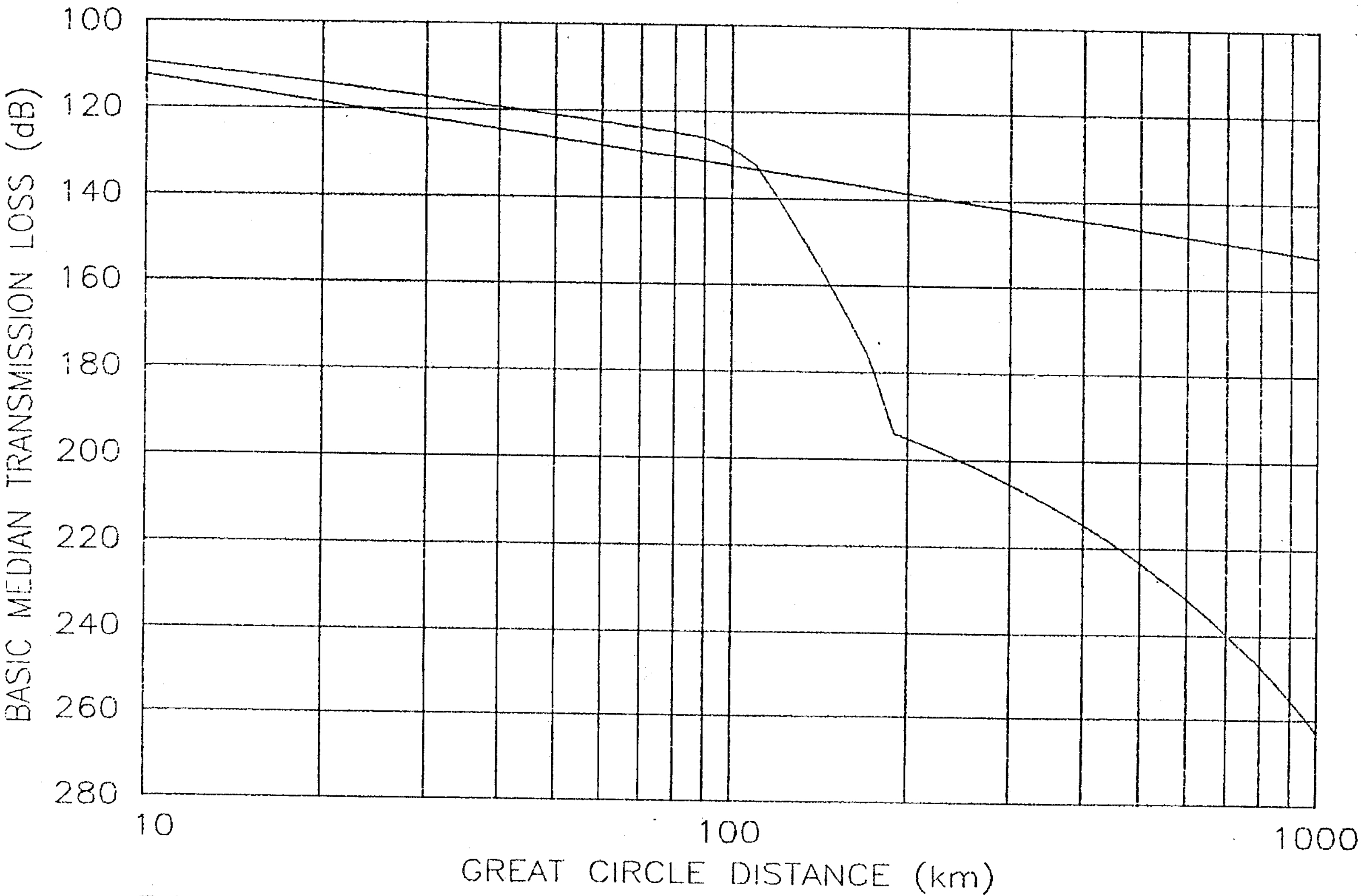

FIGURE A-52. $f=1GHz, h_1=10m, h_2=1km$, V.P., Land and Sea Water

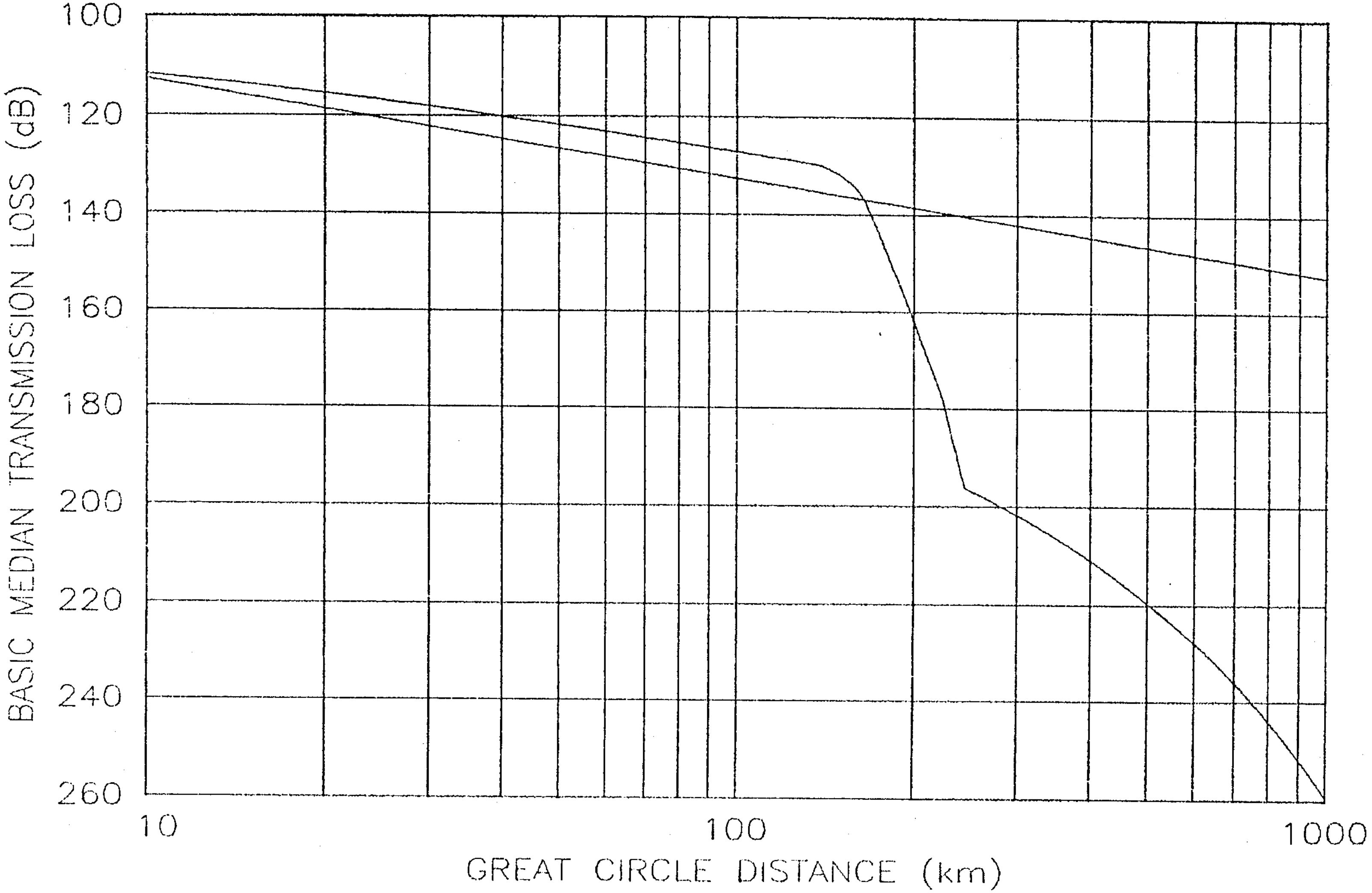

FIGURE A–53. $f=1\text{GHz}, h_1=10\text{m}, h_2=2\text{km}$, V.P., Land and Sea Water

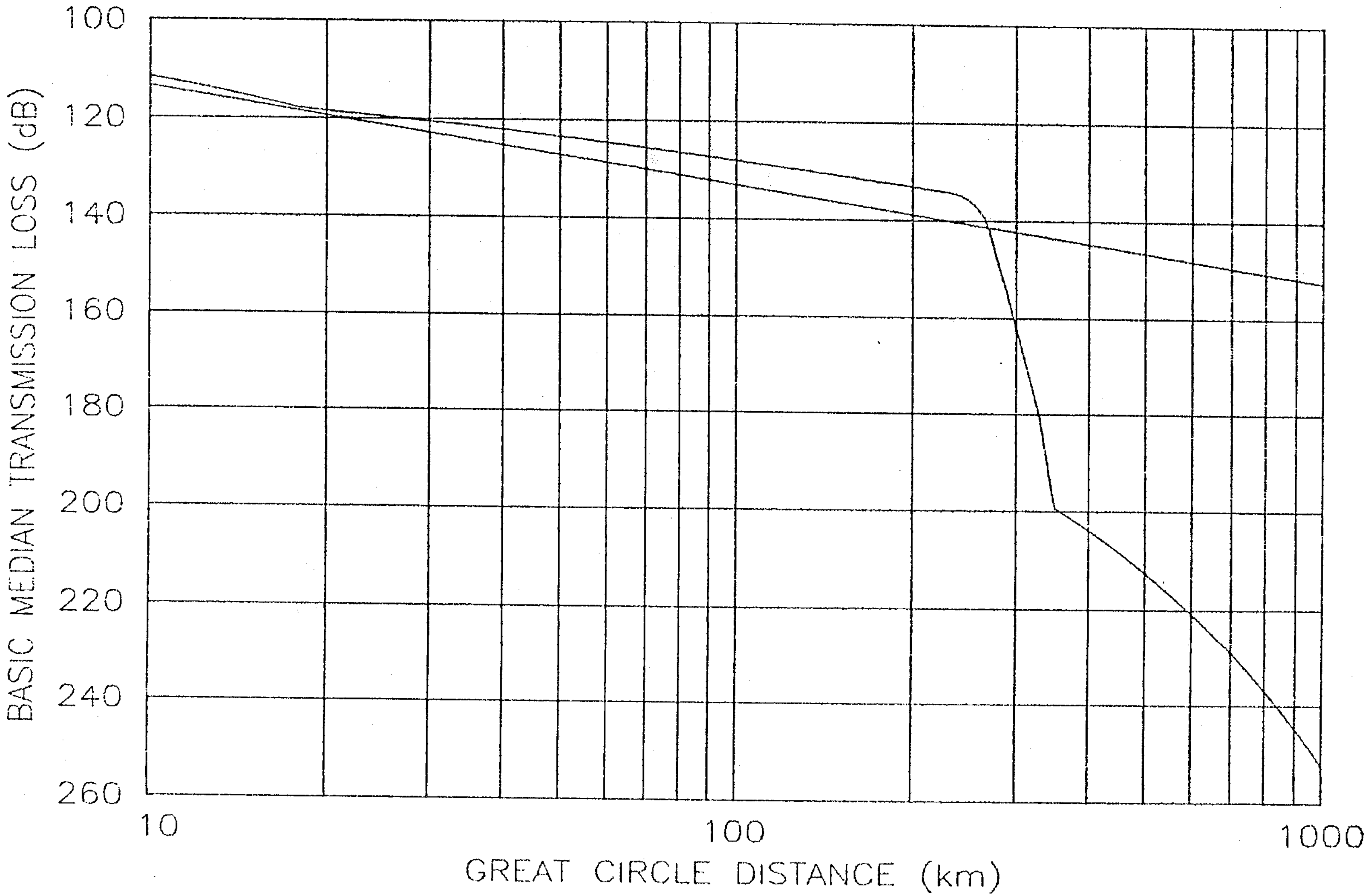

FIGURE A-54. f=1GHz,h_1=10m,h_2=5km,V.P.,Land and Sea Water

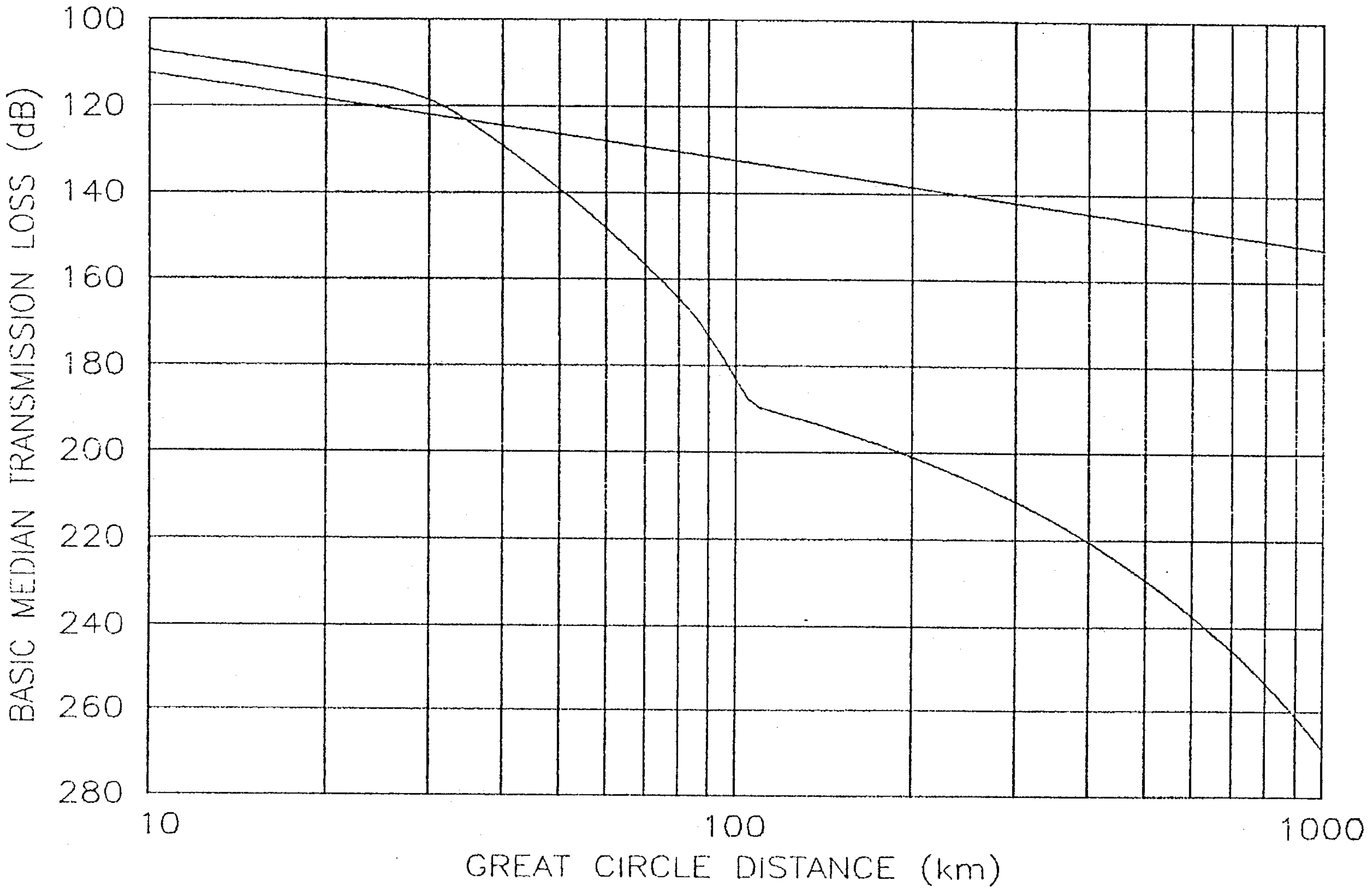

FIGURE A-55. $f=1GHz, h_1=50m, h_2=50m$, V.P., Land and Sea Water

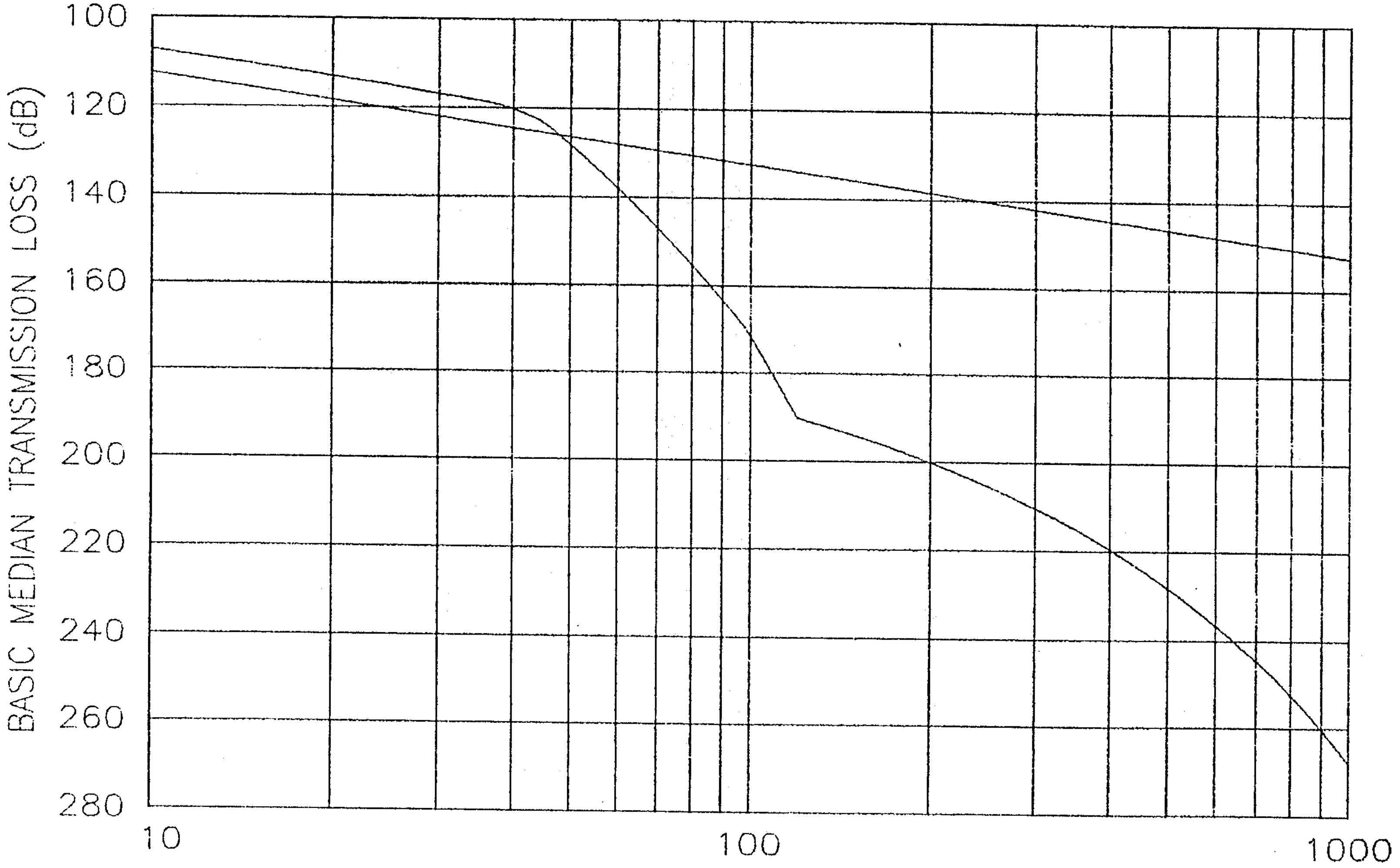

FIGURE A-56. f=1GHz,h_1=50m,h_2=100m,V.P.,Land and Sea Water

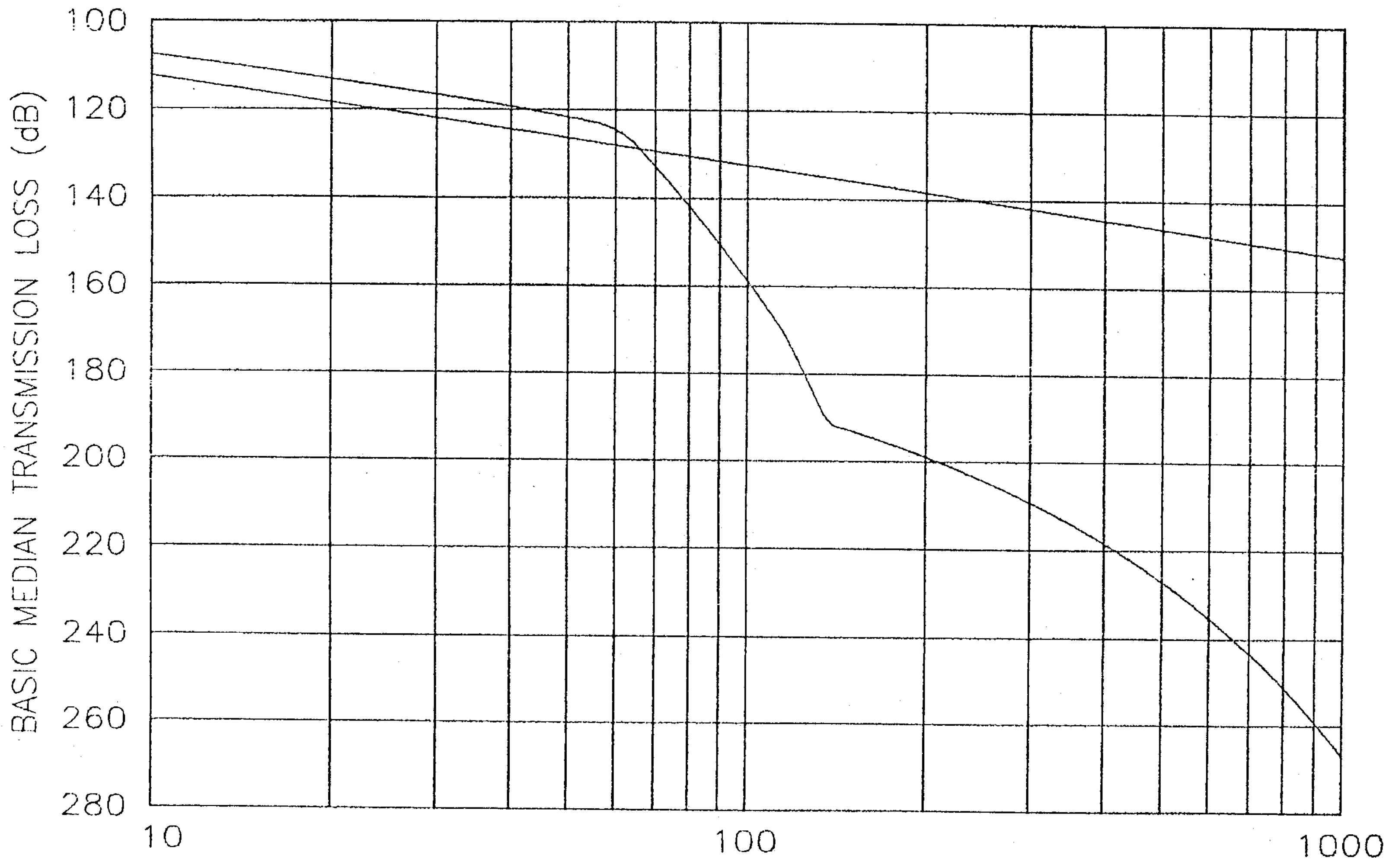

FIGURE A-57. $f=1GHz, h_1=50m, h_2=200m$, V.P., Land and Sea Water

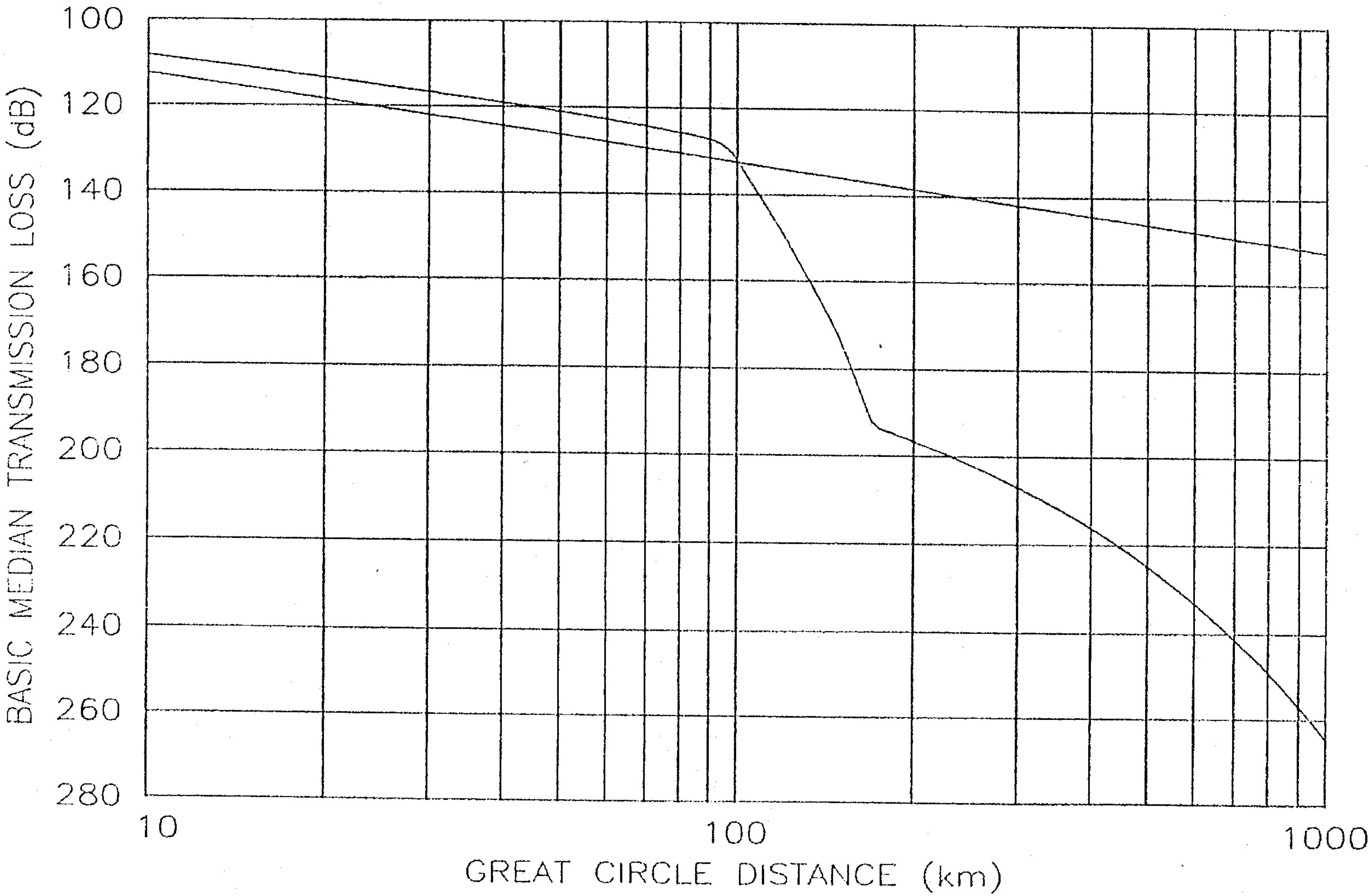

FIGURE A-58. $f=1\text{GHz}, h_1=50\text{m}, h_2=500\text{m}$, V.P., Land and Sea Water

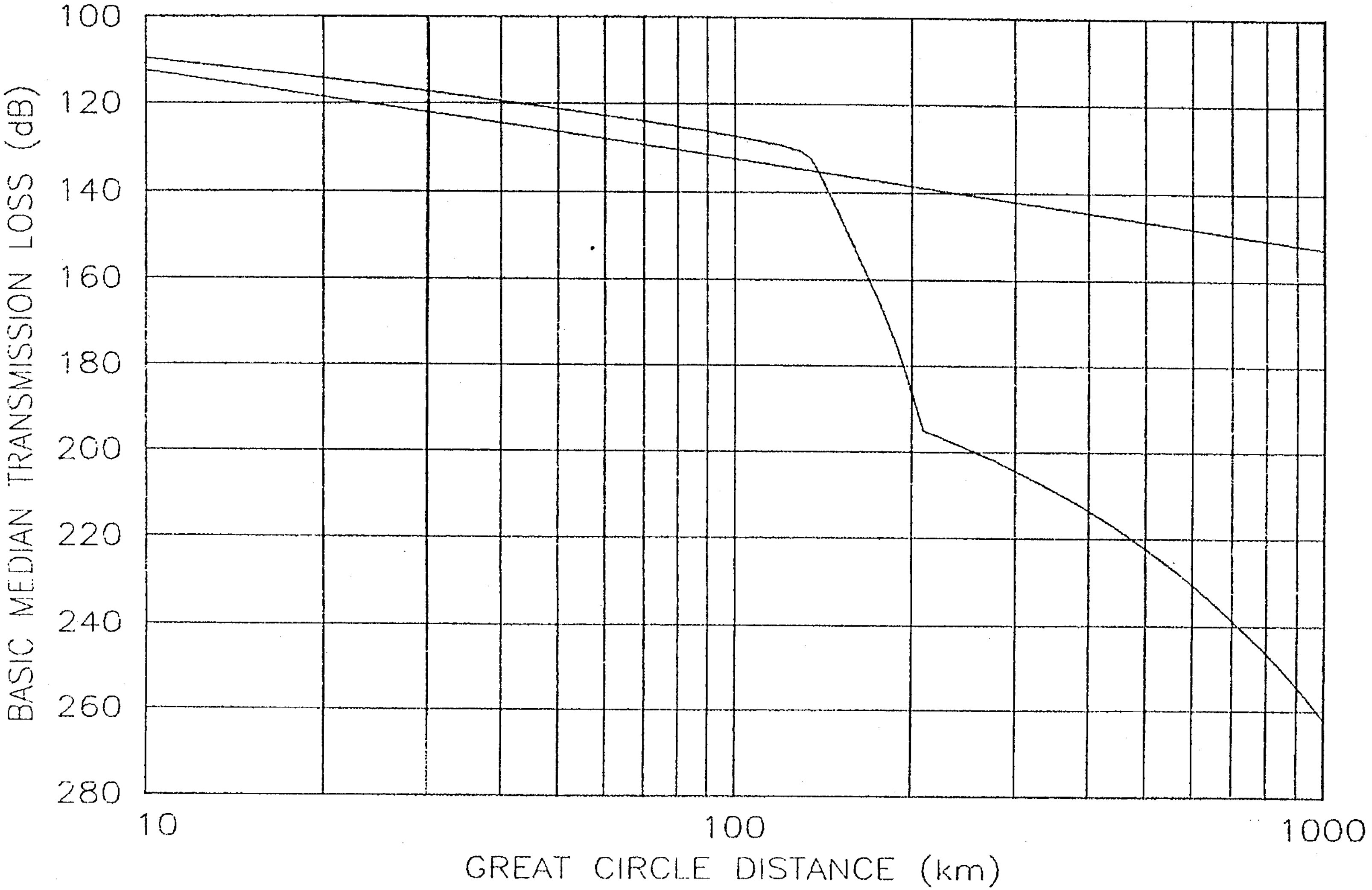

FIGURE A-59. $f=1\text{GHz}, h_1=50\text{m}, h_2=1\text{km}$, V.P., Land and Sea Water

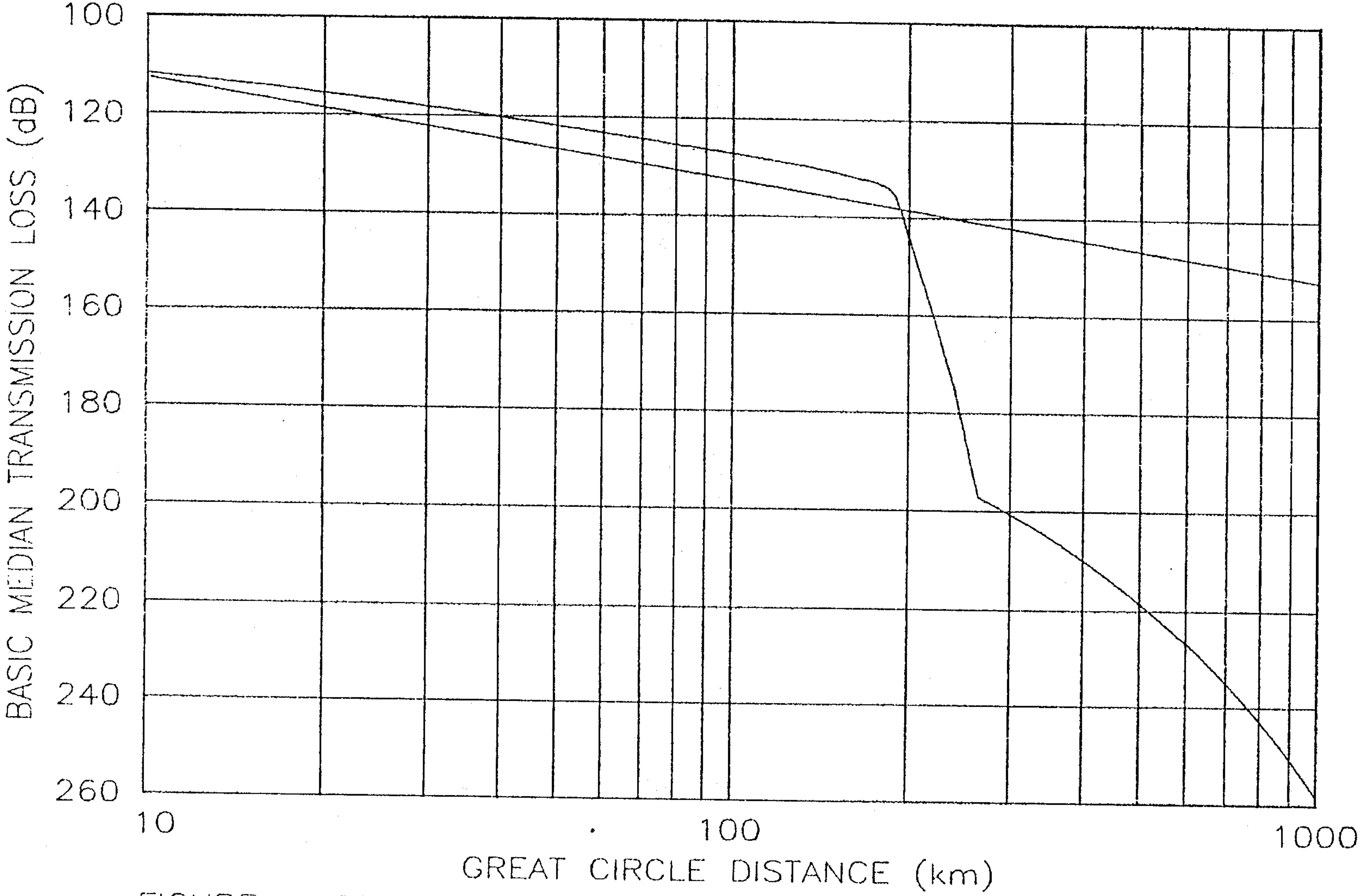

FIGURE A-60. $f=1GHz, h_1=50m, h_2=2km$, V.P., Land and Sea Water

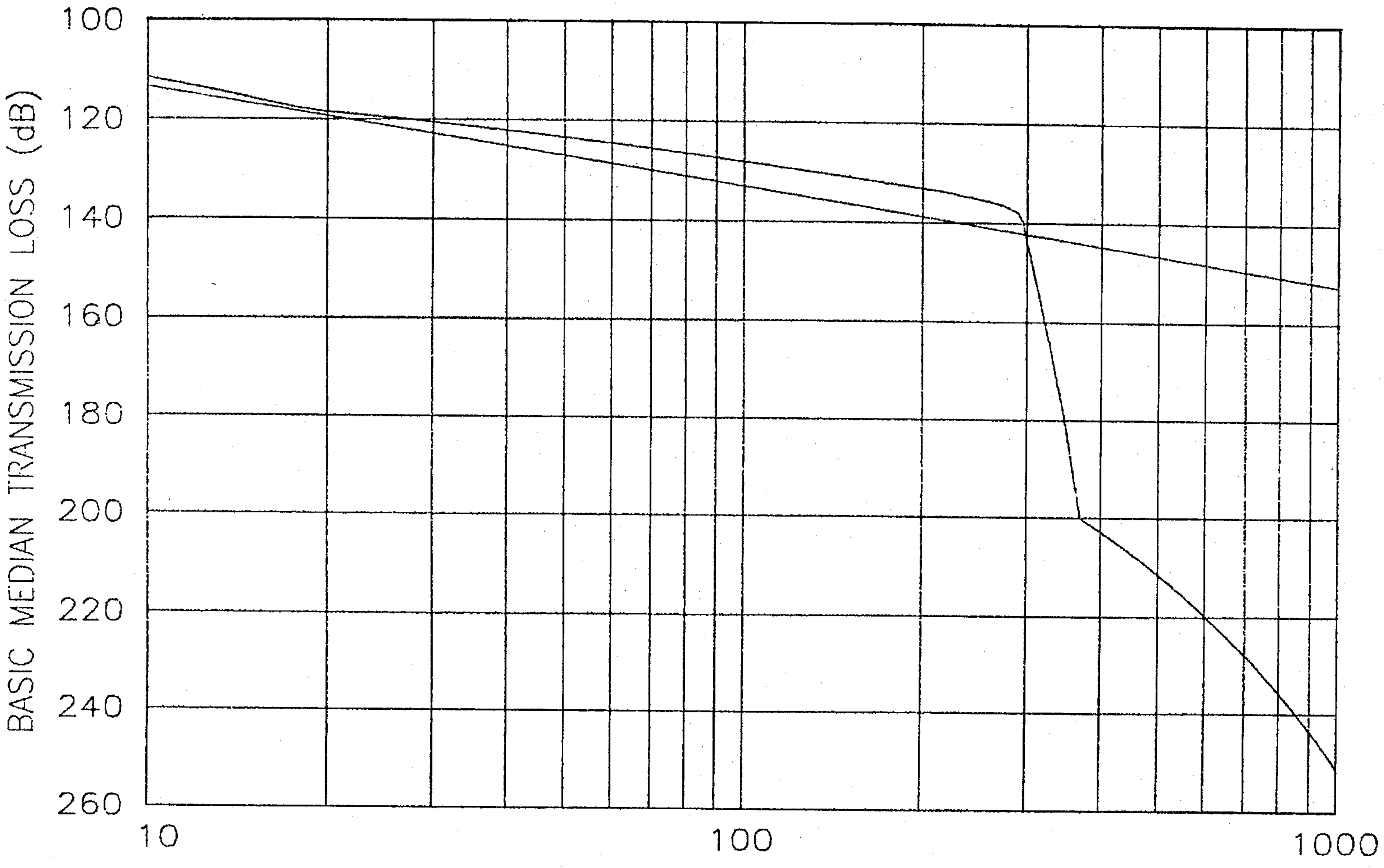

FIGURE A-61. f=1GHz,h_1=50m,h_2=5km,V.P.,Land and Sea Water

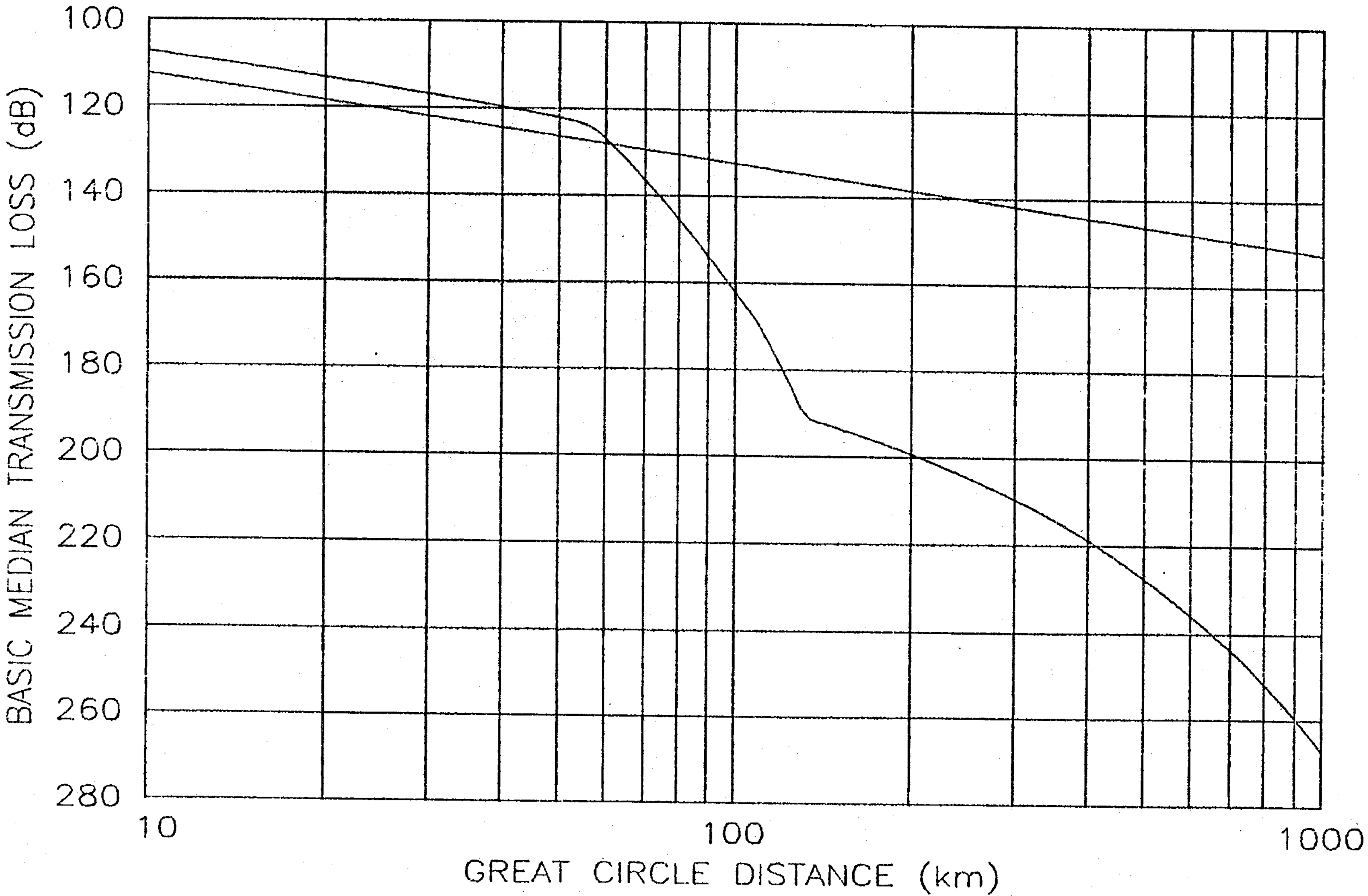

FIGURE A-62. $f=1GHz, h_1=100m, h_2=100m$, V.P., Land and Sea Water

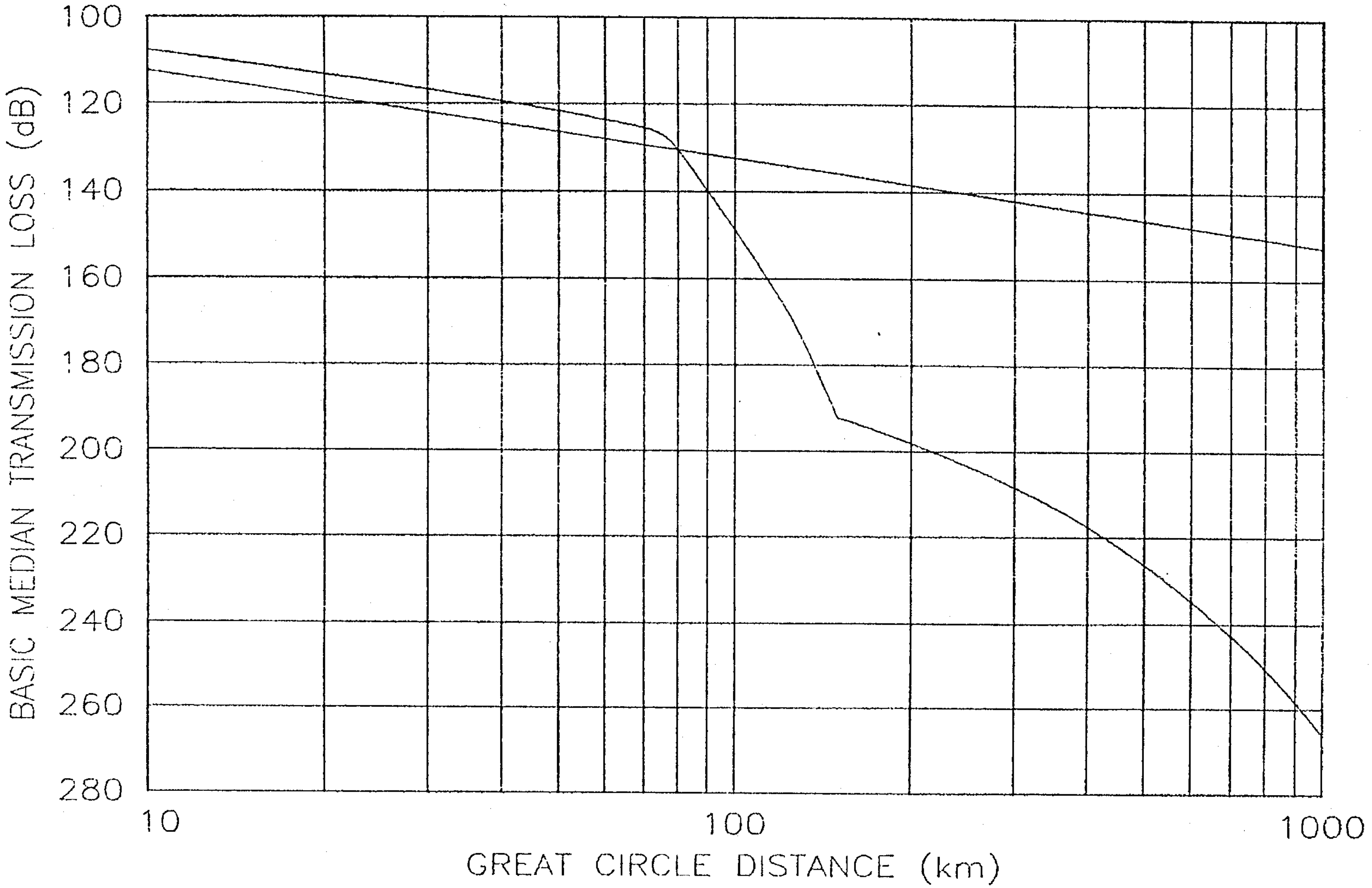

FIGURE A-63. f=1GHz,h_1=100m,h_2=200m,V.P.,Land and Sea Water

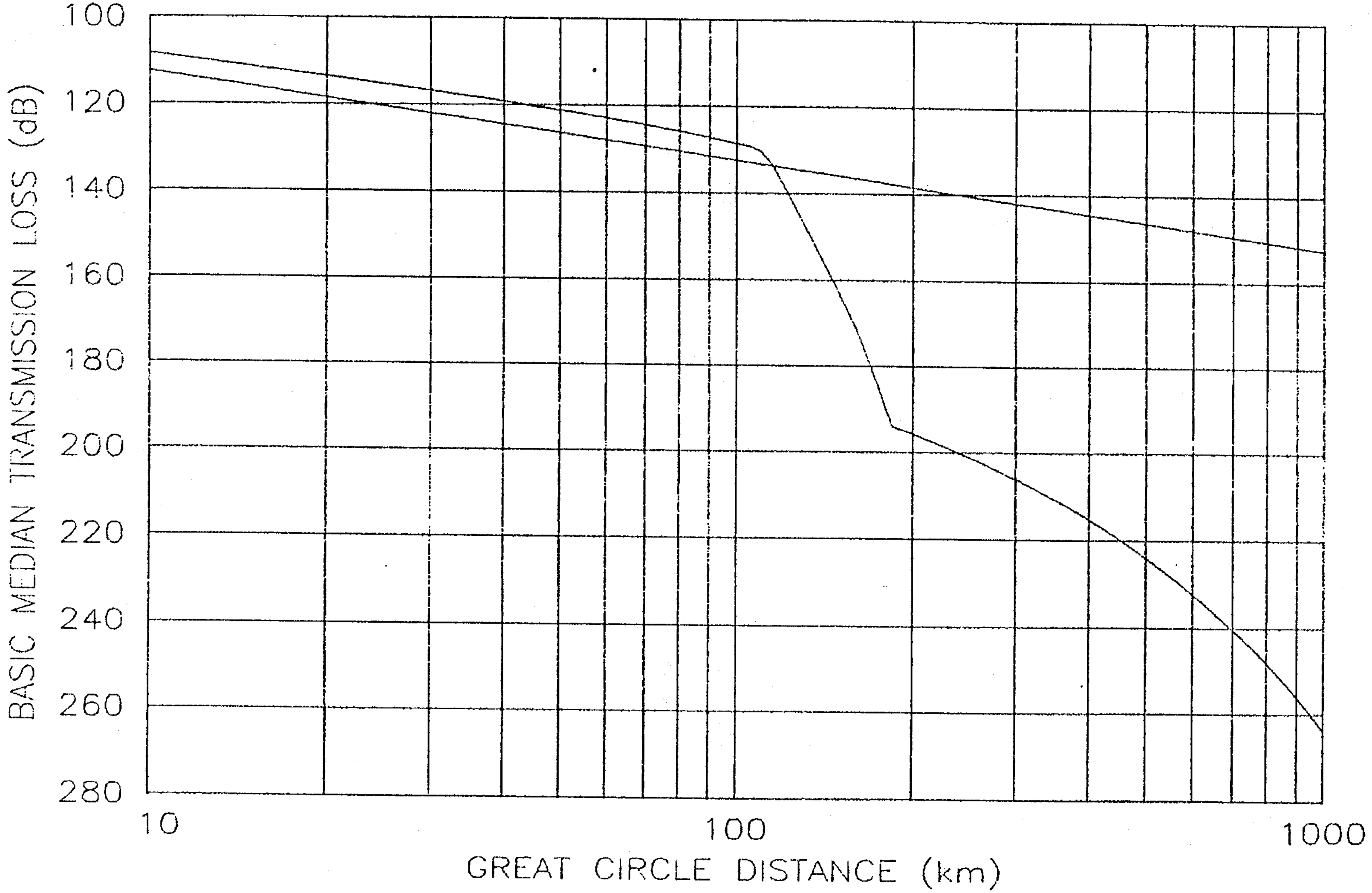

FIGURE A-64. $f=1\text{GHz}, h_1=100\text{m}, h_2=500\text{m}$, V.P., Land and Sea Water

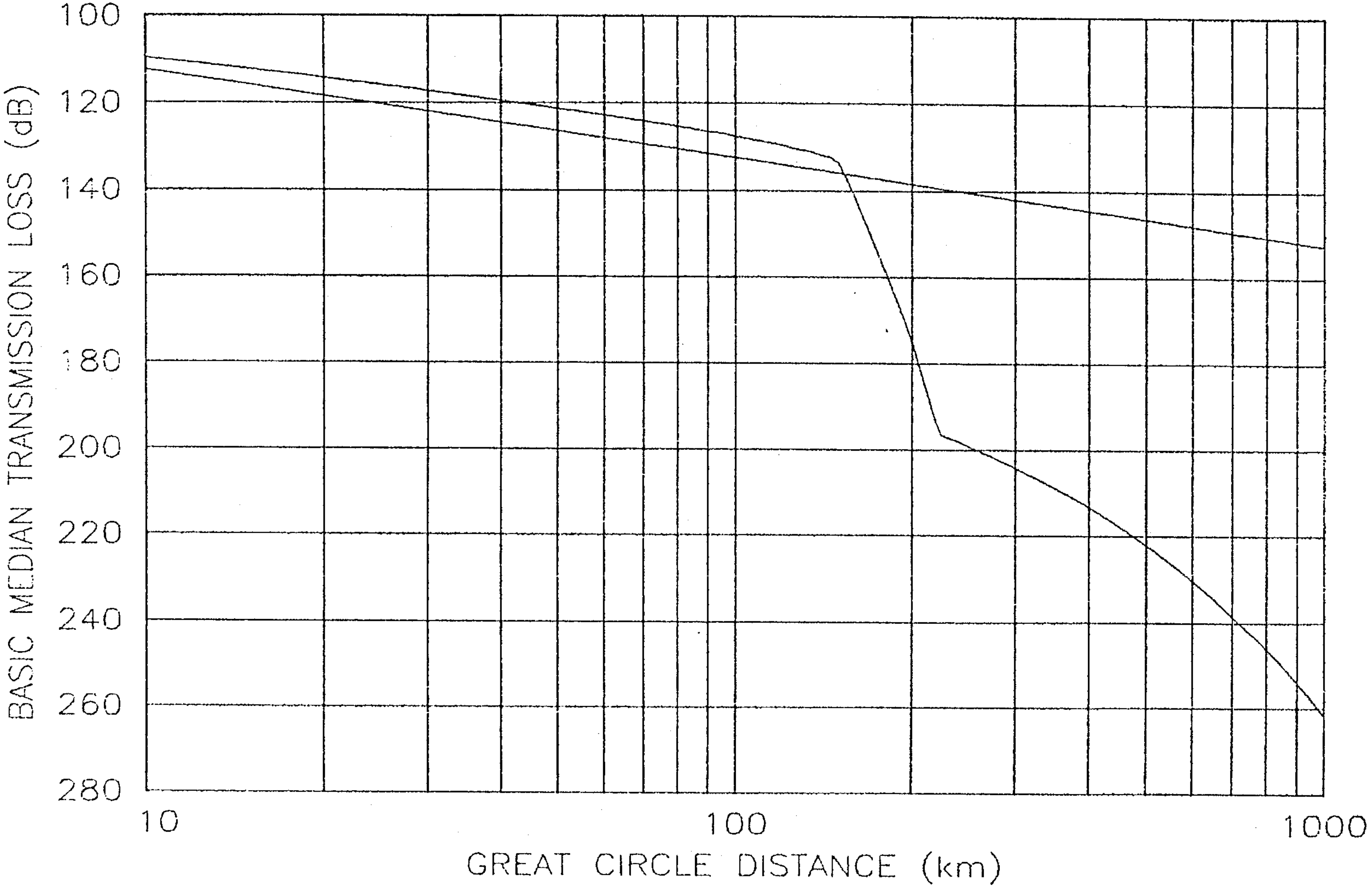

FIGURE A-65. $f=1GHz, h_1=100m, h_2=1km$, V.P., Land and Sea Water

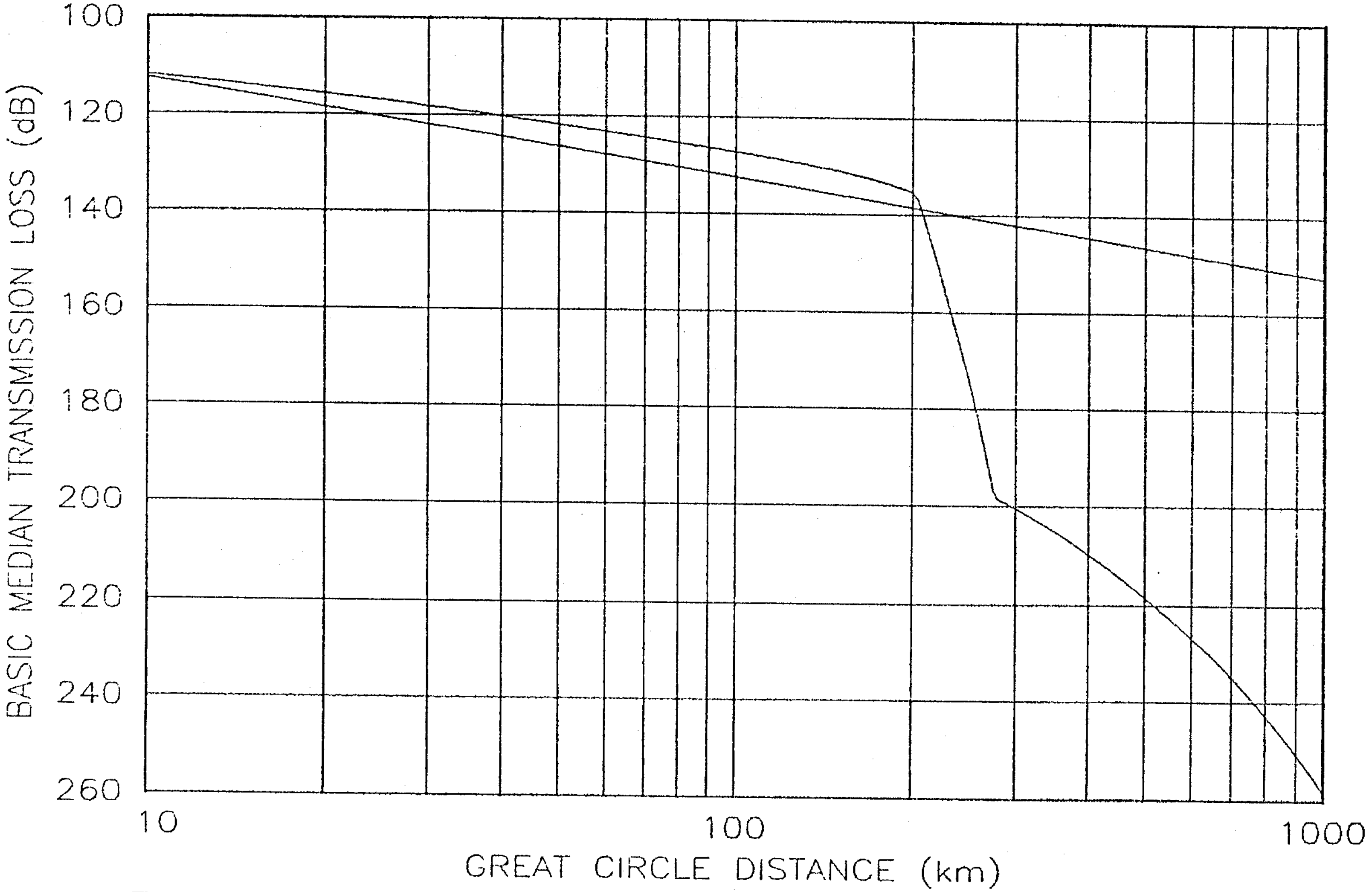

FIGURE A-66. $f=1GHz, h_1=100m, h_2=2km$, V.P., Land and Sea Water

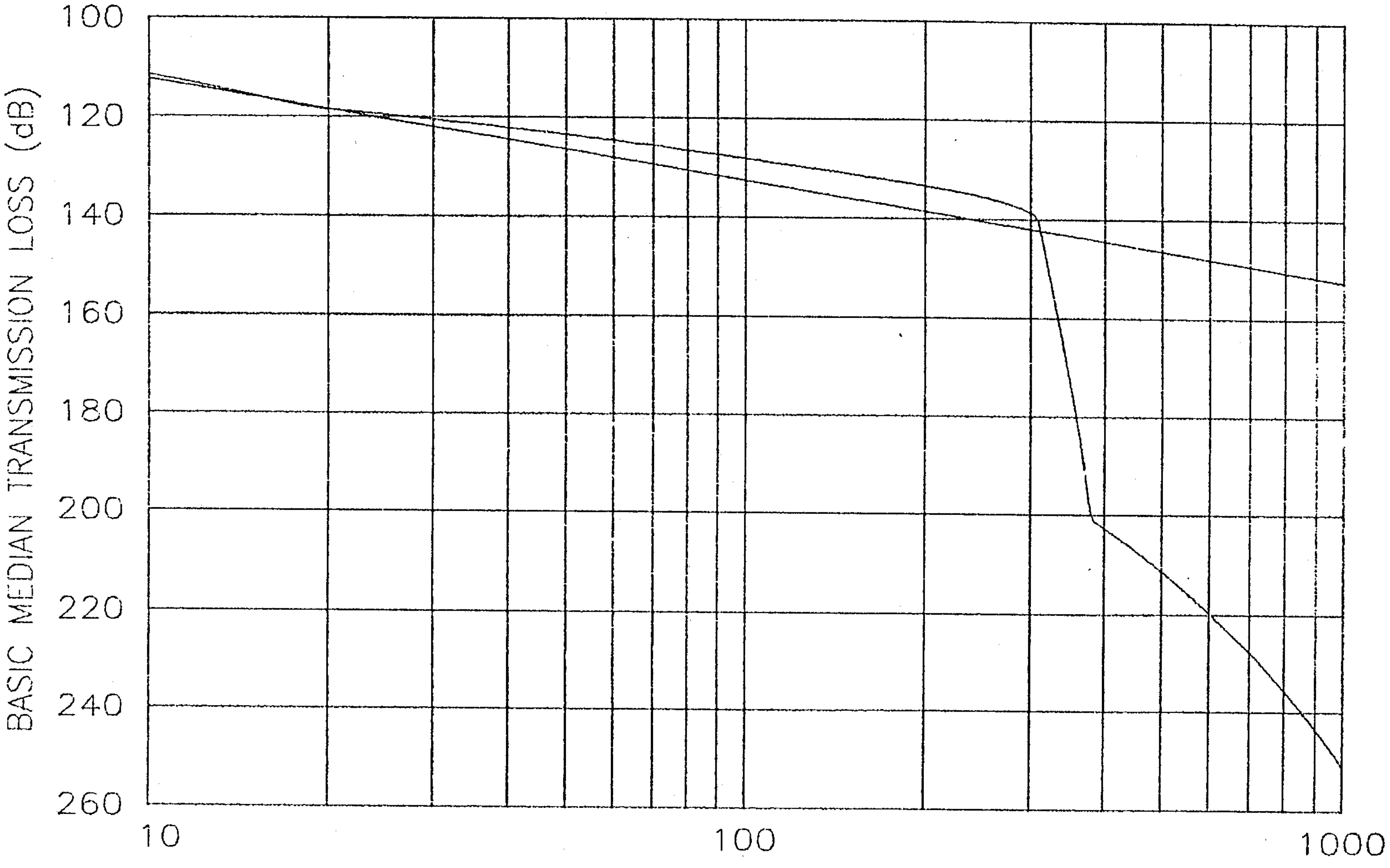

FIGURE A-67. $f=1GHz, h_1=100m, h_2=5km$, V.P., Land and Sea Water

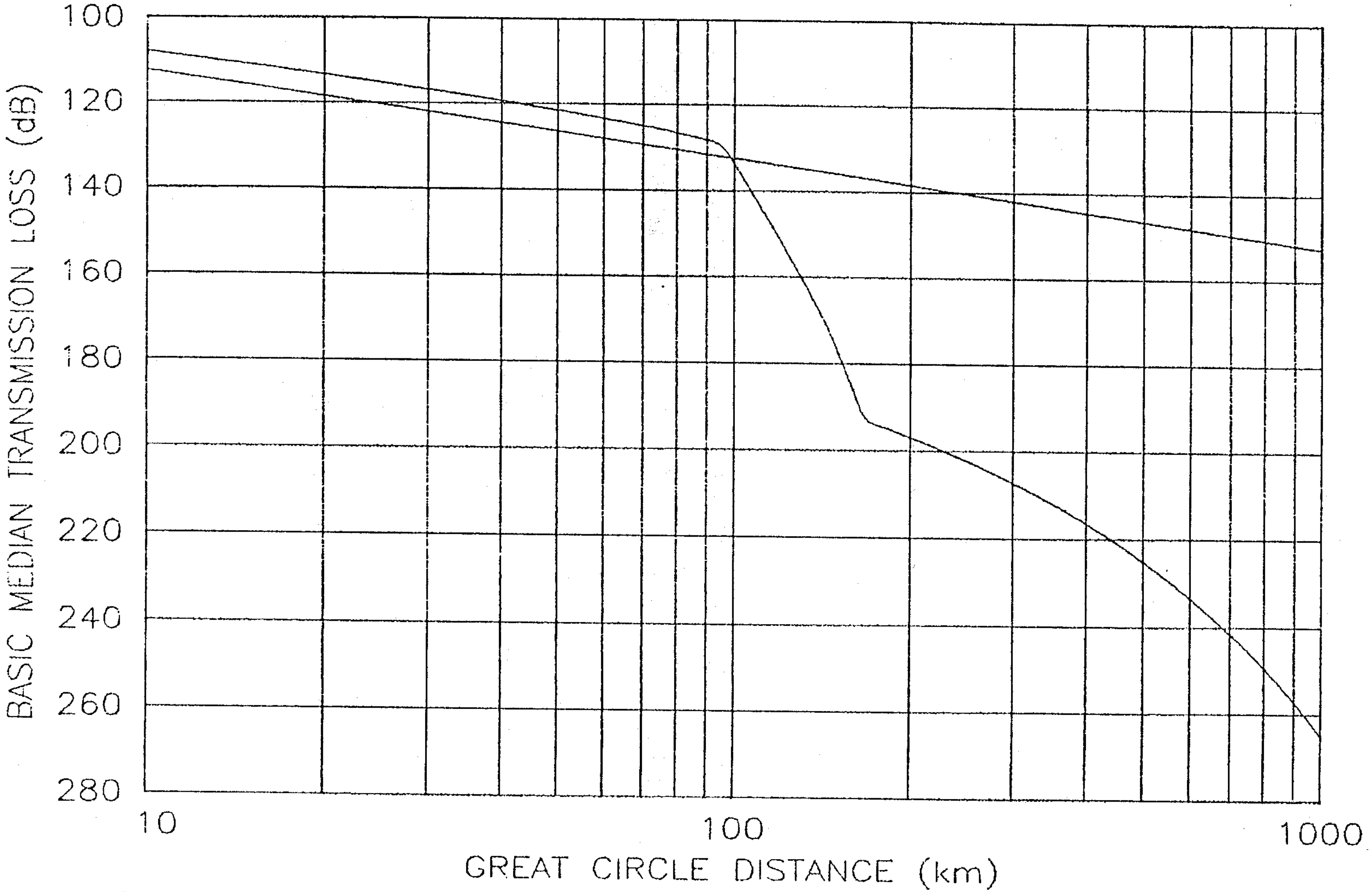

FIGURE A-68. $f=1\text{GHz}, h_1=200\text{m}, h_2=200\text{m}$, V.P., Land and Sea Water

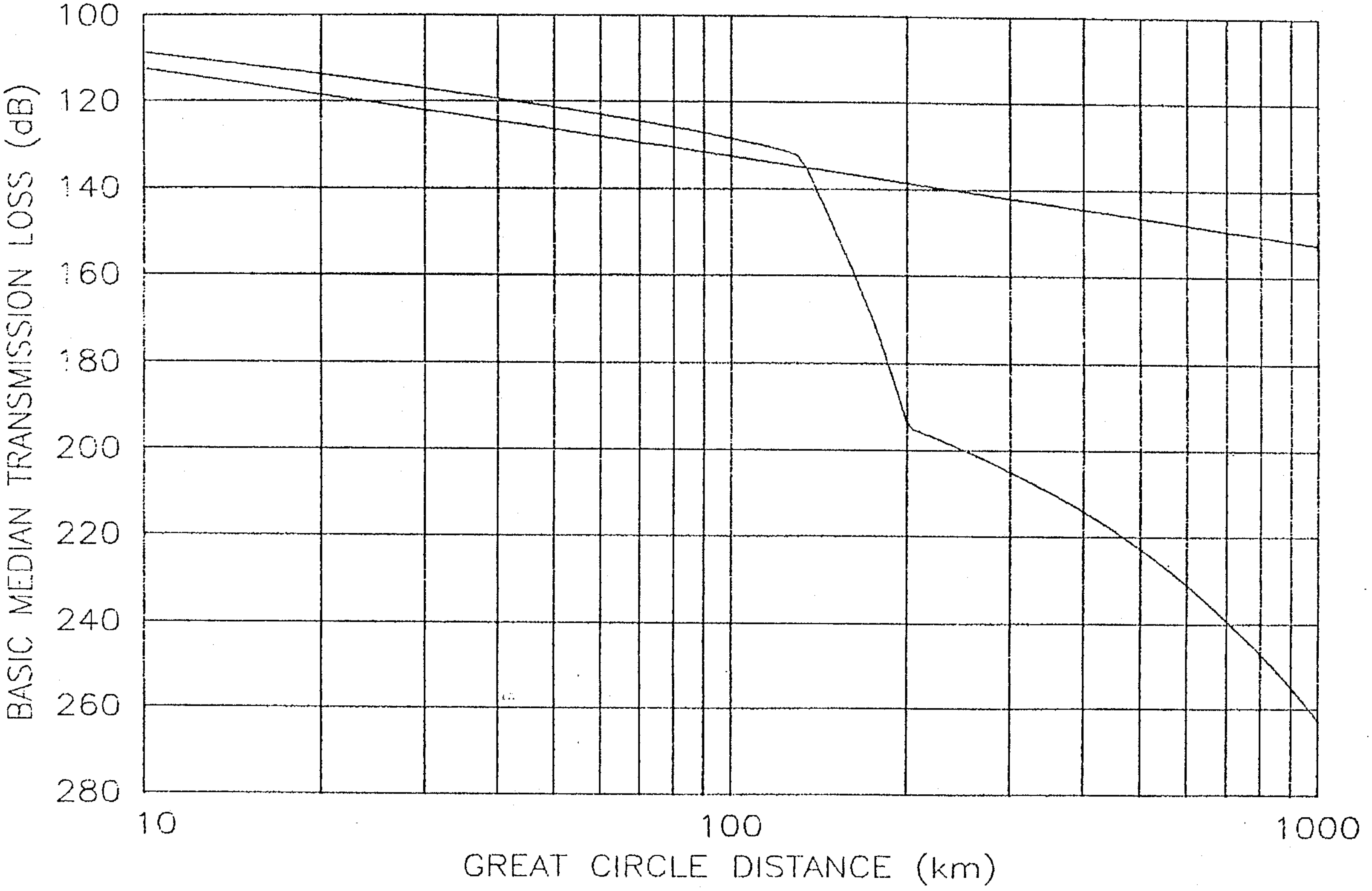

FIGURE A-69. f=1GHz,h_1=200m,h_2=500m,V.P.,Land and Sea Water

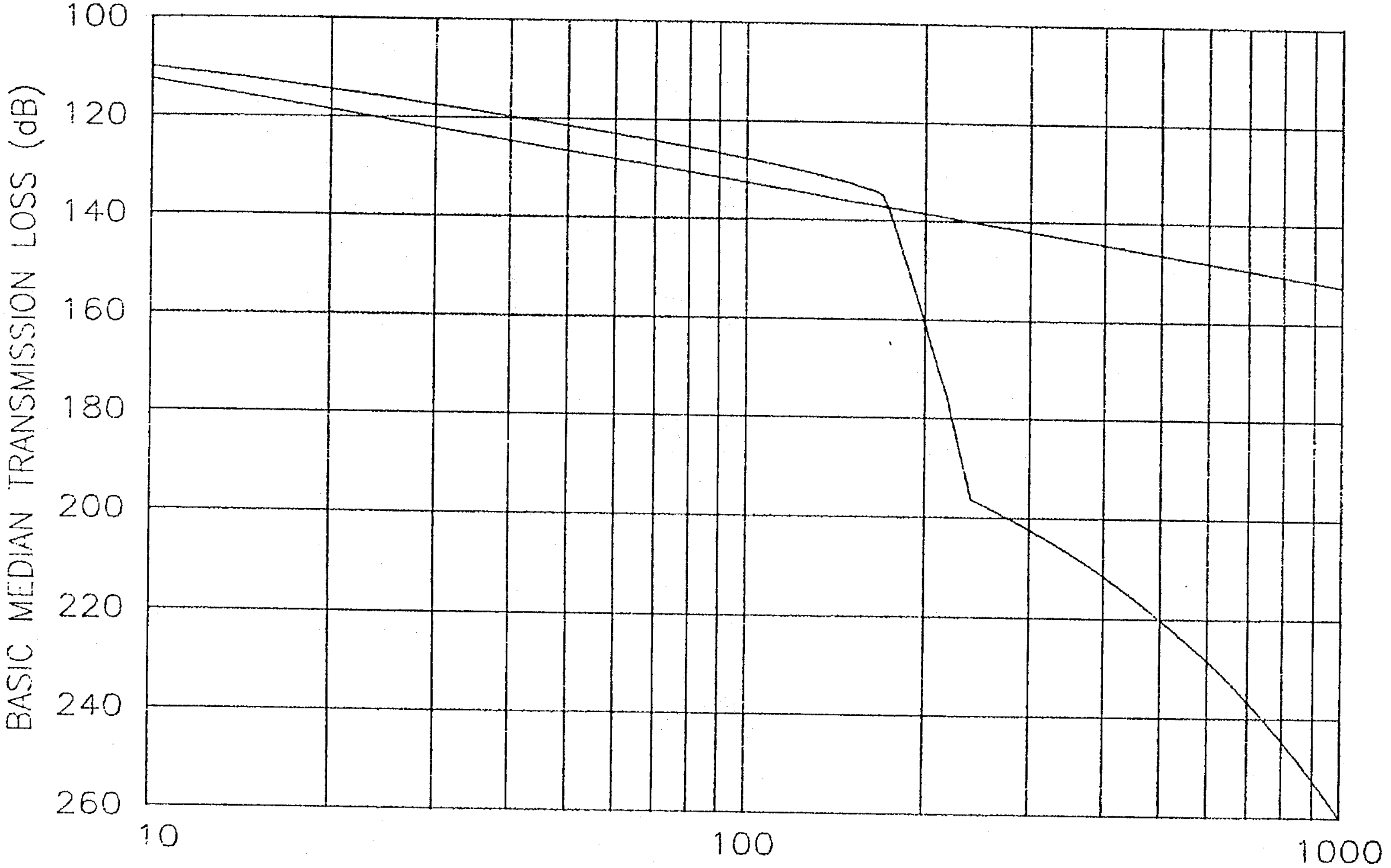

FIGURE A-70. $f=1GHz, h_1=200m, h_2=1km$, V.P., Land and Sea Water

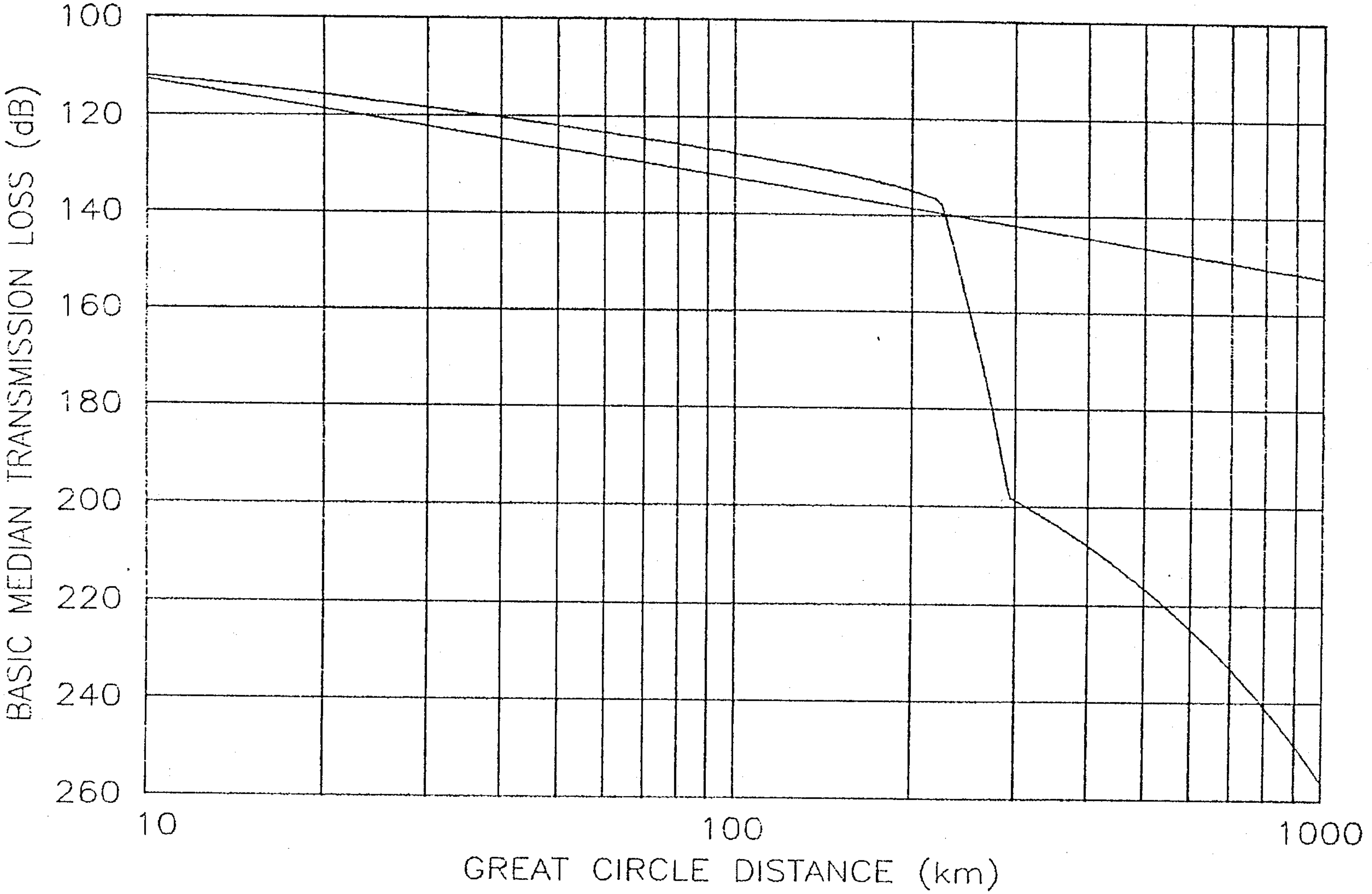

FIGURE A-71. f=1GHz,h_1=200m,h_2=2km,V.P.,Land and Sea Water

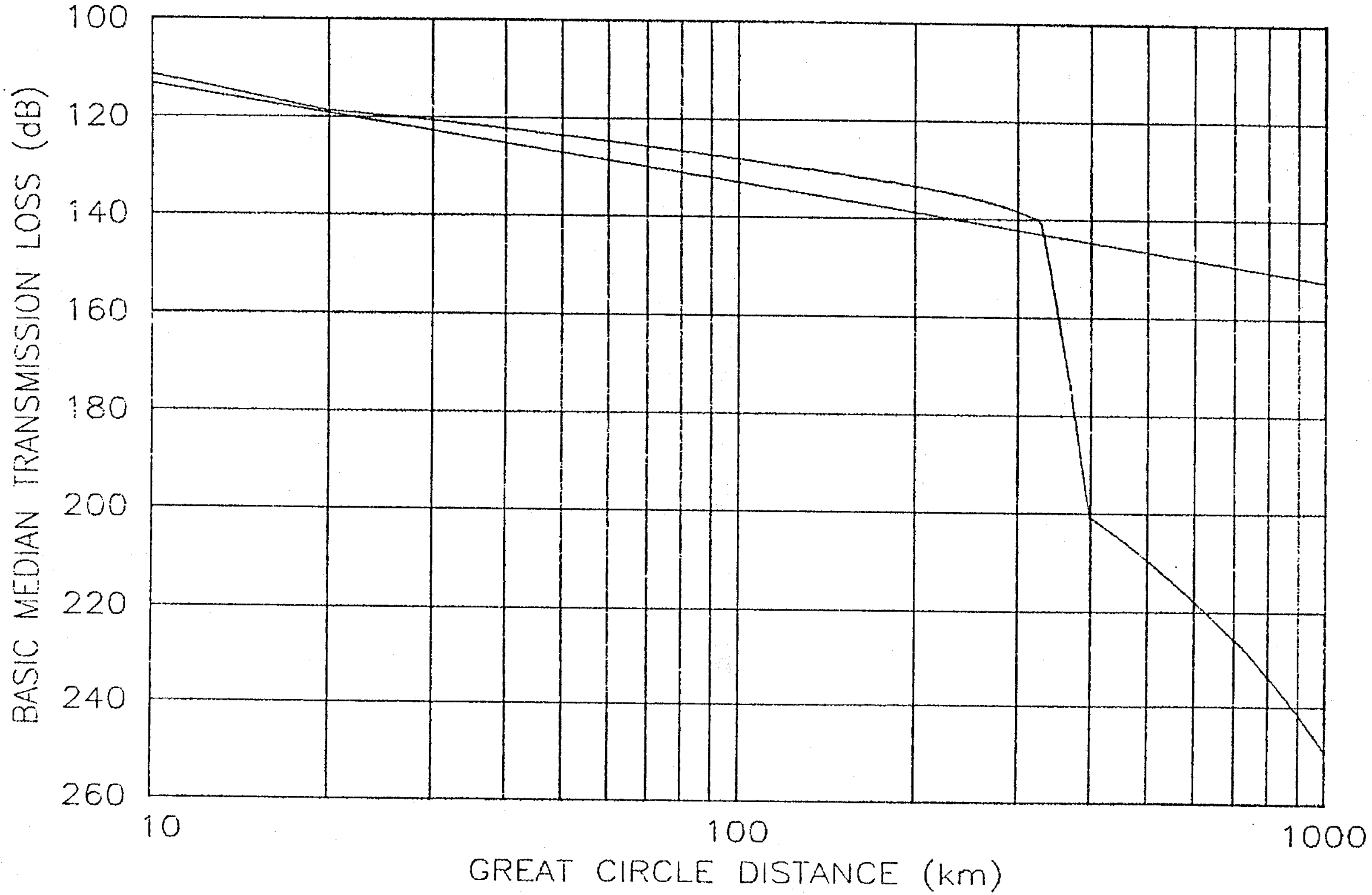

FIGURE A–72. $f=1\text{GHz}, h_1=200\text{m}, h_2=5\text{km}$, V.P., Land and Sea Water

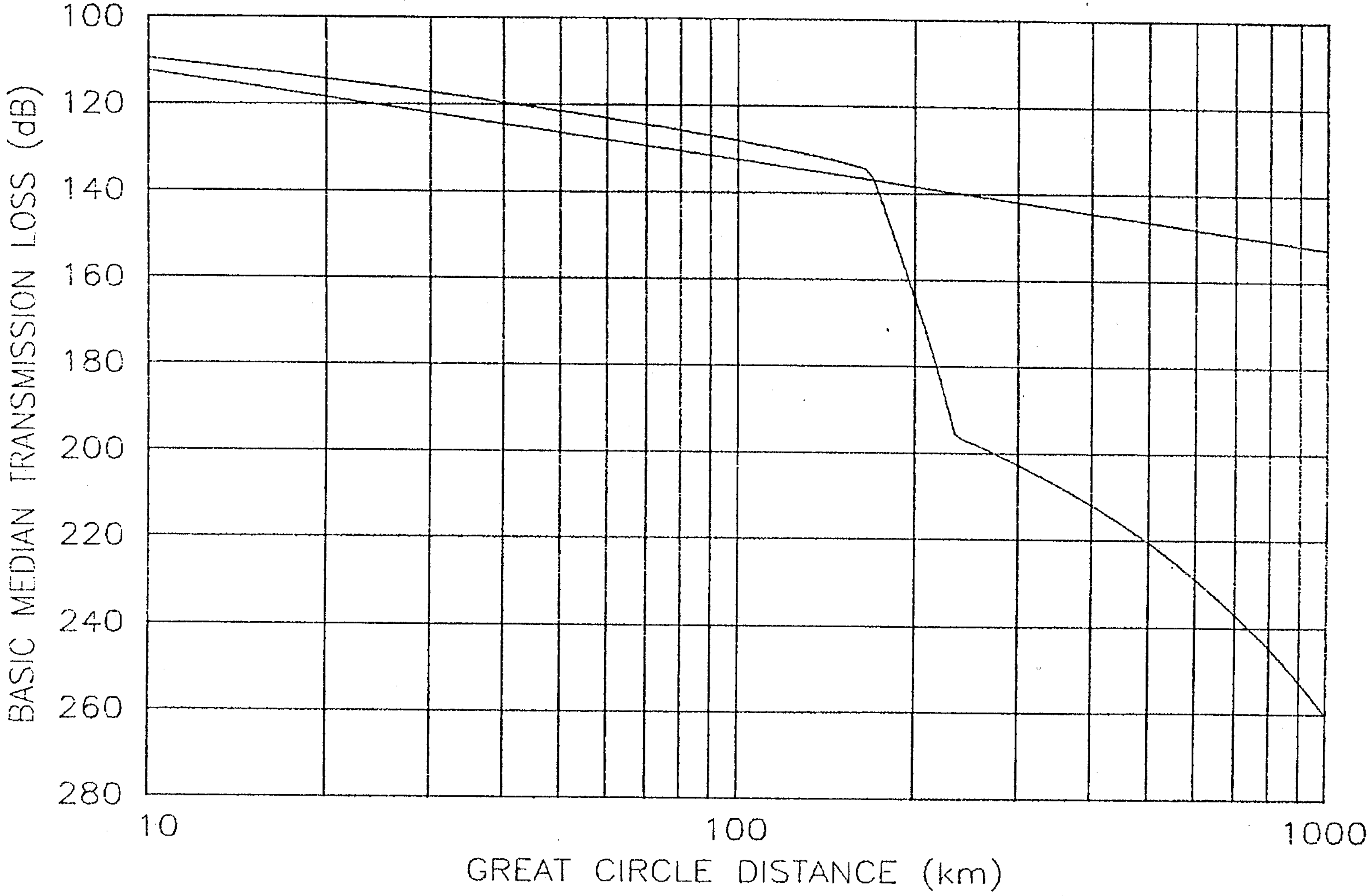

FIGURE A-73. f=1GHz,h_1=500m,h_2=500m,V.P.,Land and Sea Water

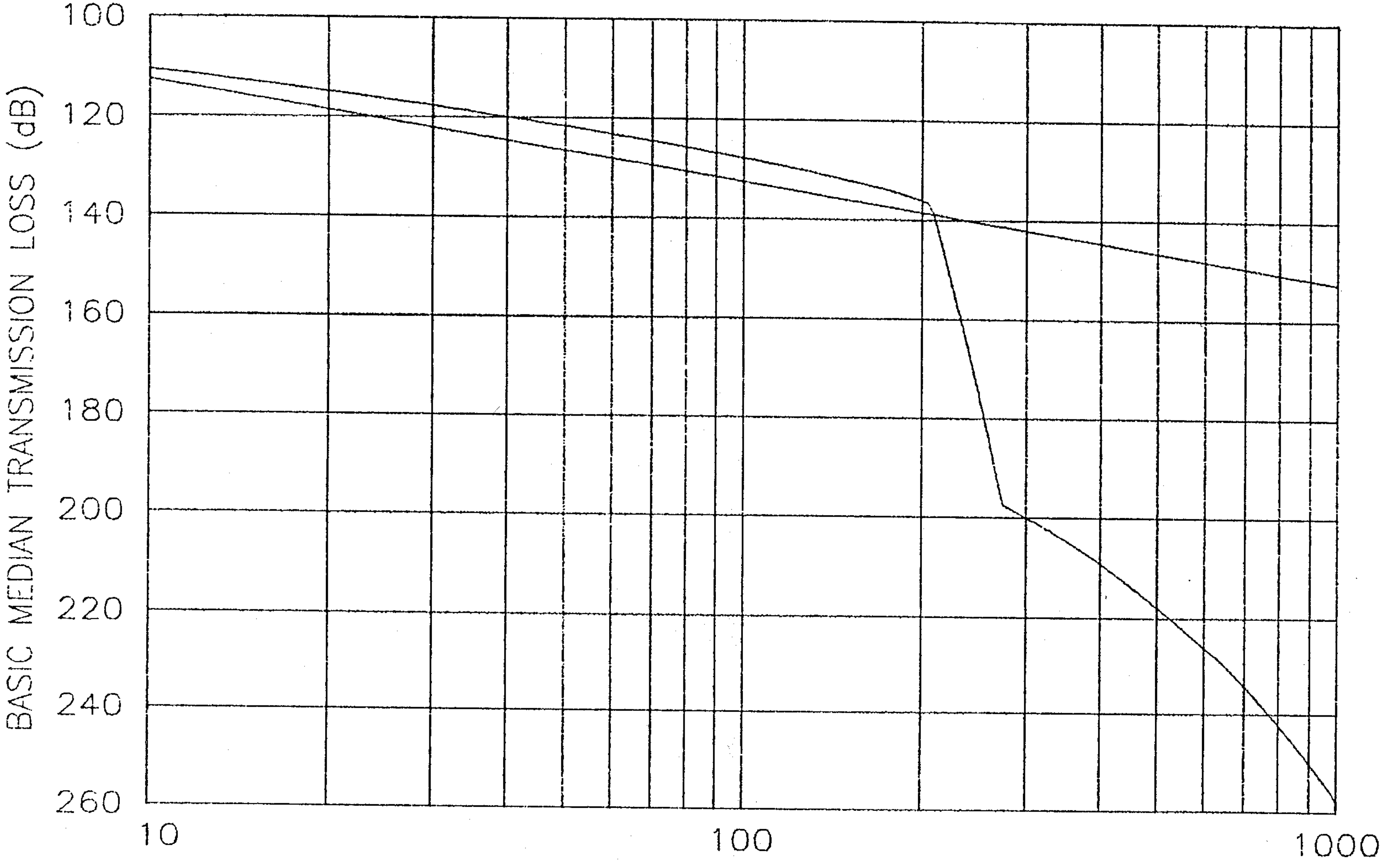

FIGURE A-74. $f=1GHz, h_1=500m, h_2=1km$, V.P., Land and Sea Water

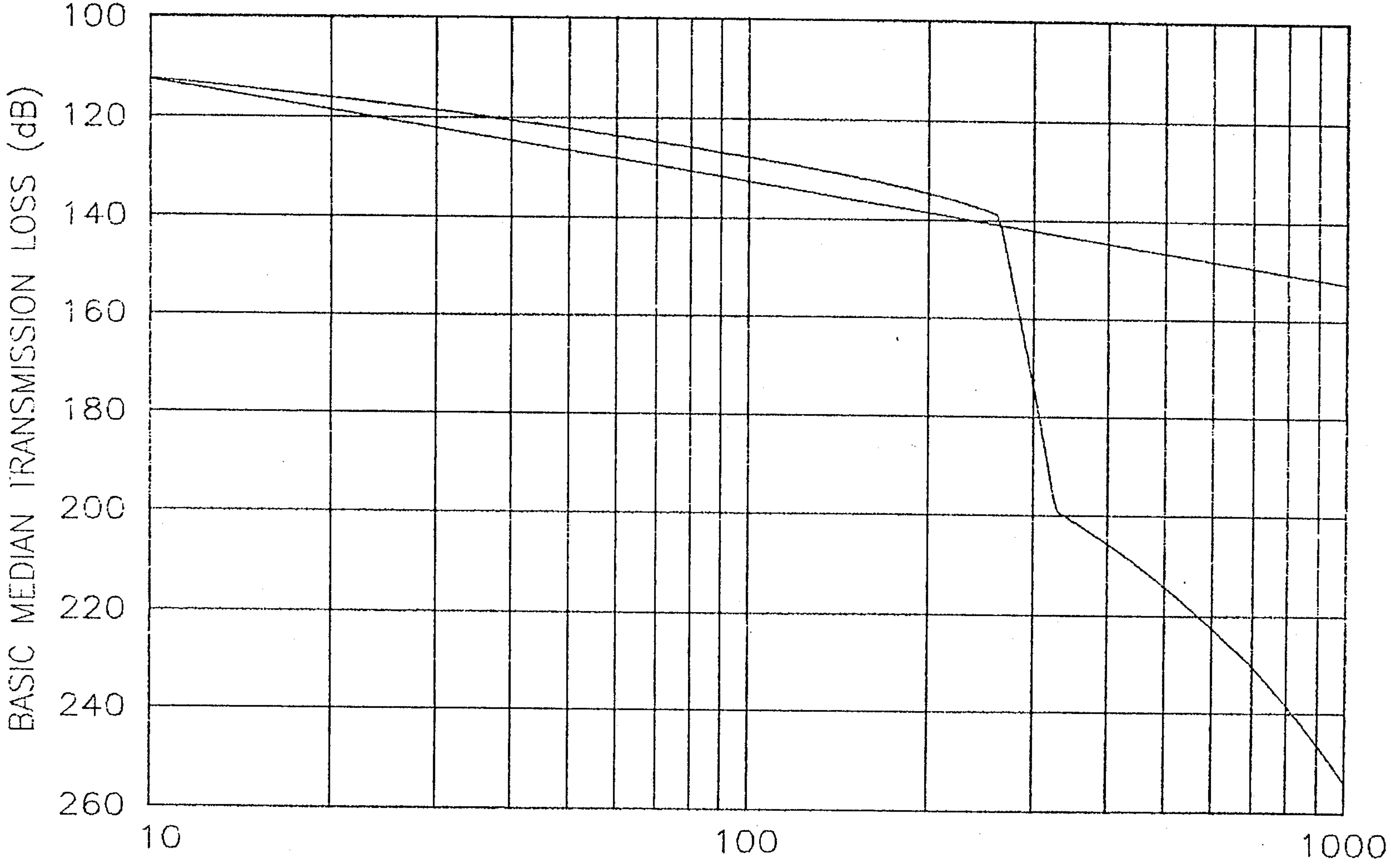

FIGURE A-75. f=1GHz,h_1=500m,h_2=2km,V.P.,Land and Sea Water

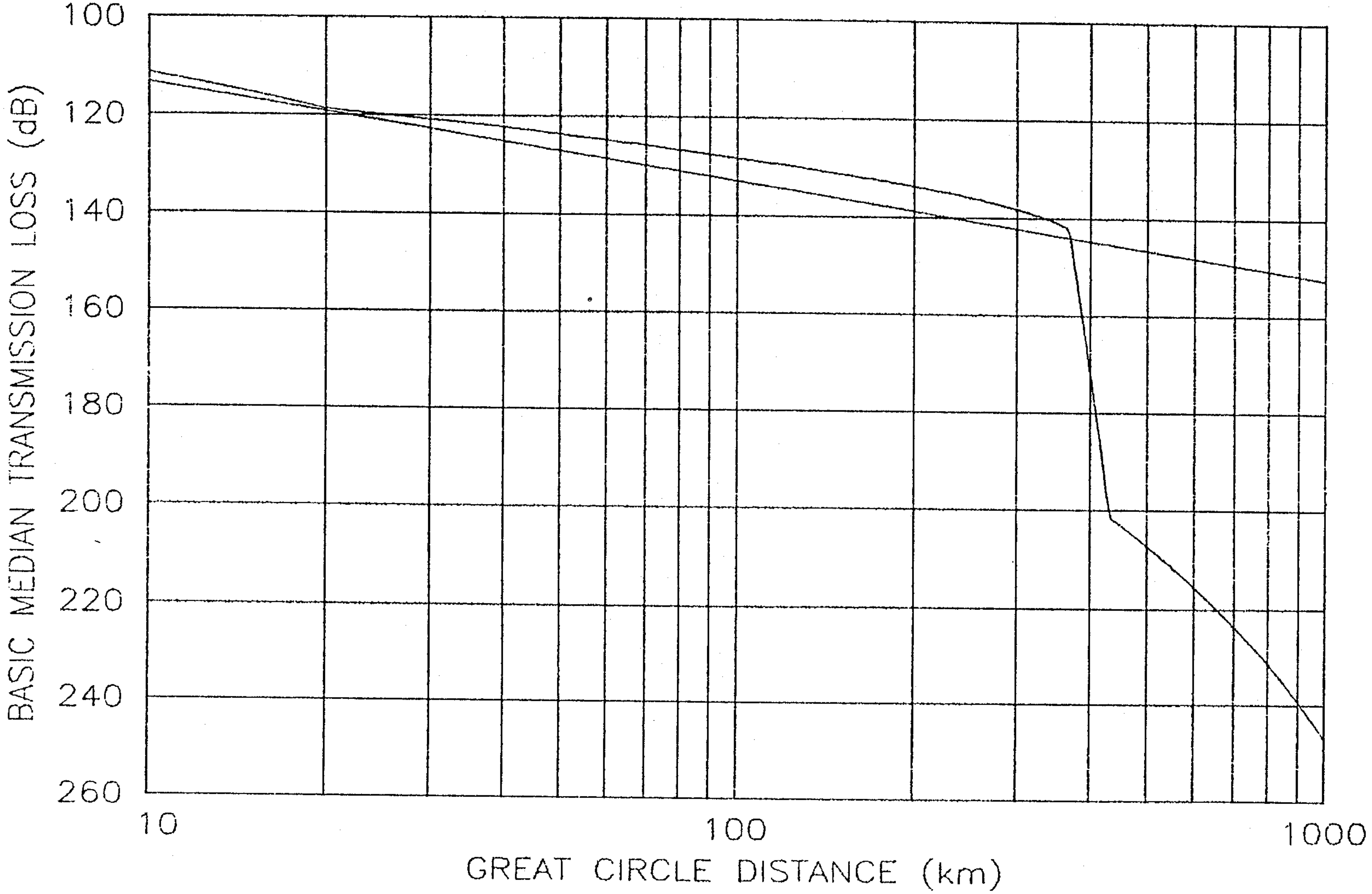

FIGURE A-76. f=1GHz,h_1=500m,h_2=5km,V.P.,Land and Sea Water

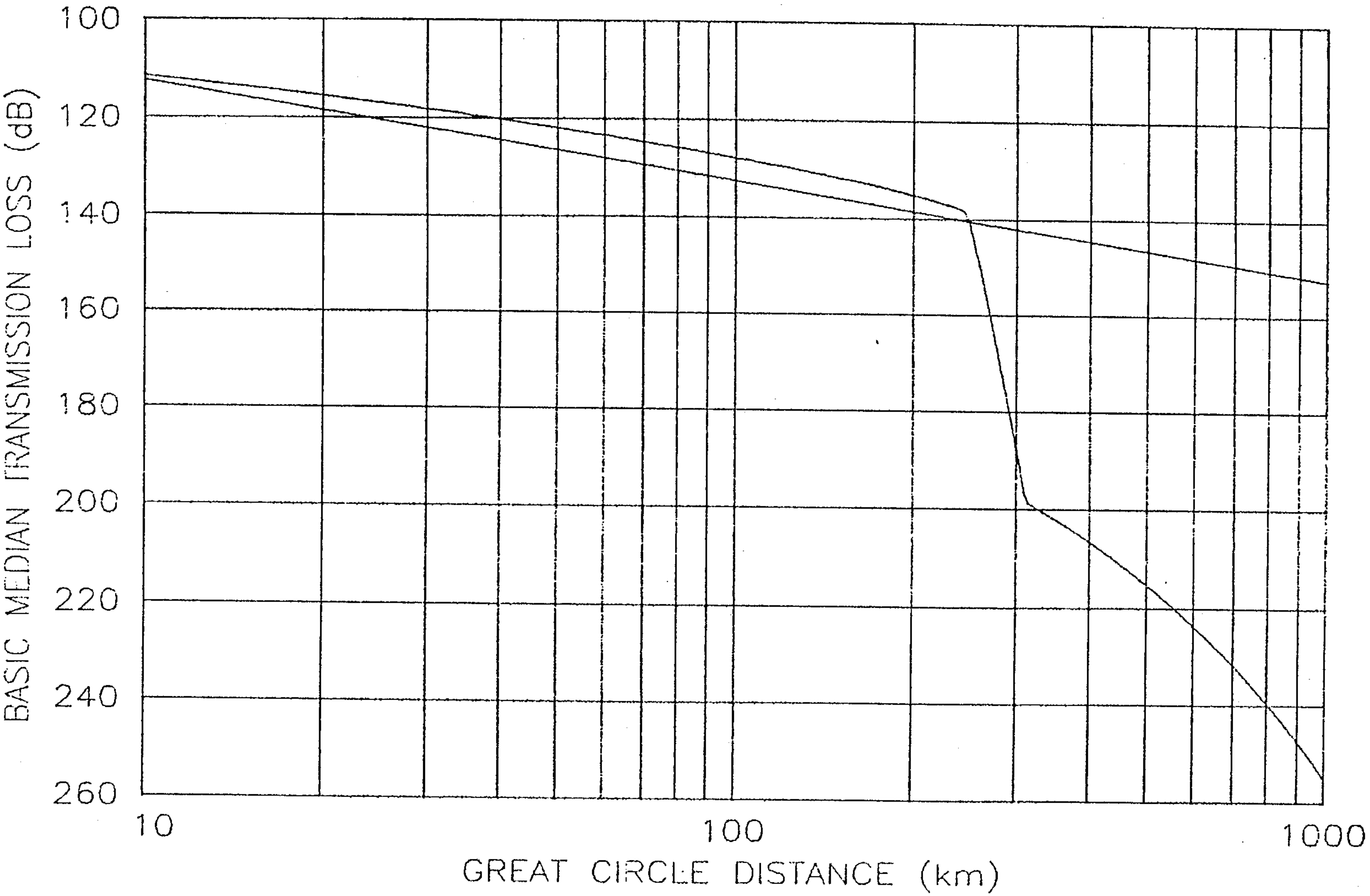

FIGURE A-77. $f=1GHz, h_1=1km, h_2=1km$, V.P., Land and Sea Water

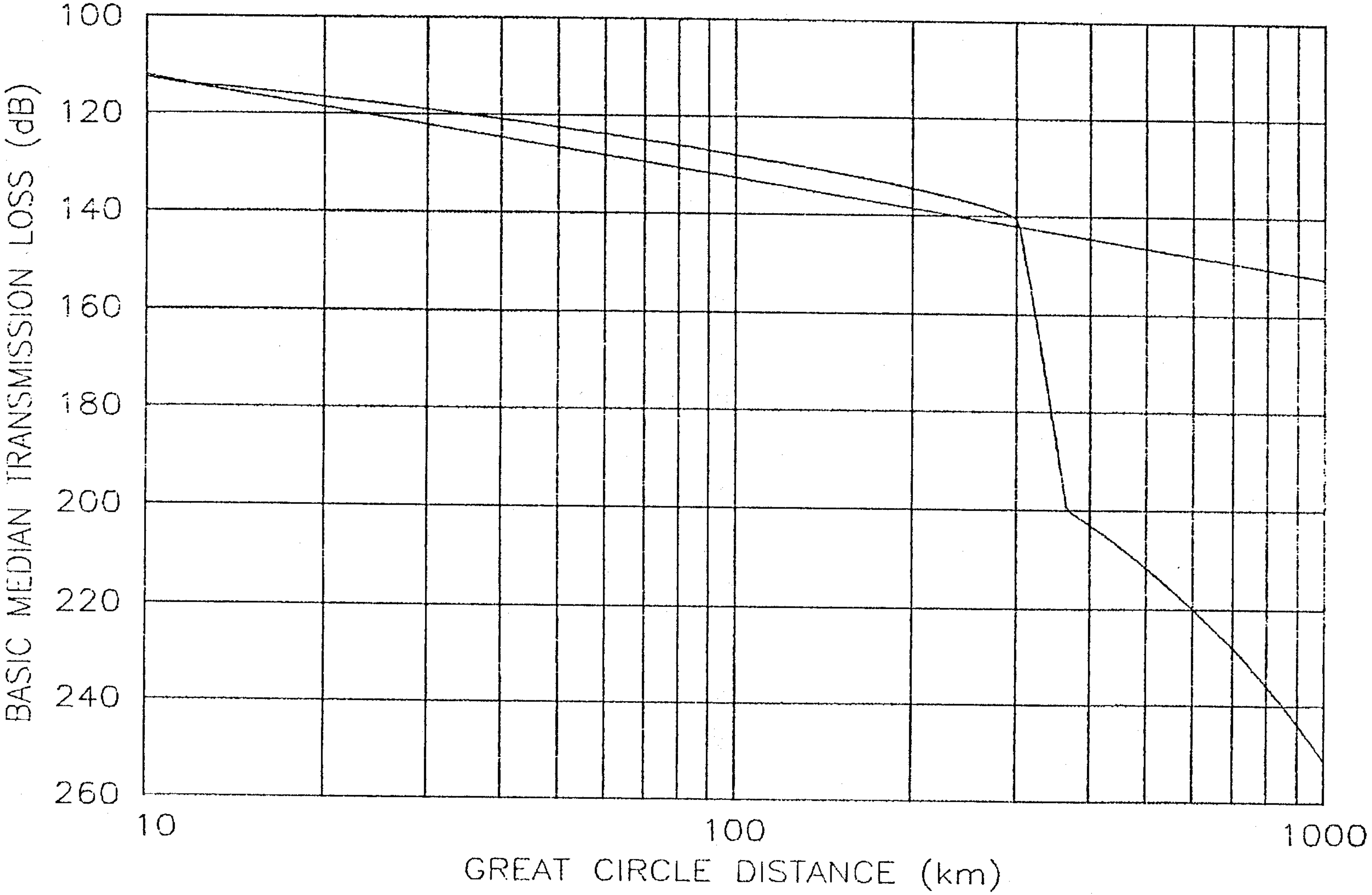

FIGURE A-78. $f = 1\mathrm{GHz}, h_1 = 1\mathrm{km}, h_2 = 2\mathrm{km}$, V.P., Land and Sea Water

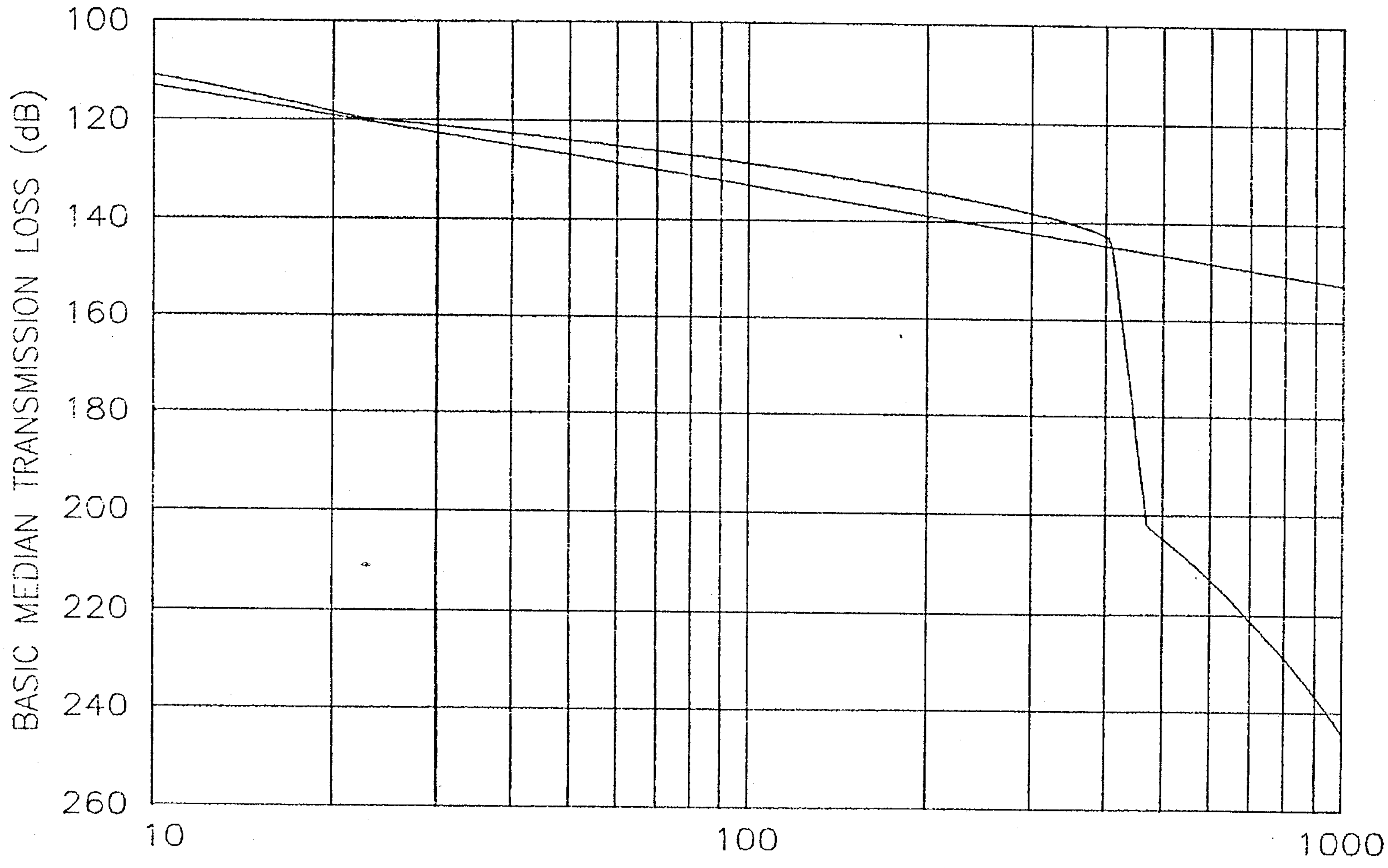

FIGURE A–79. $f=1\text{GHz}, h_1=1\text{km}, h_2=5\text{km}$, V.P., Land and Sea Water

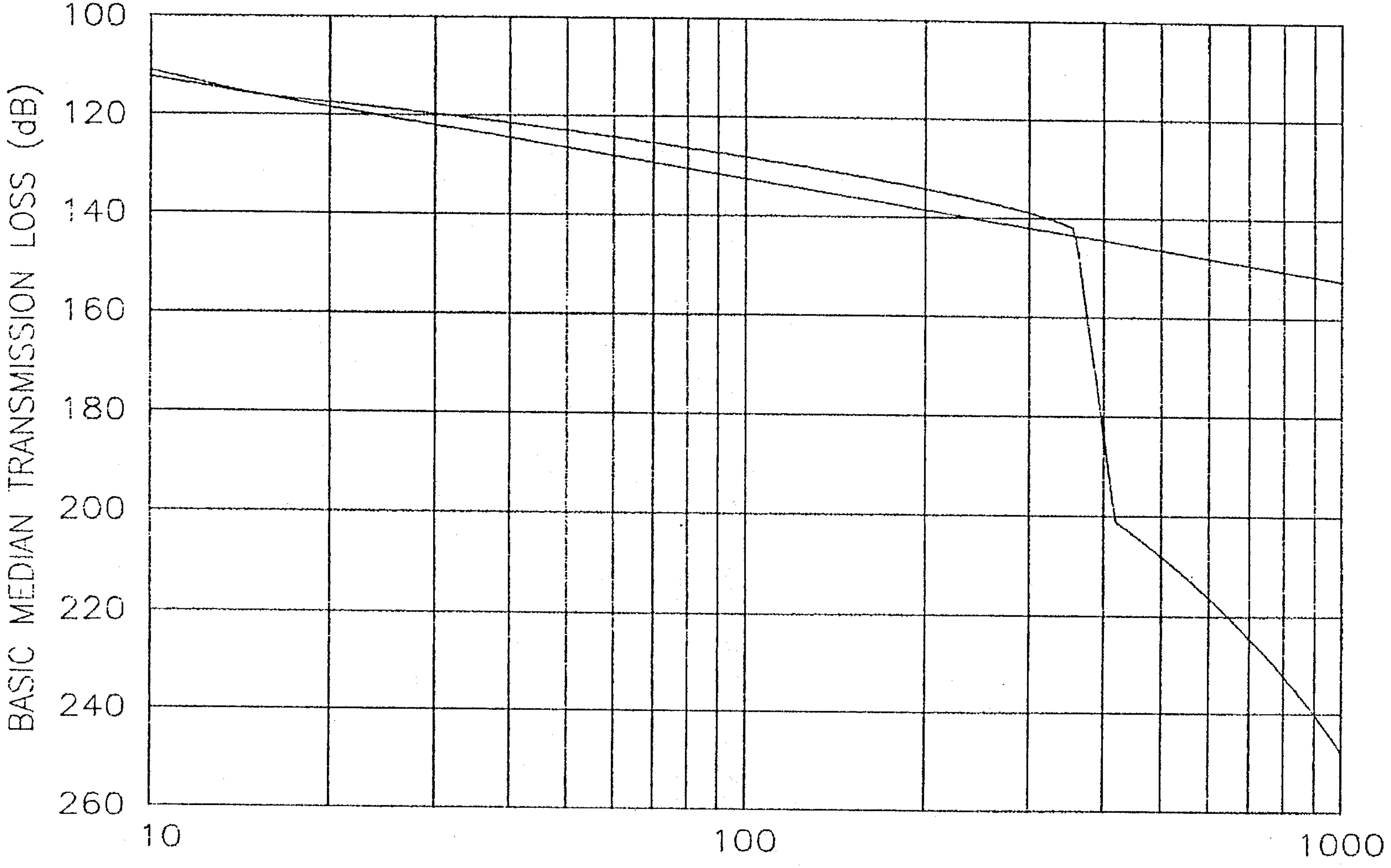

FIGURE A-80. $f=1\text{GHz}, h_1=2\text{km}, h_2=2\text{km}$, V.P., Land and Sea Water

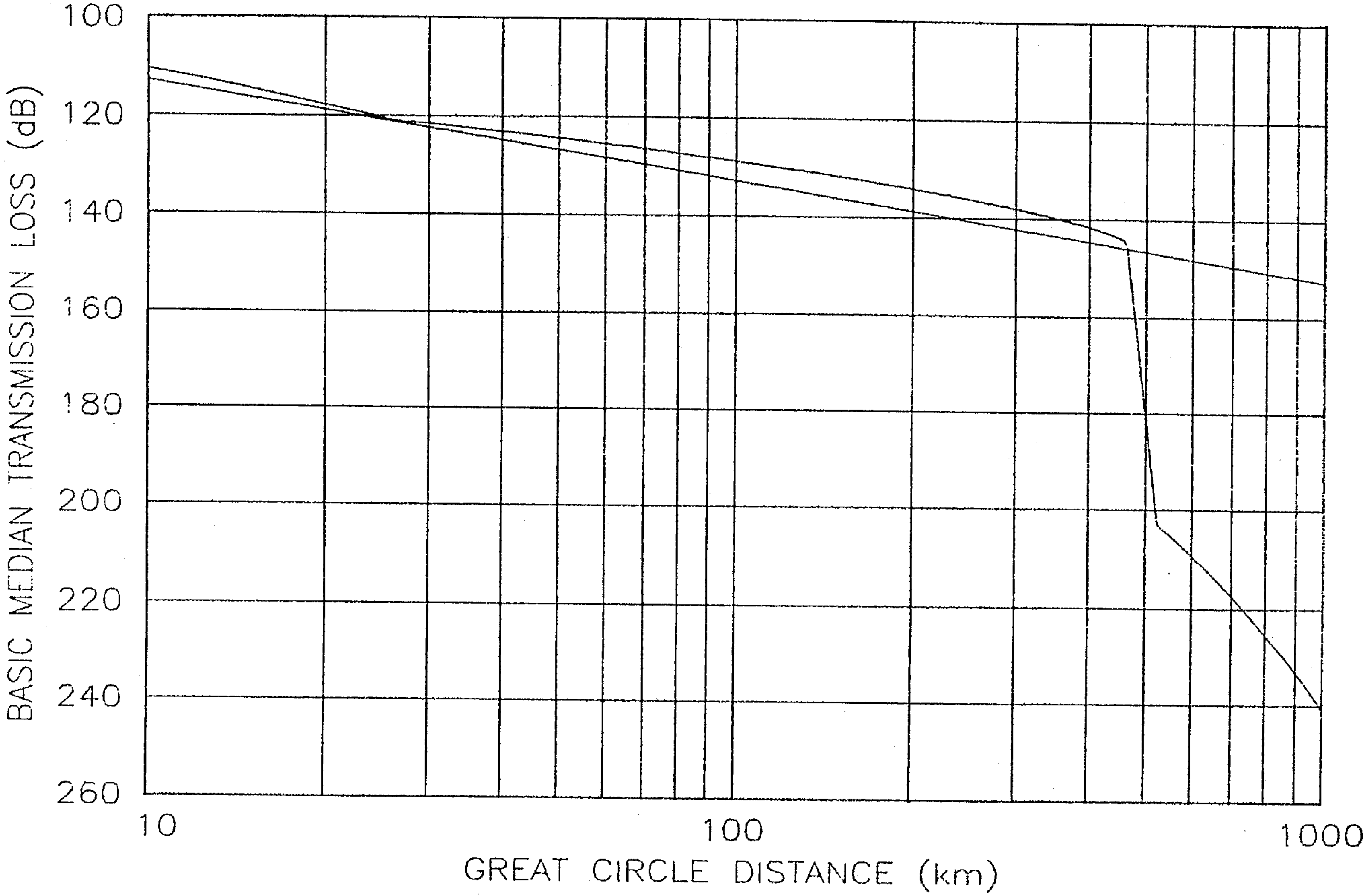

FIGURE A-81. $f=1\text{GHz}, h_1=2\text{km}, h_2=5\text{km}$, V.P., Land and Sea Water

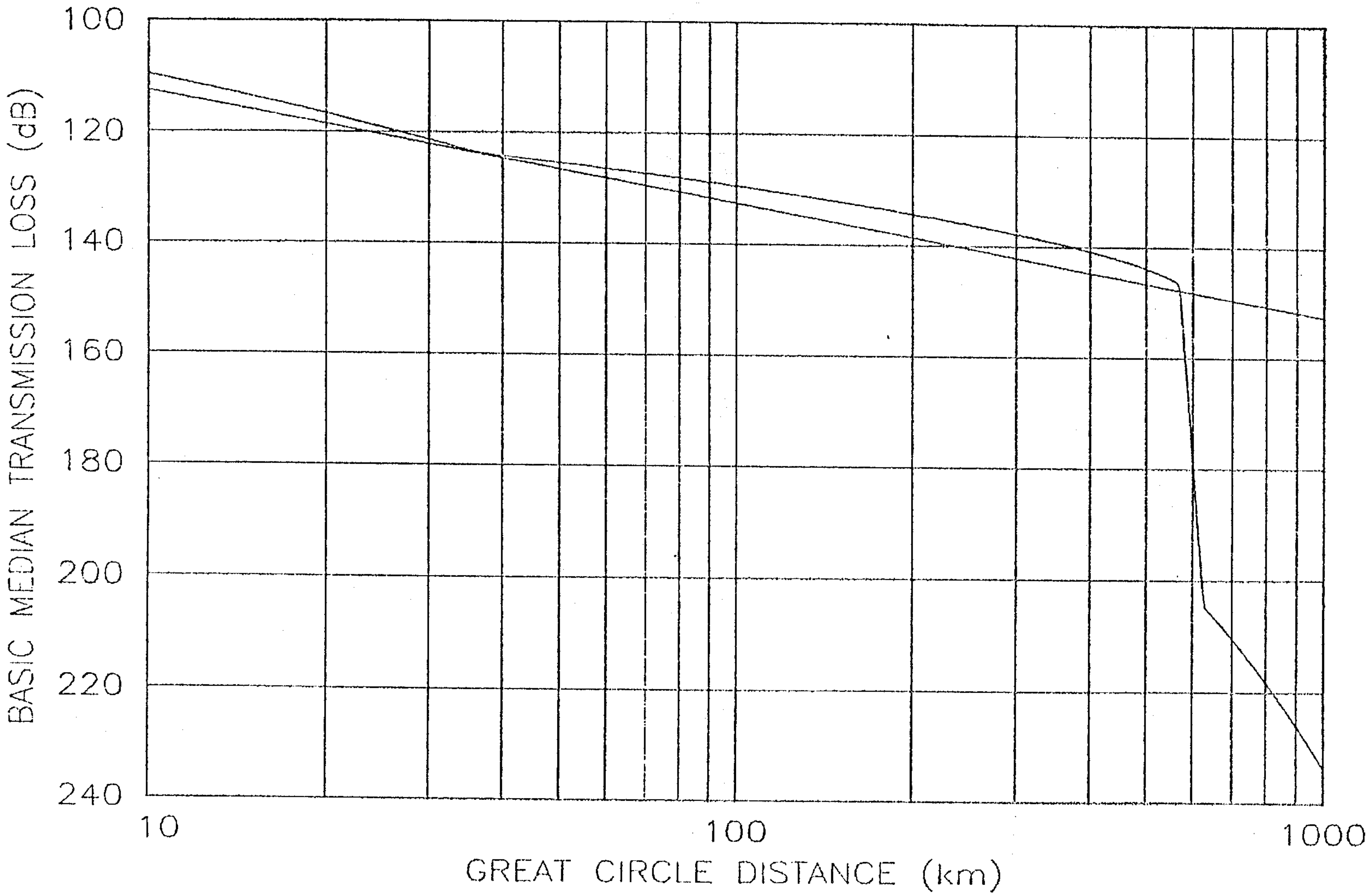

FIGURE A-82. $f=1\text{GHz}, h_1=5\text{km}, h_2=5\text{km}$, V.P., Land and Sea Water

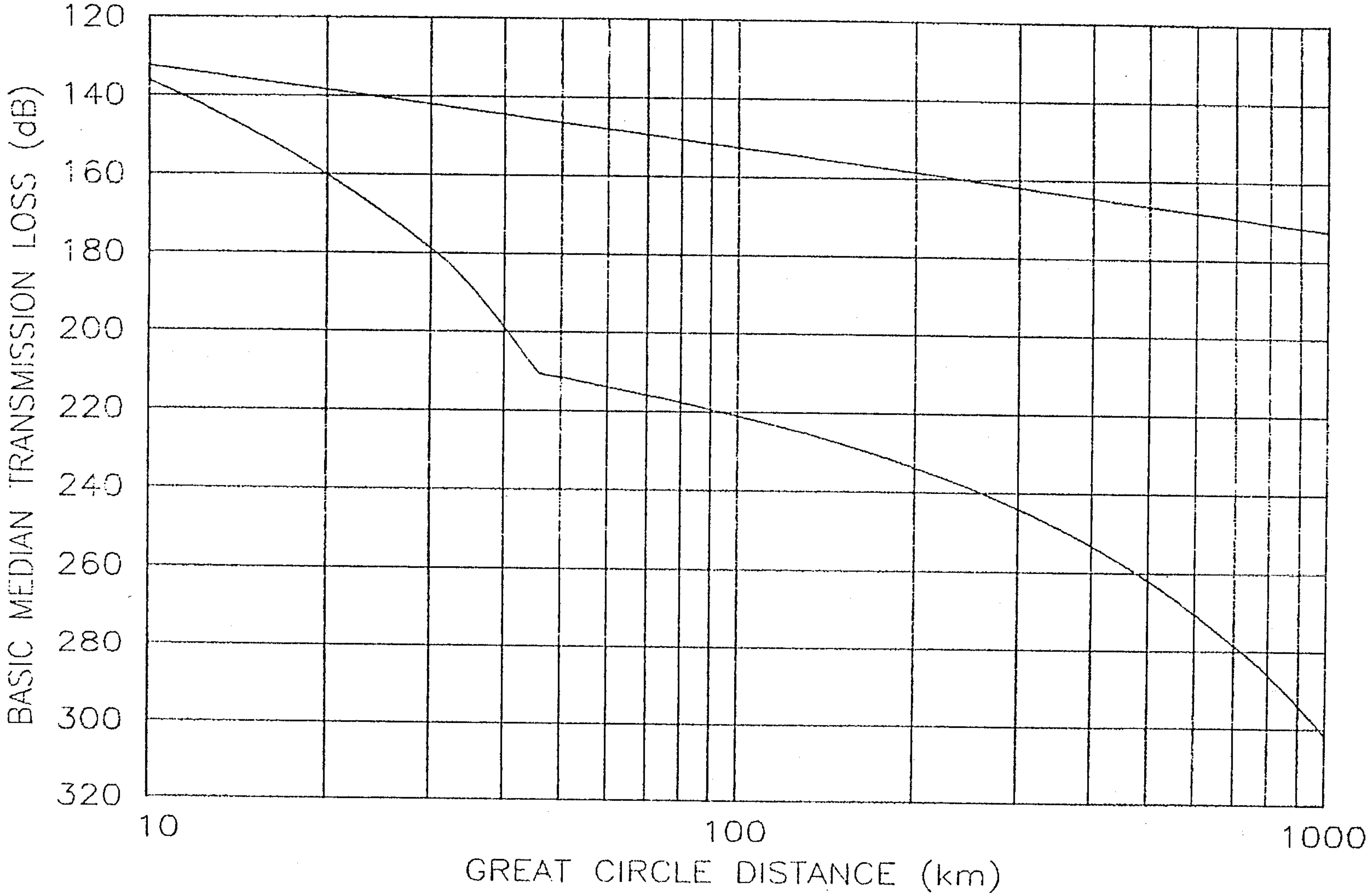

FIGURE A-83. $f=10GHz, h_1=1m, h_2=10m$, V.P., Land and Sea Water

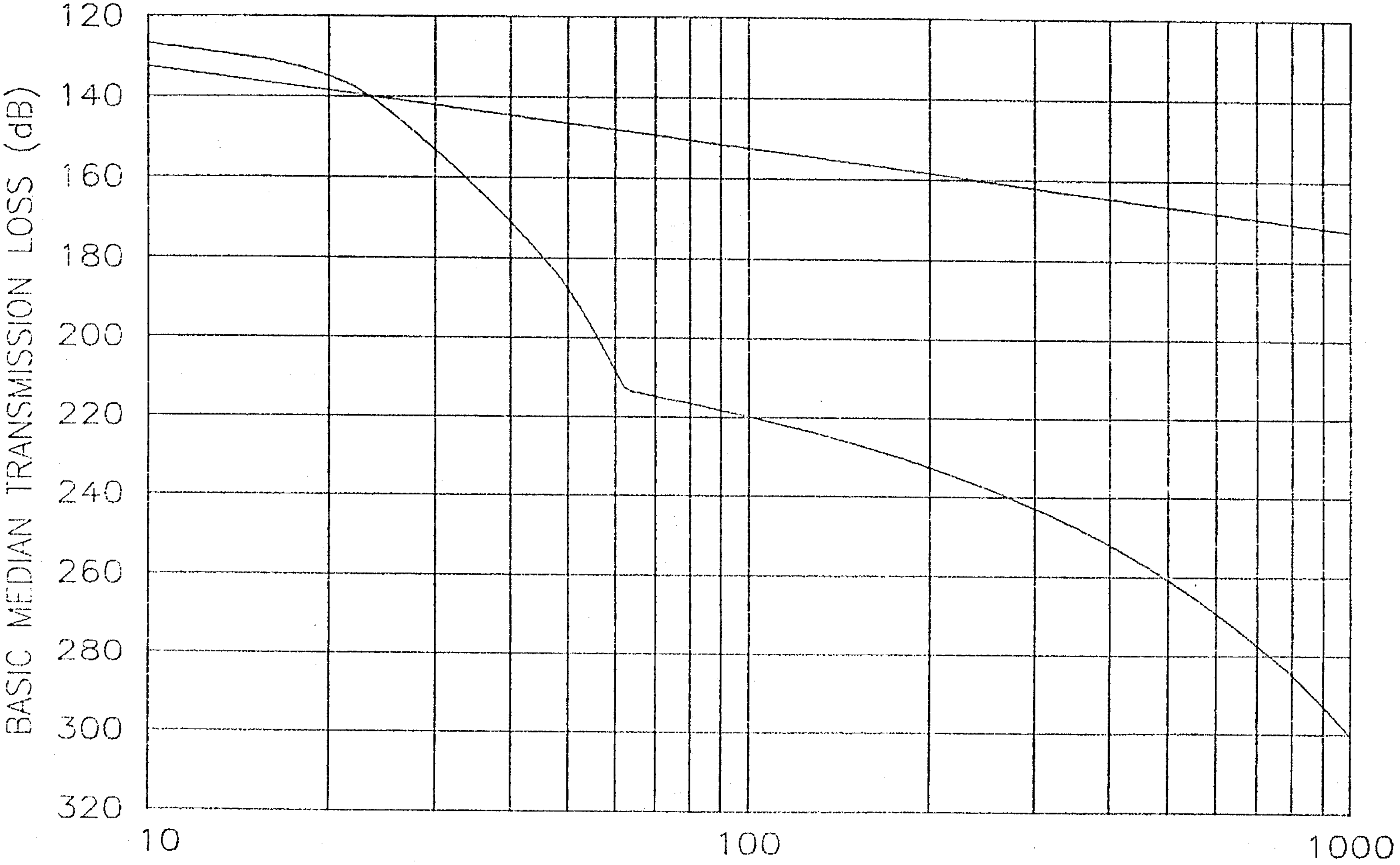

FIGURE A-84. $f=10GHz, h_1=1m, h_2=50m$, V.P., Land and Sea Water

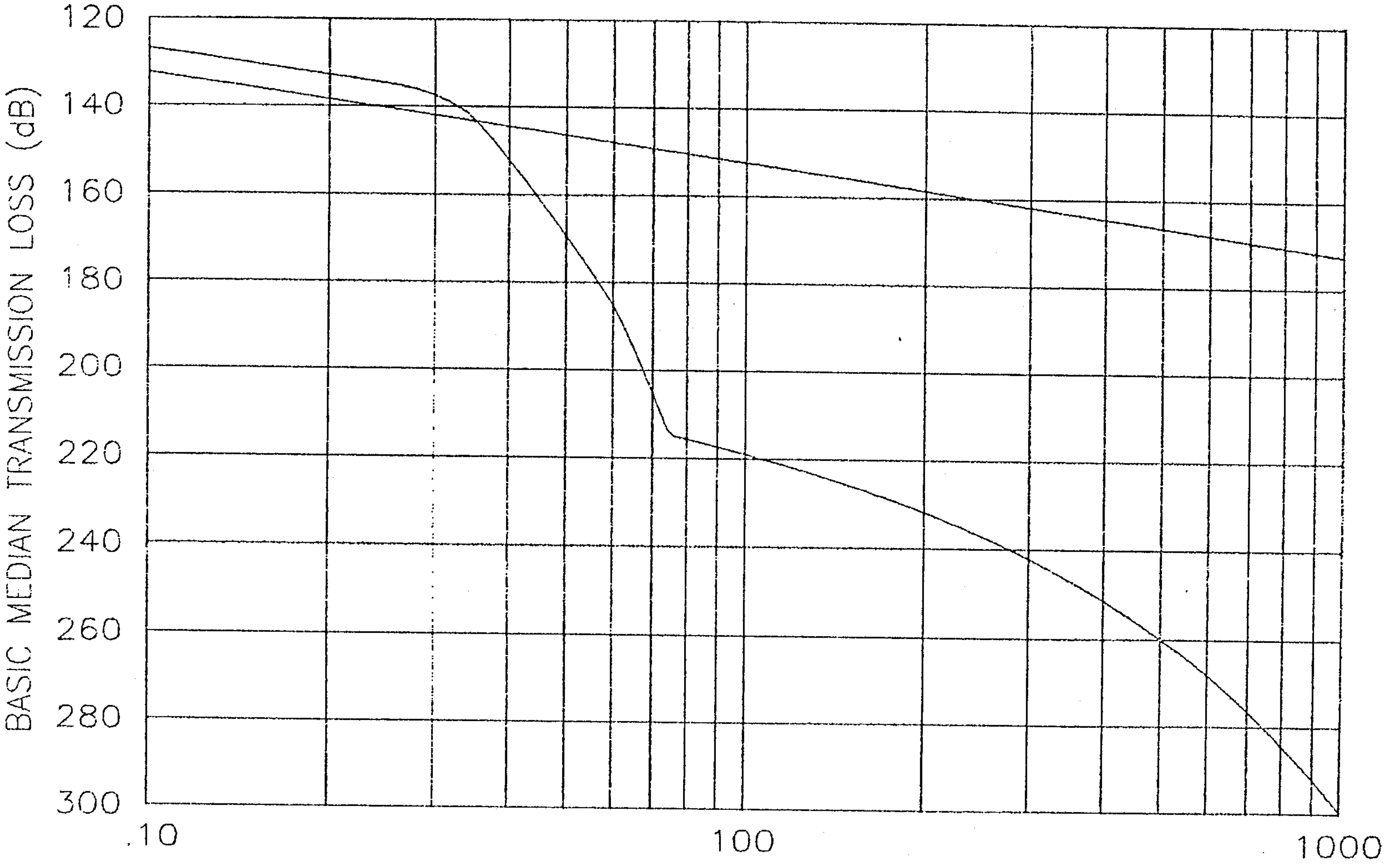

FIGURE A-85. $f=10GHz, h_1=1m, h_2=100m$, V.P., Land and Sea Water

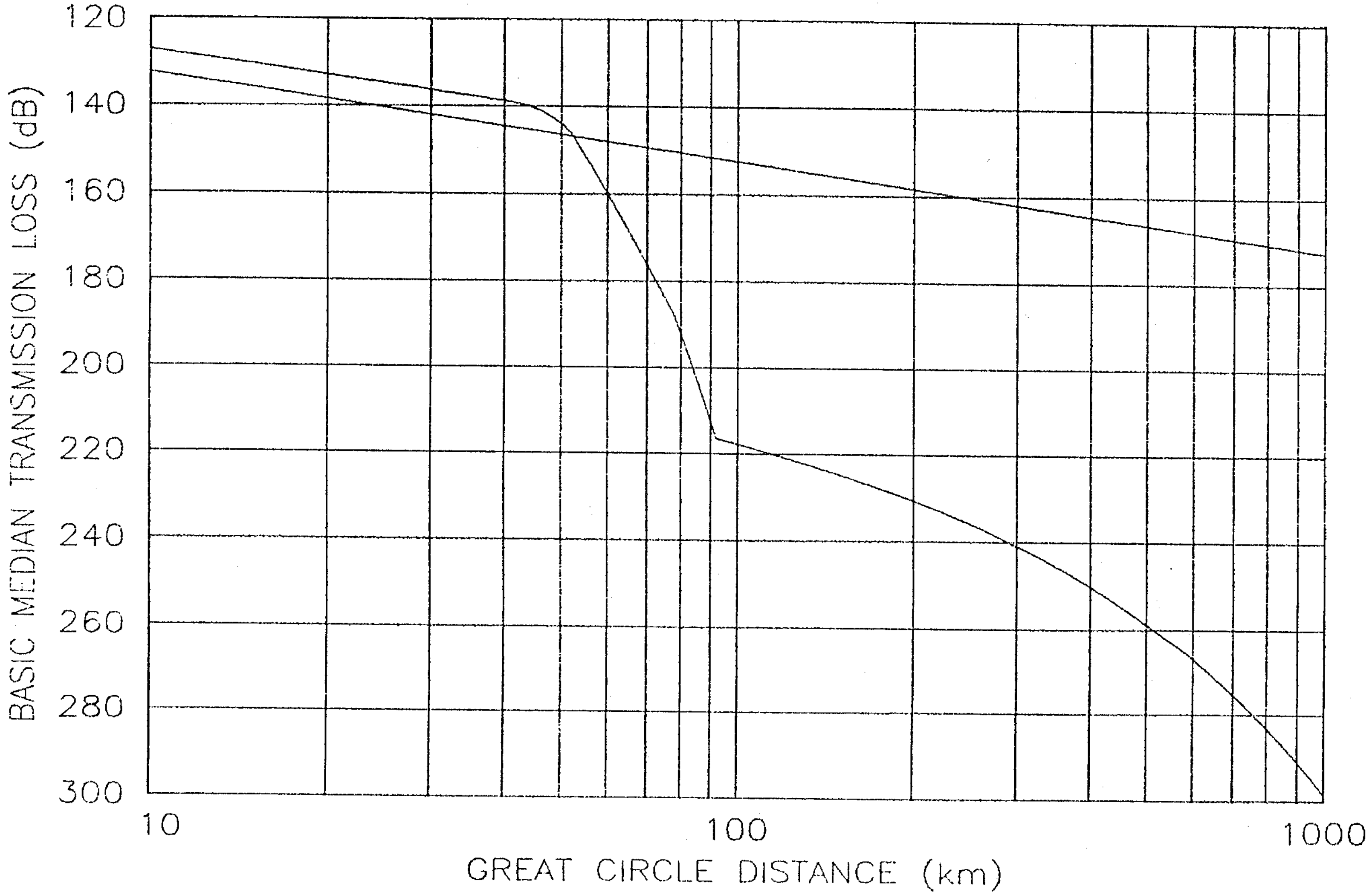

FIGURE A-86. f=10GHz,h_1=1m,h_2=200m,V.P.,Land and Sea Water

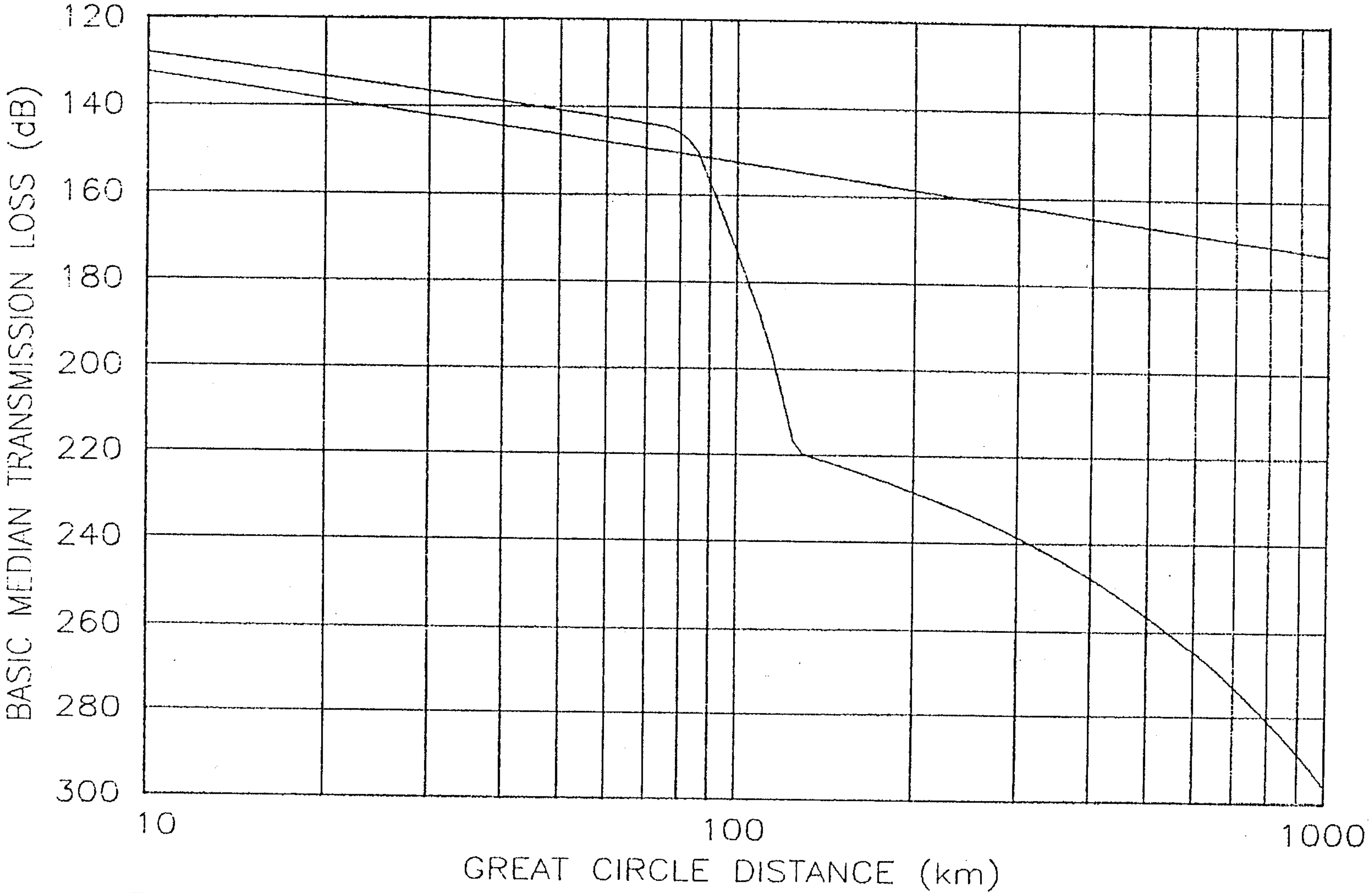

FIGURE A-87. $f=10GHz, h_1=1m, h_2=500m$, V.P., Land and Sea Water

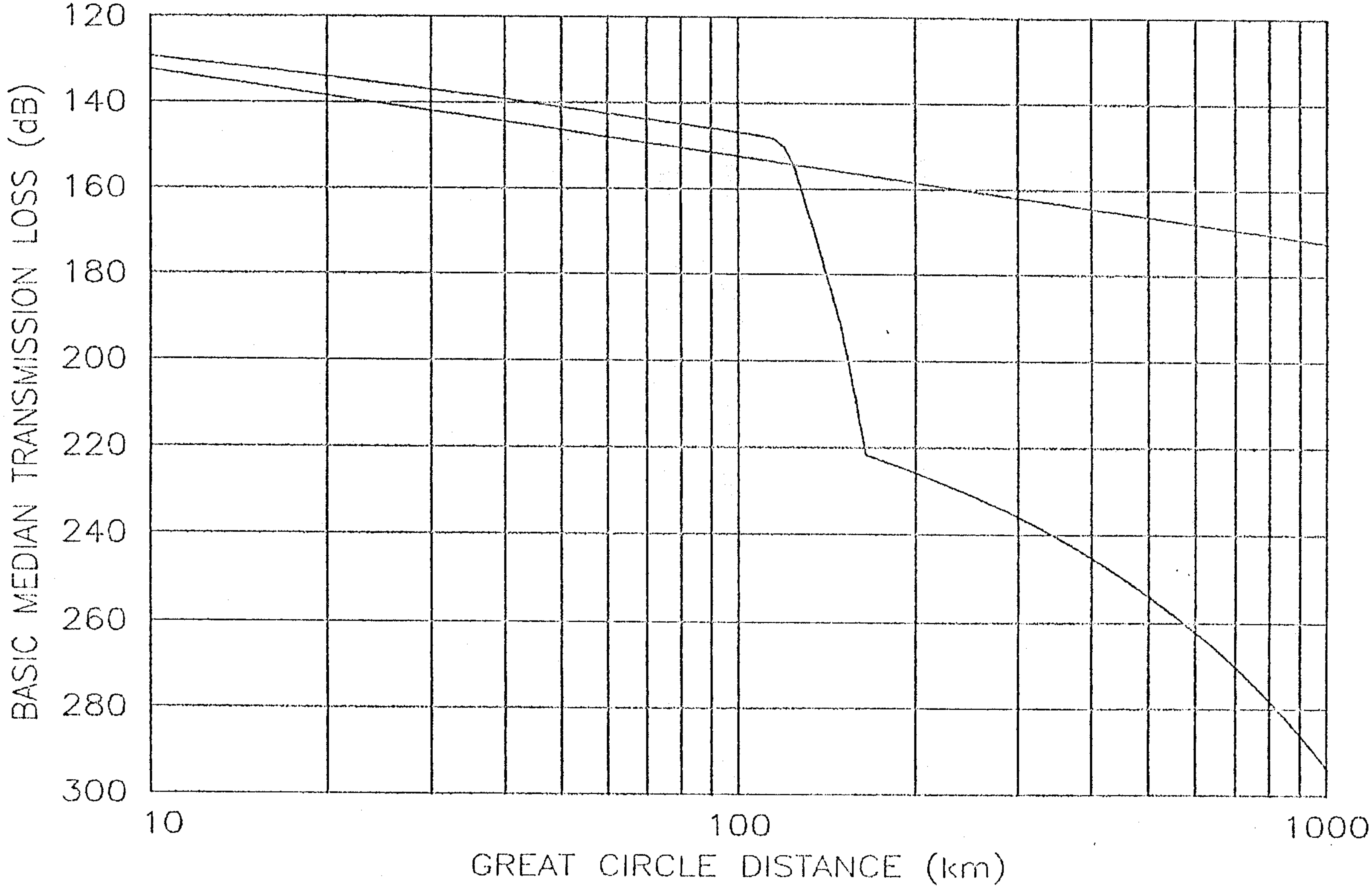

FIGURE A–88. $f = 10GHz, h_1 = 1m, h_2 = 1km$, V.P., Land and Sea Water

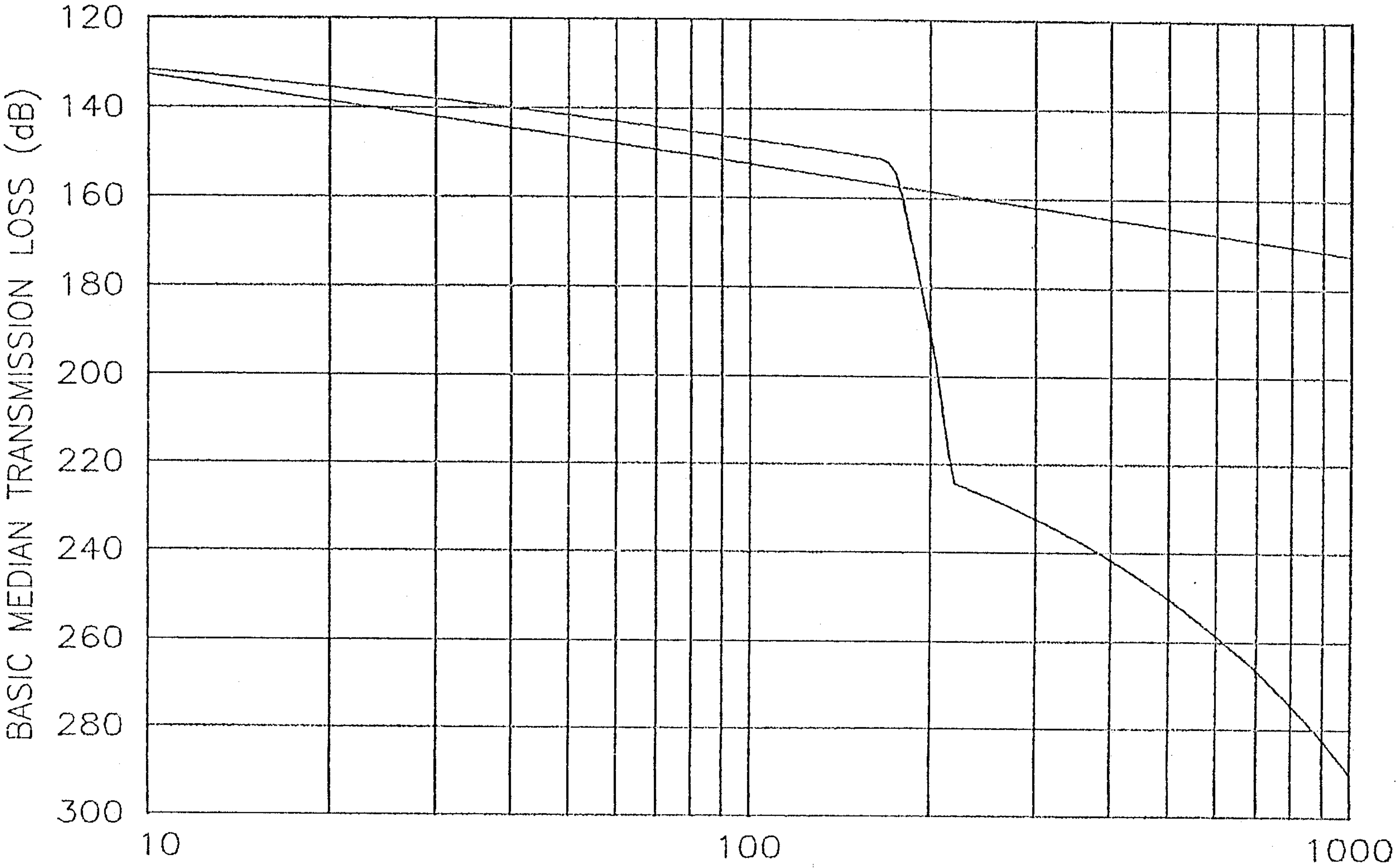

FIGURE A-89. $f=10GHz, h_1=1m, h_2=2km$, V.P., Land and Sea Water

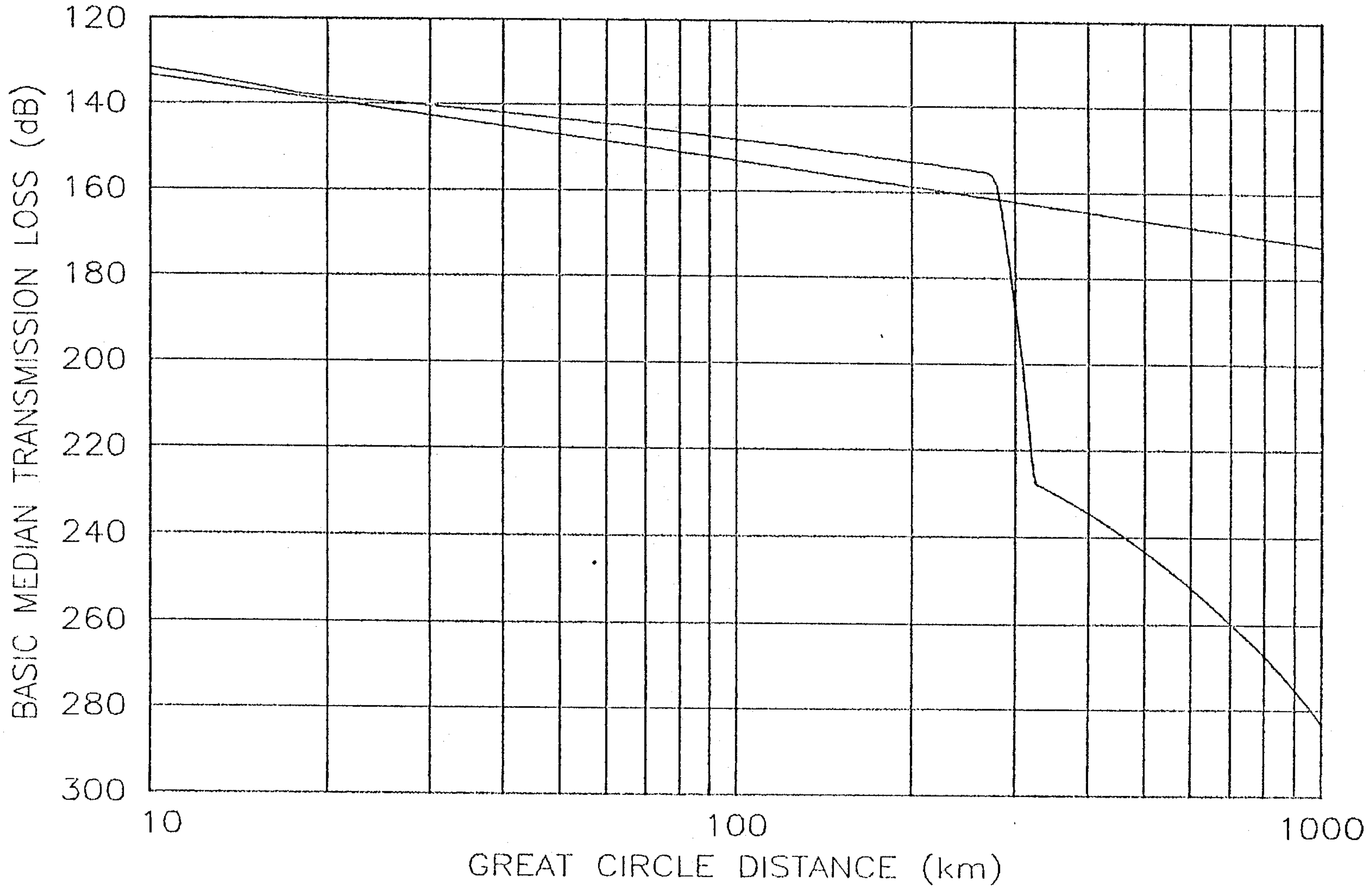

FIGURE A–90. $f=10\text{GHz}, h_1=1\text{m}, h_2=5\text{km}$, V.P., Land and Sea Water

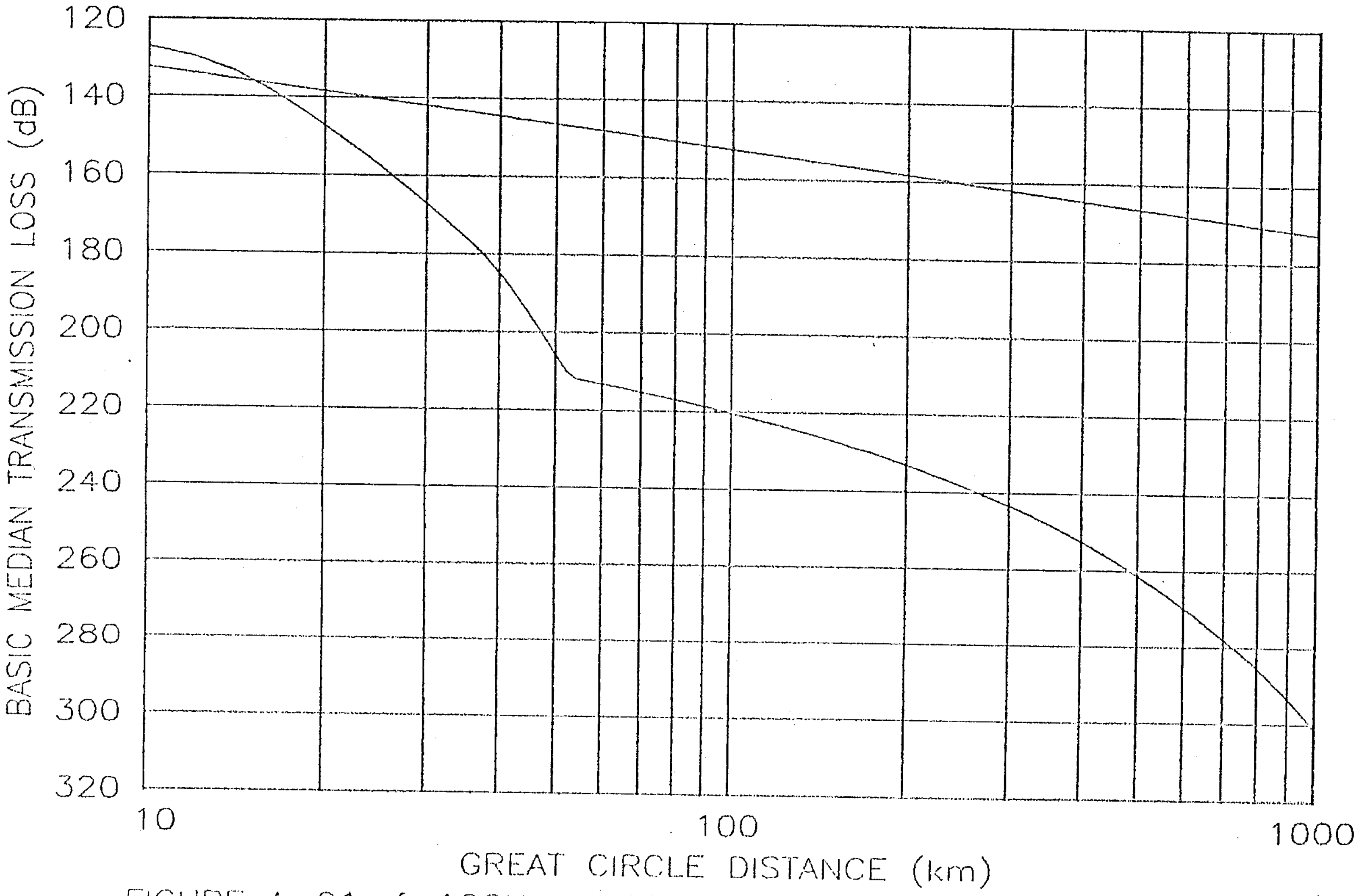

FIGURE A–91. f=10GHz, h_1=10m, h_2=10m, V.P., Land and Sea Water

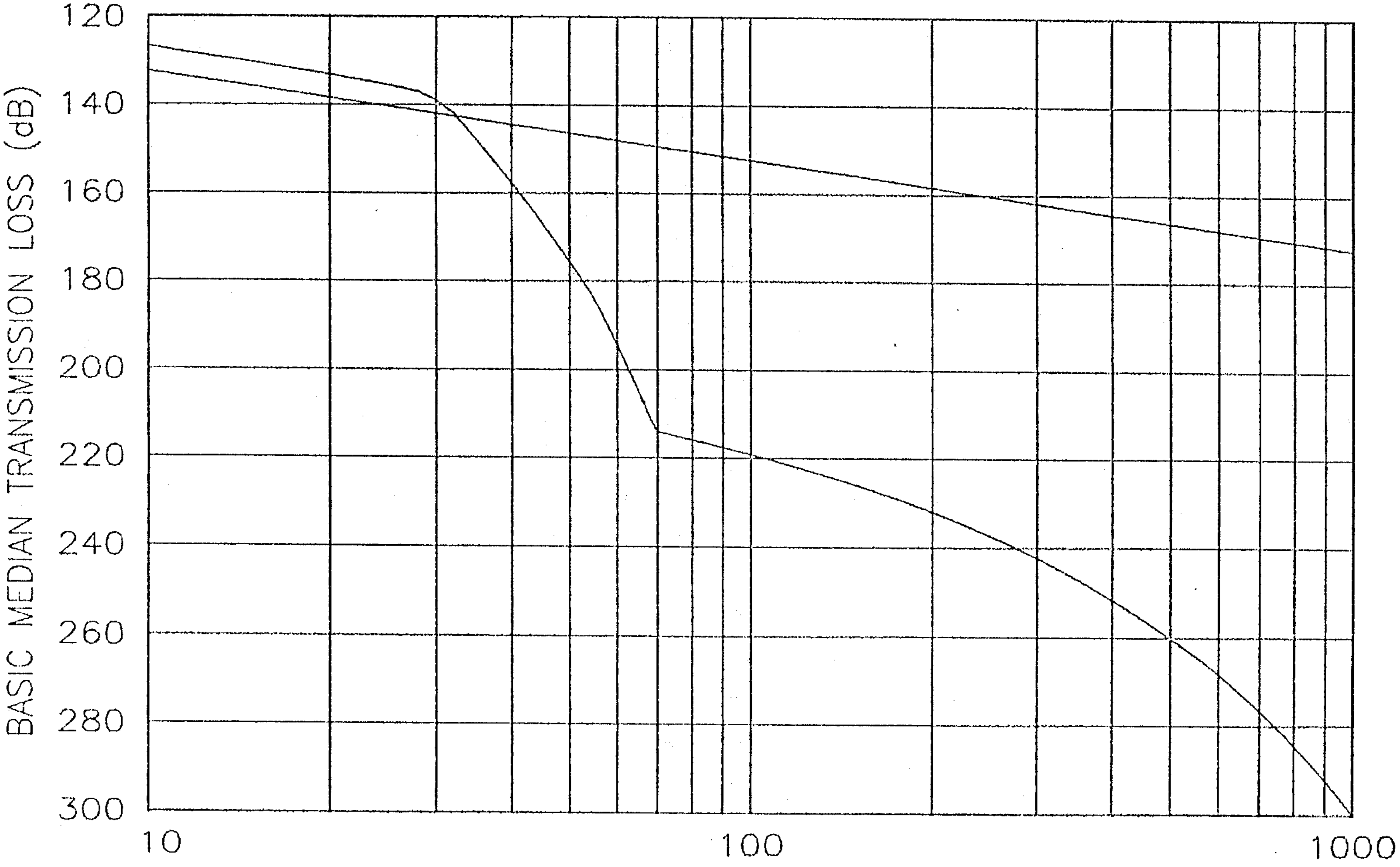

FIGURE A-92. $f=10GHz, h_1=10m, h_2=50m$, V.P., Land and Sea Water

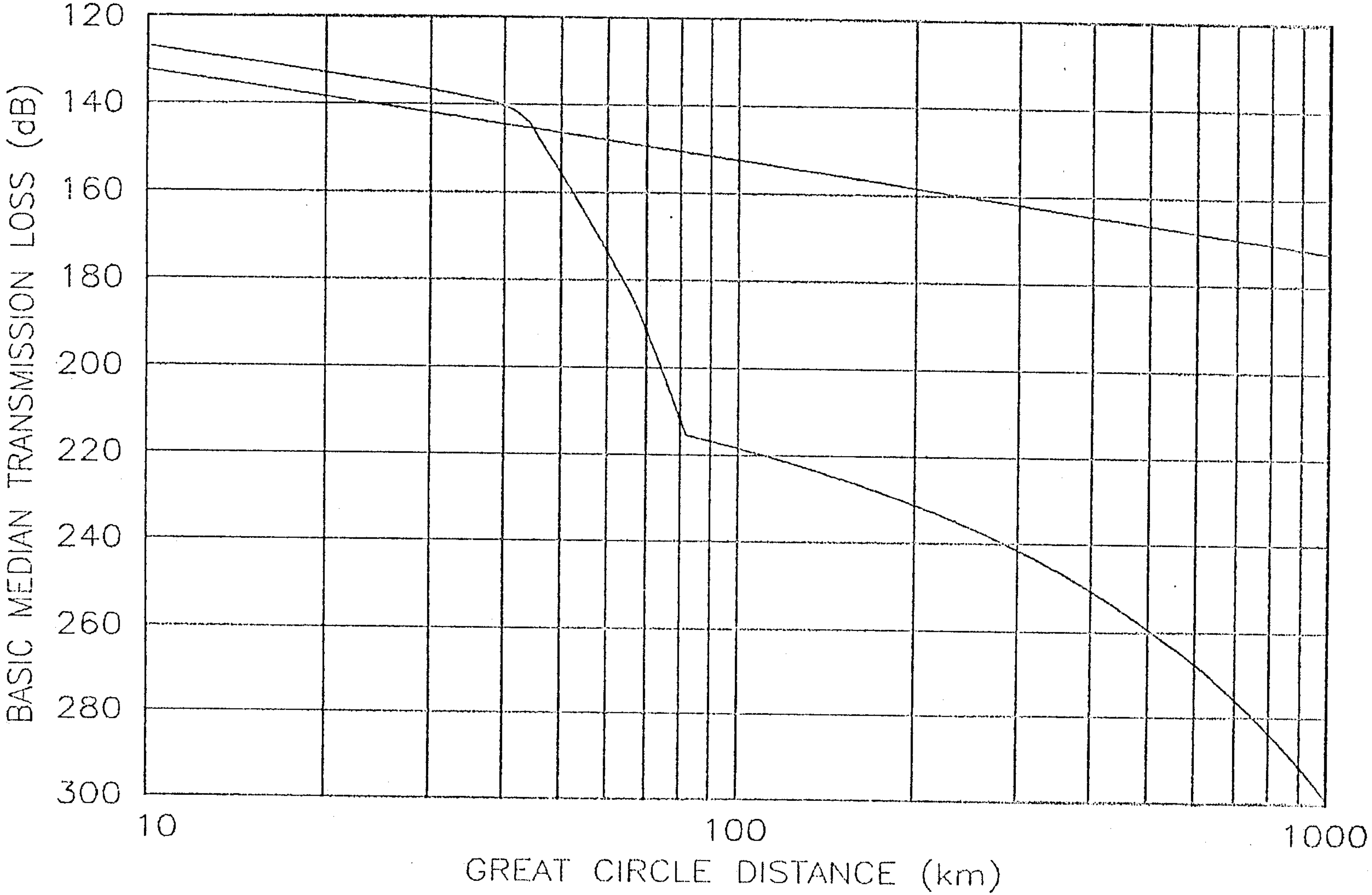

FIGURE A-93. $f=10GHz, h_1=10m, h_2=100m$, V.P., Land and Sea Water

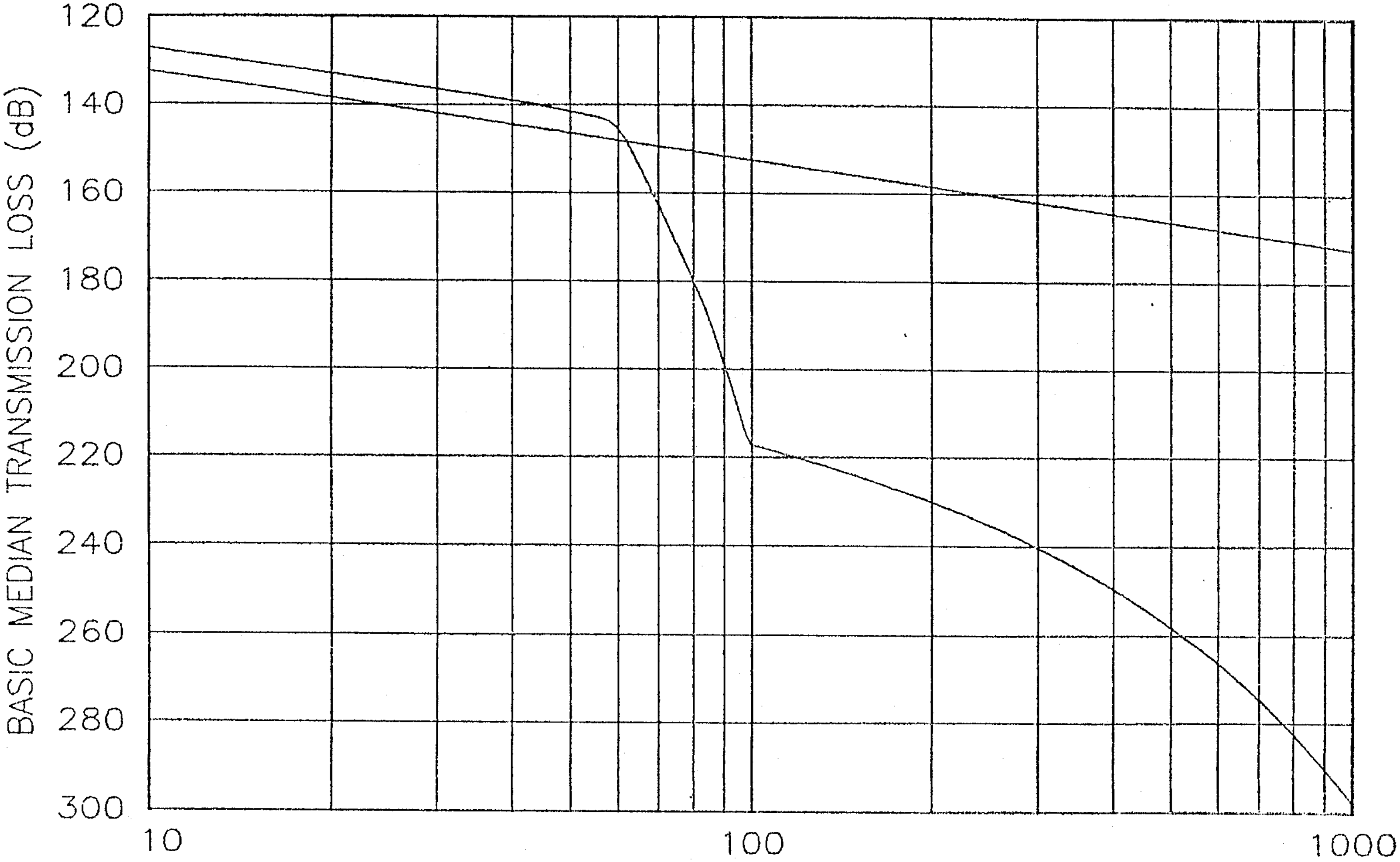

FIGURE A-94. $f=10GHz, h_1=10m, h_2=200m$, V.P., Land and Sea Water

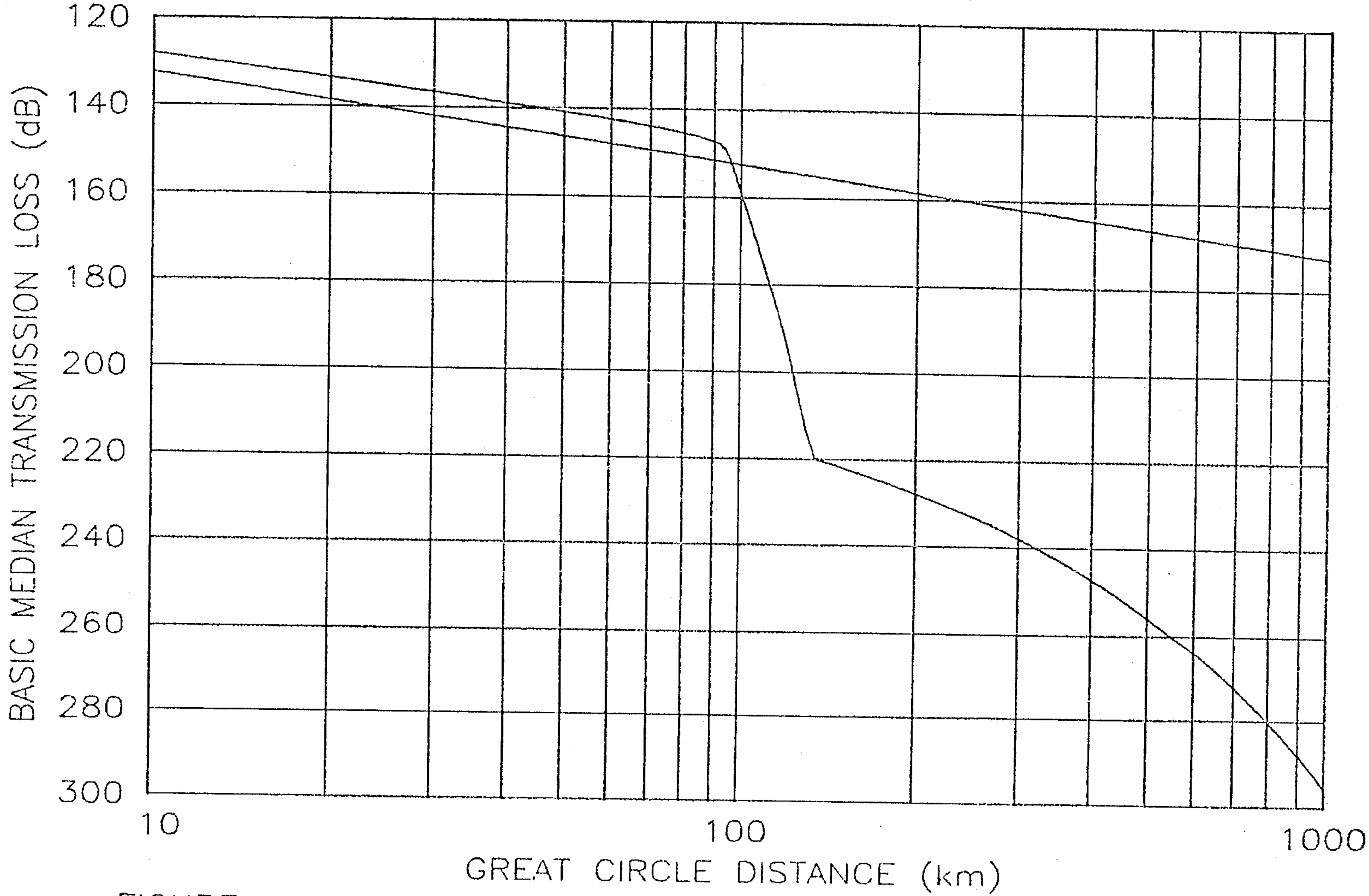

FIGURE A–95. f=10GHz,h_1=10m,h_2=500m,V.P.,Land and Sea Water

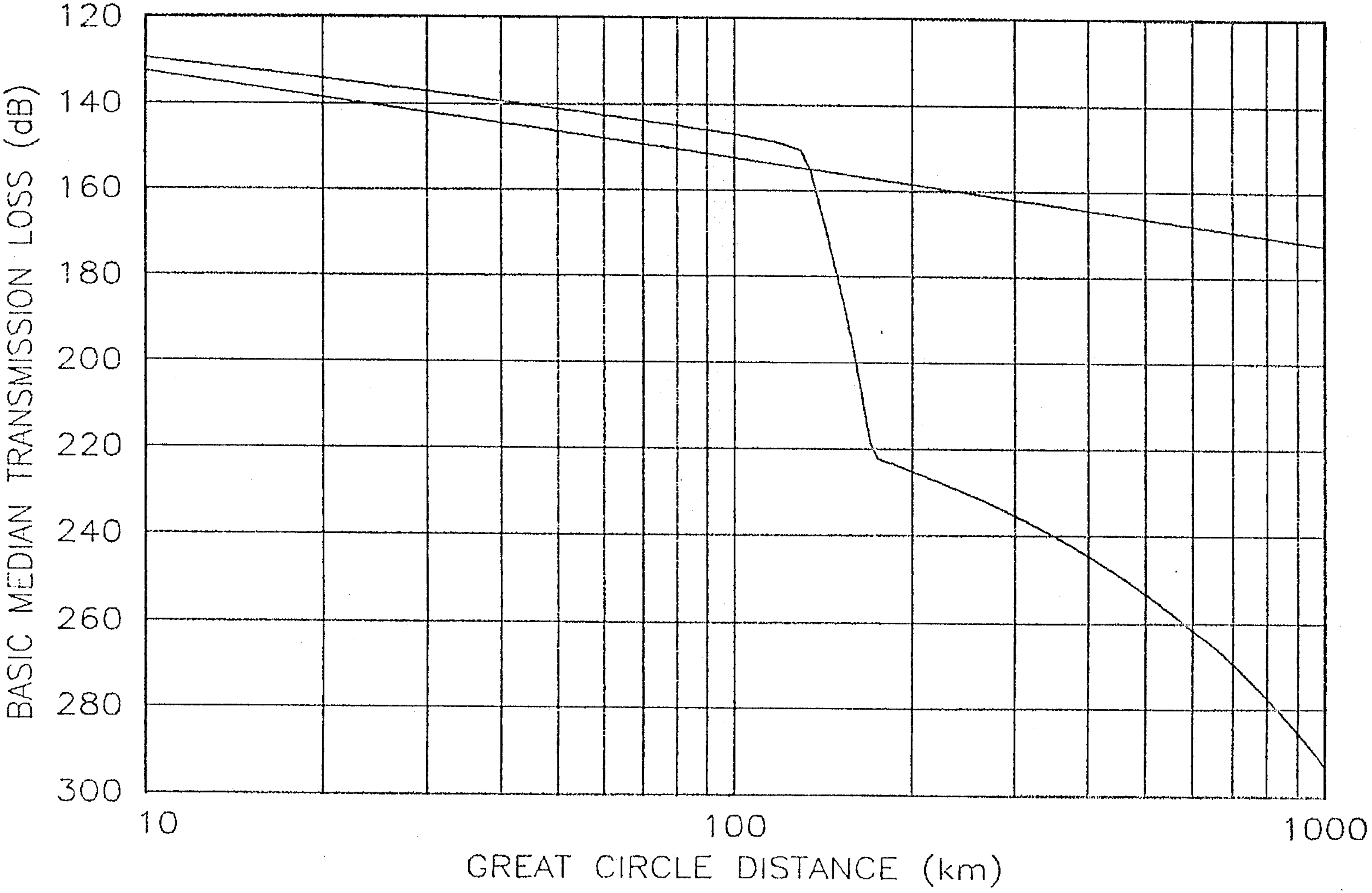

FIGURE A-96. $f=10GHz, h_1=10m, h_2=1km$, V.P., Land and Sea Water

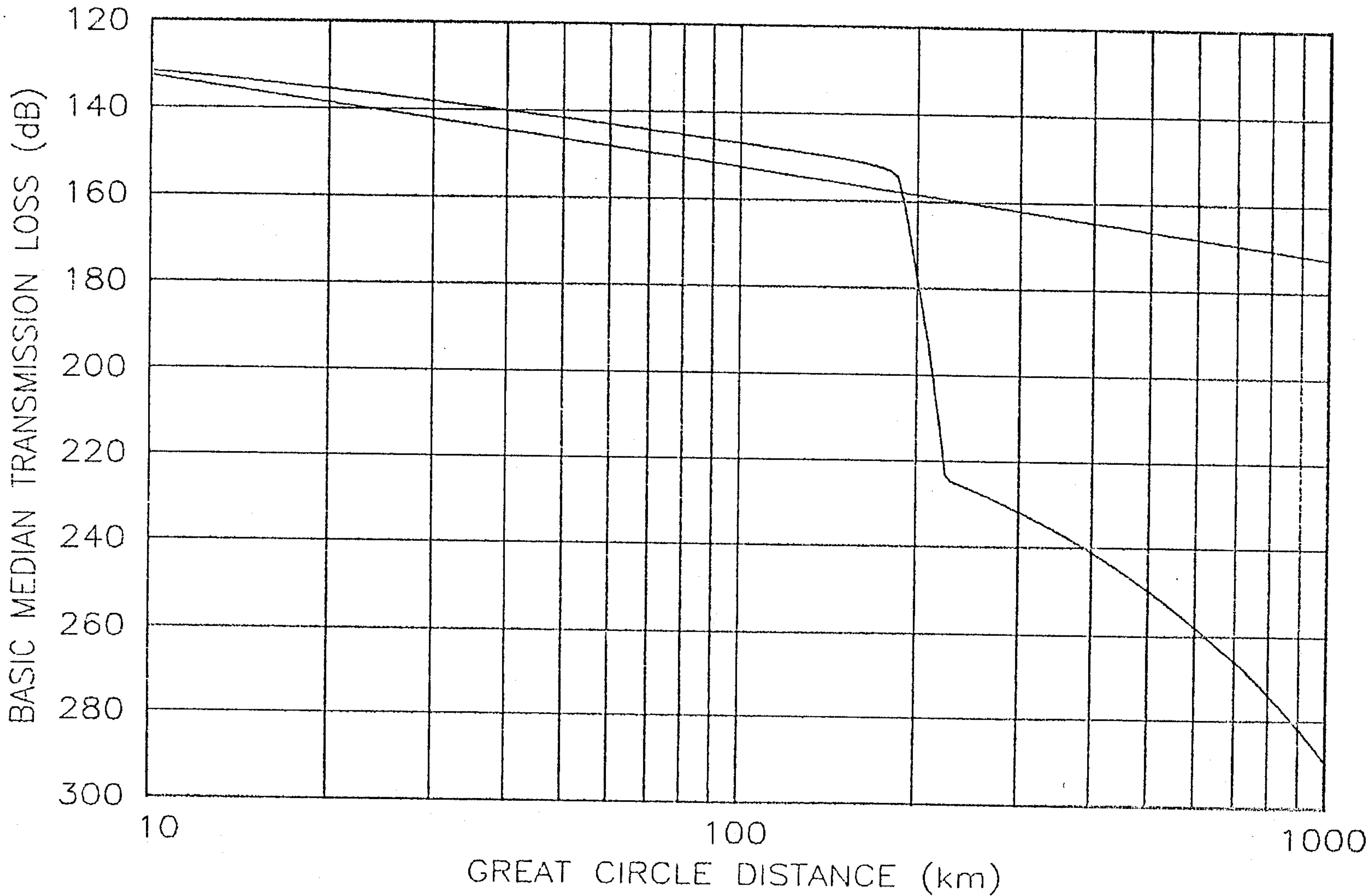

FIGURE A–97. $f=10GHz, h_1=10m, h_2=2km$, V.P., Land and Sea Water

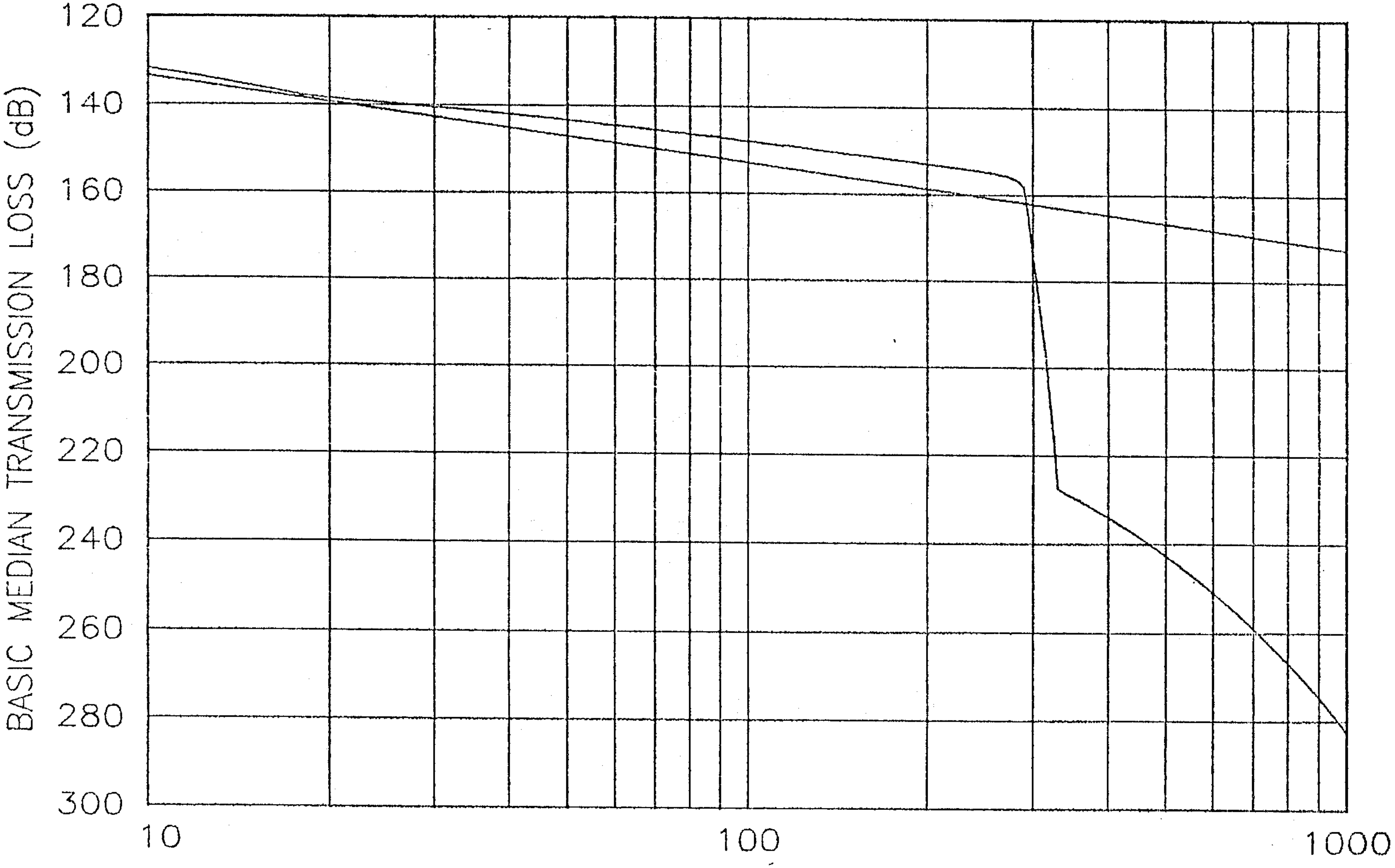

FIGURE A-98. $f=10GHz, h_1=10m, h_2=5km$, V.P., Land and Sea Water

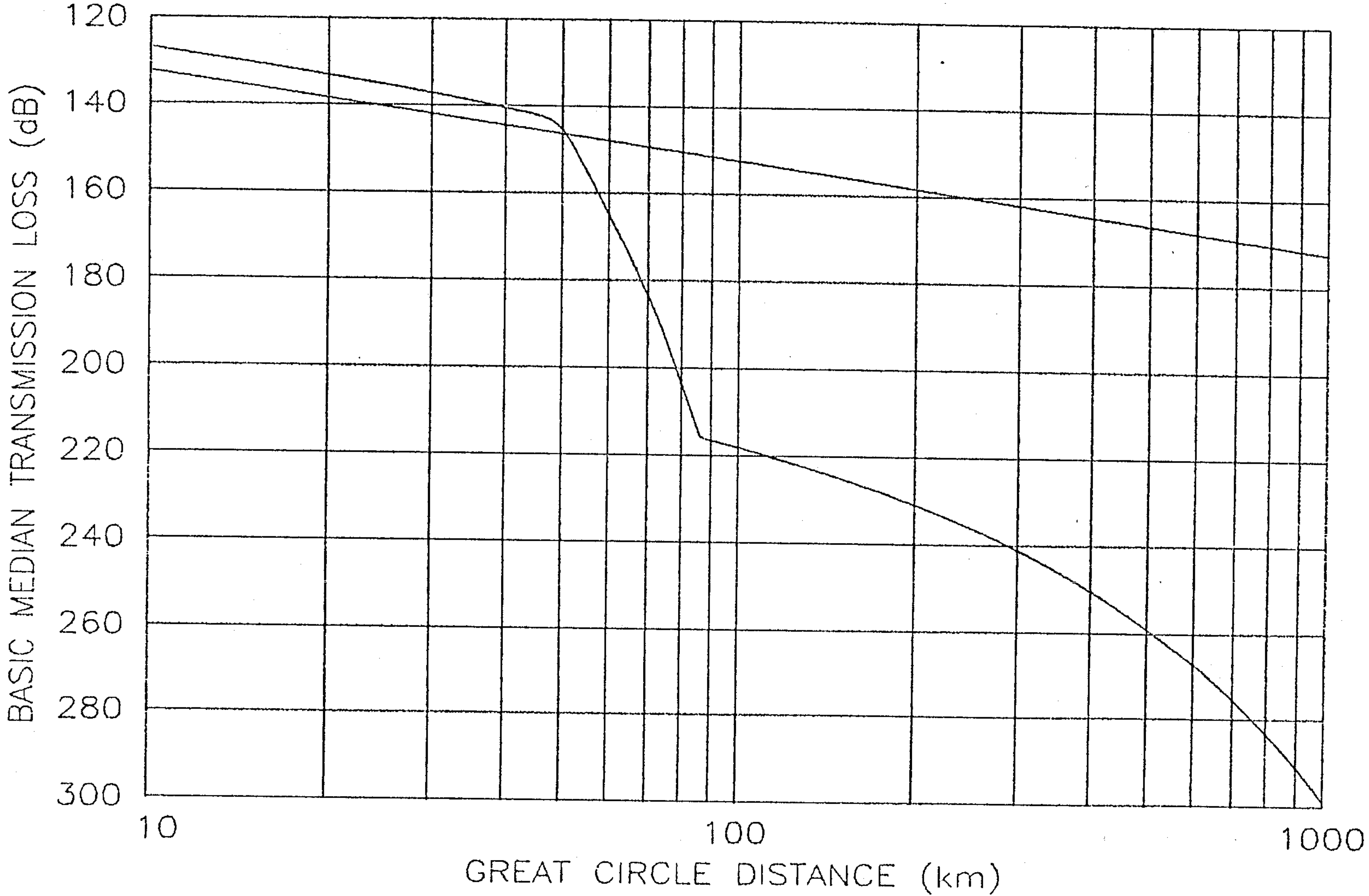

FIGURE A-99. f=10GHz,h_1=50m,h_2=50m,V.P.,Land and Sea Water

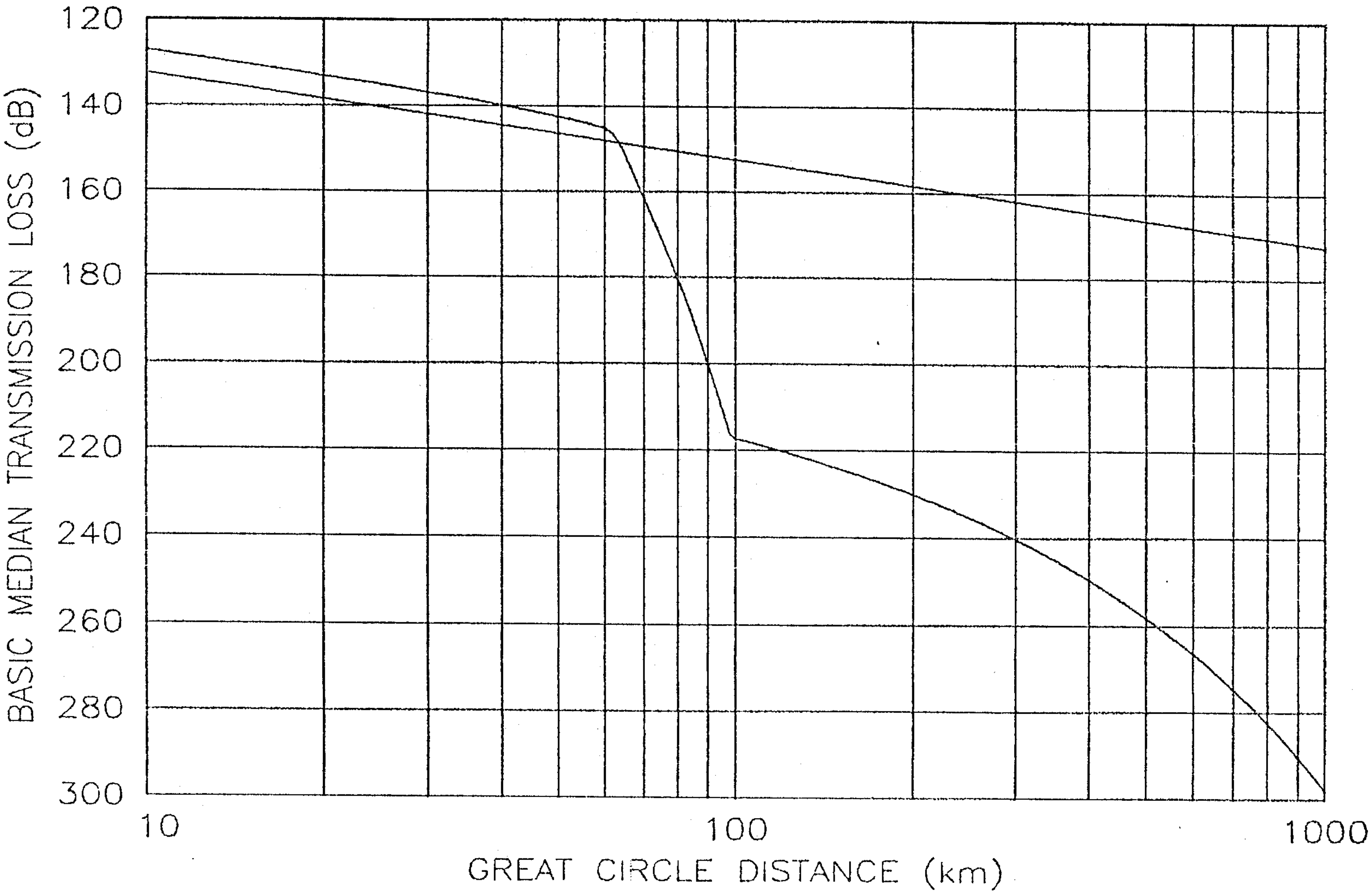

FIGURE A–100. $f=10GHz, h_1=50m, h_2=100m$, V.P., Land and Sea Water

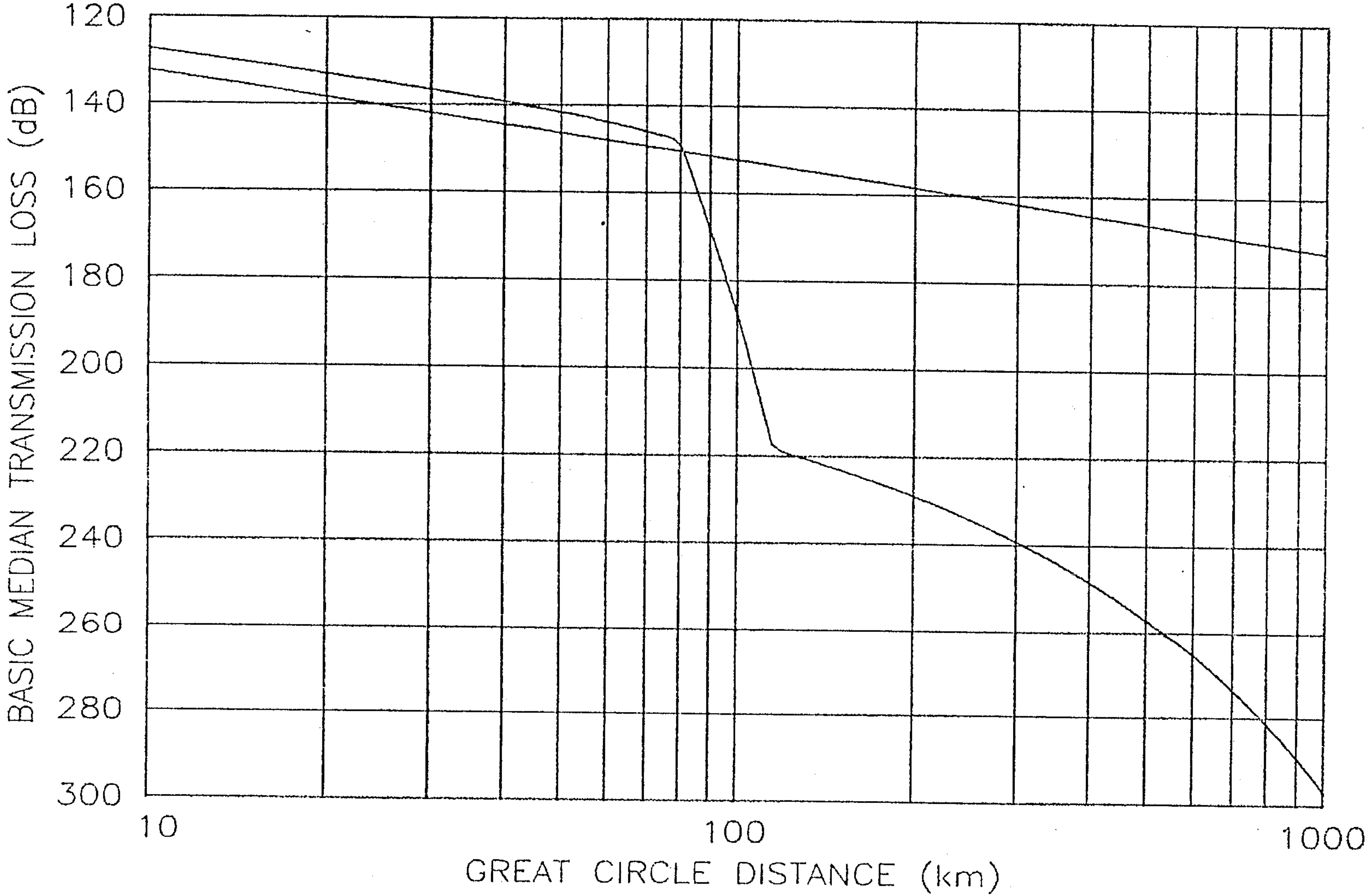

FIGURE A–101. $f=10\text{GHz}, h_1=50\text{m}, h_2=200\text{m}$, V.P., Land and Sea Water

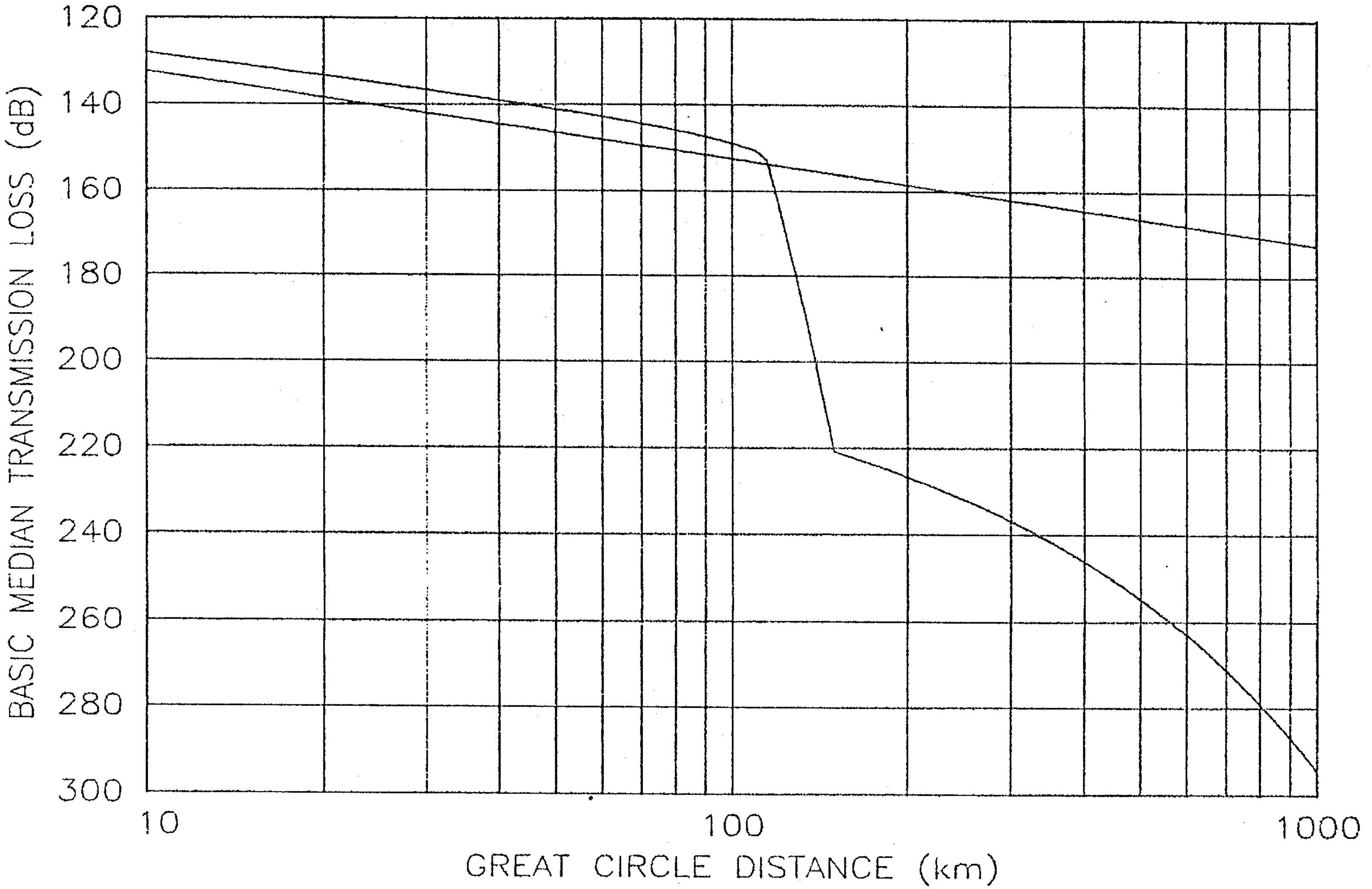

FIGURE A-102. $f=10GHz, h_1=50m, h_2=500m$, V.P., Land and Sea Water

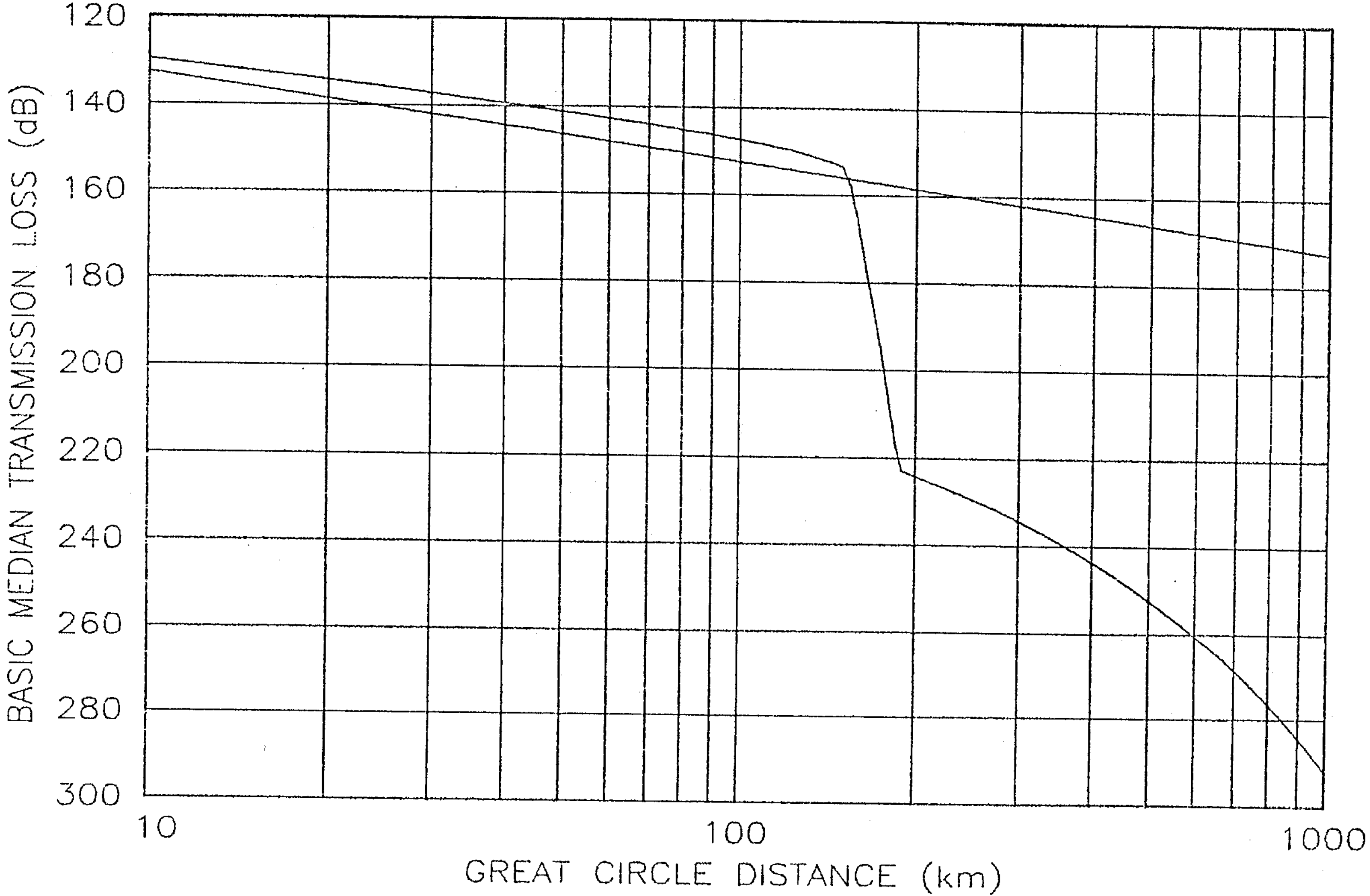

FIGURE A-103. $f=10GHz, h_1=50m, h_2=1km$, V.P., Land and Sea Water

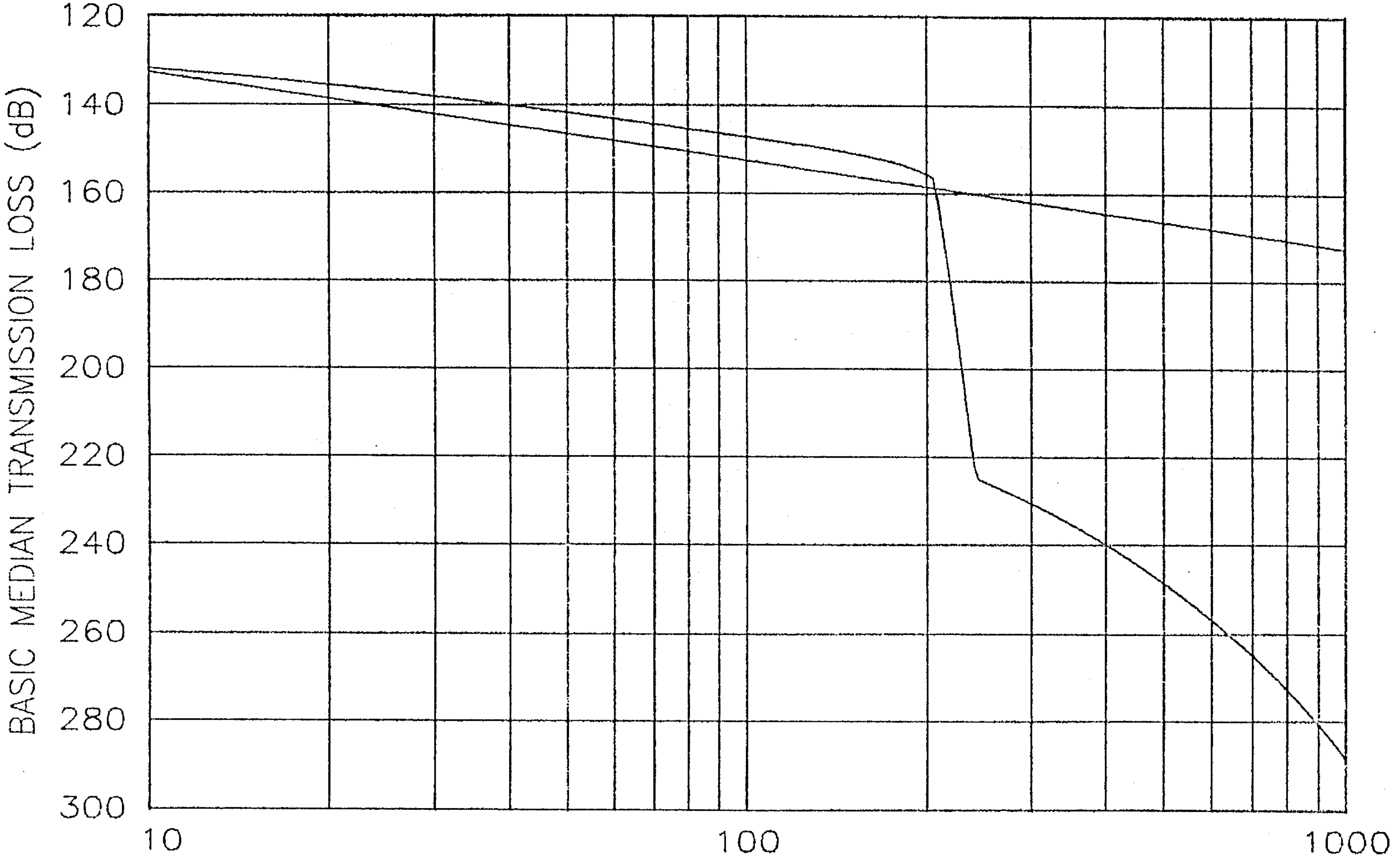

FIGURE A-104. $f=10GHz, h_1=50m, h_2=2km$, V.P., Land and Sea Water

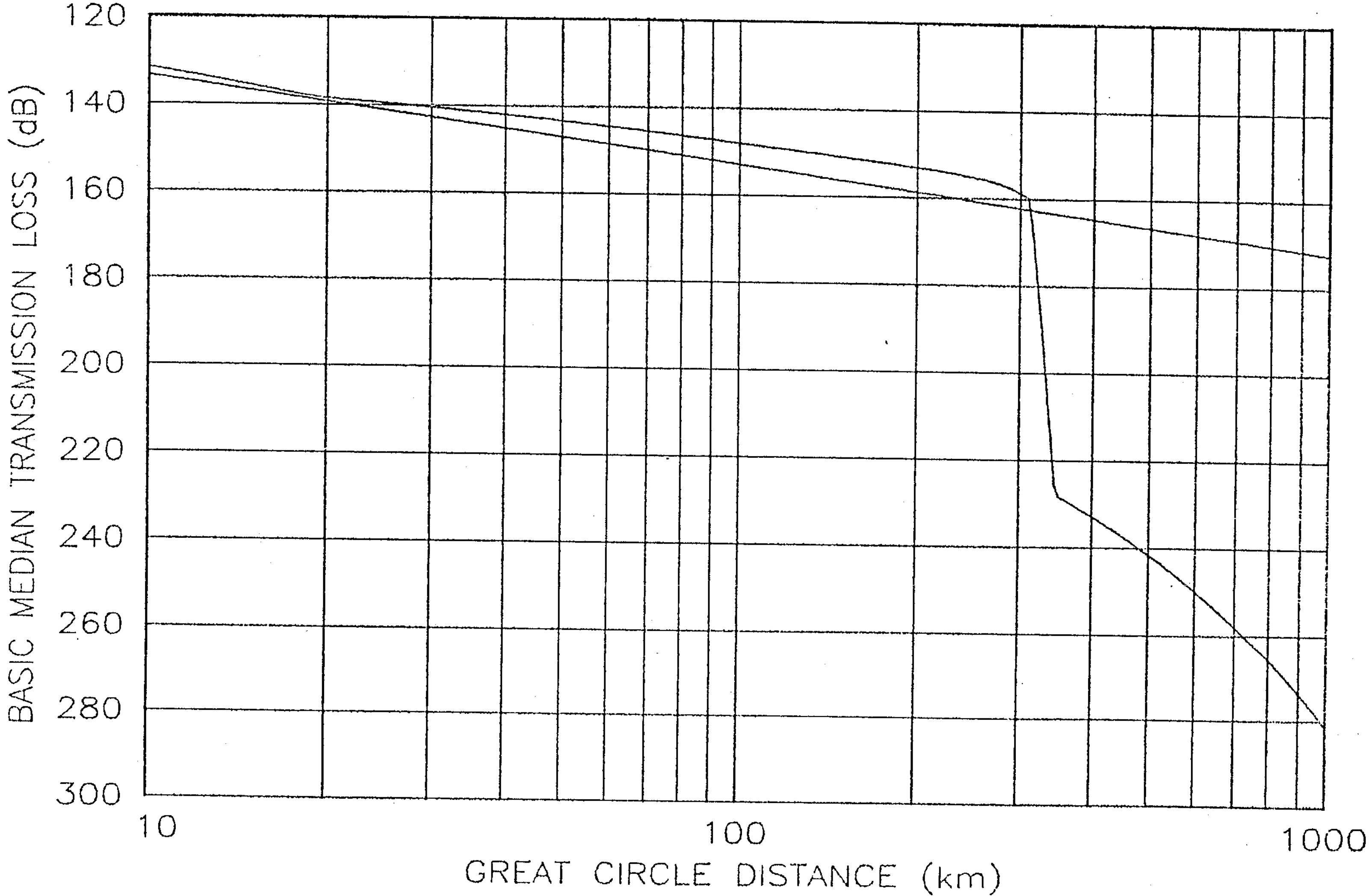

FIGURE A–105. $f=10GHz, h_1=50m, h_2=5km$, V.P., Land and Sea Water

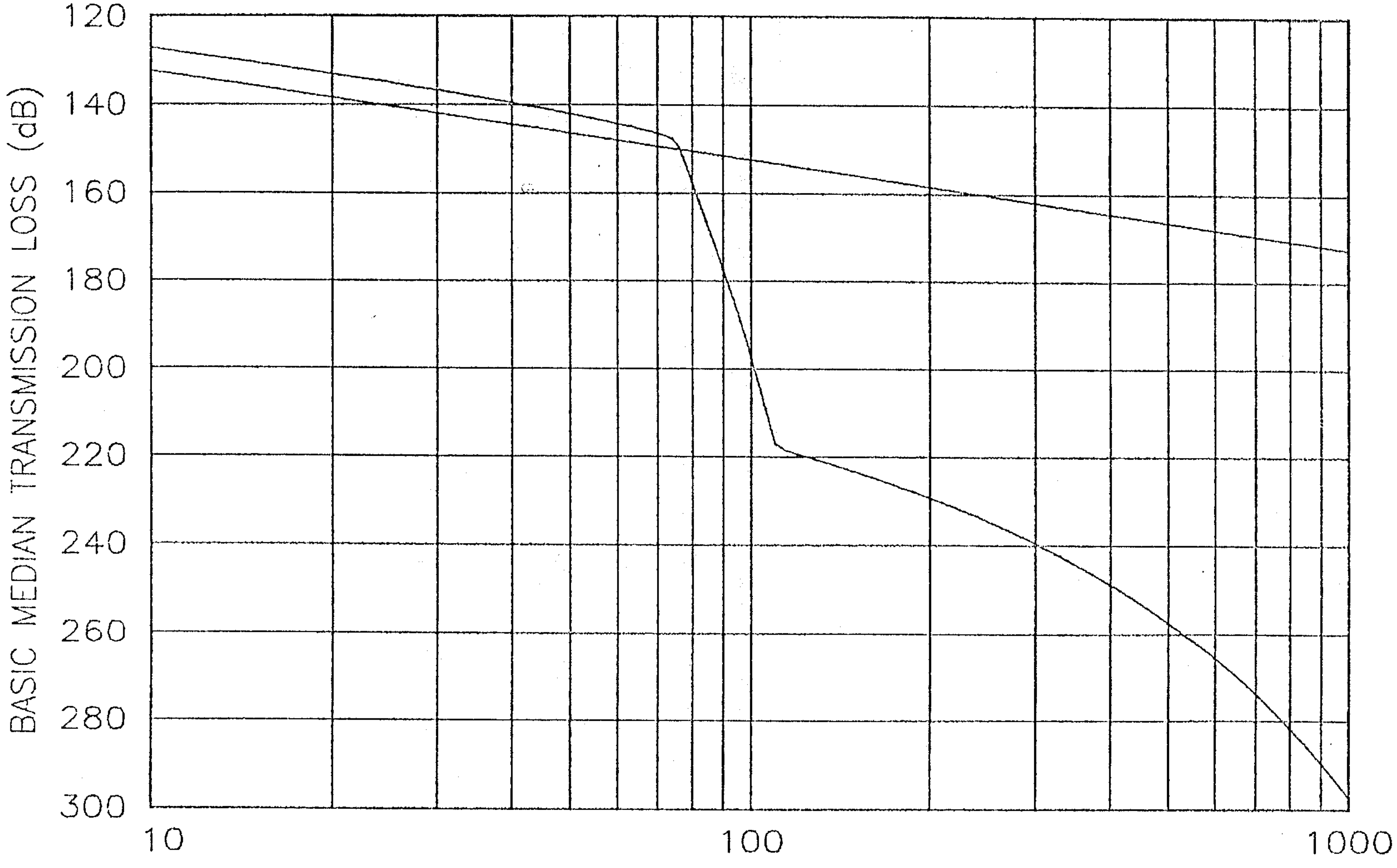

FIGURE A-106. $f=10GHz, h_1=100m, h_2=100m$, V.P., Land and Sea Water

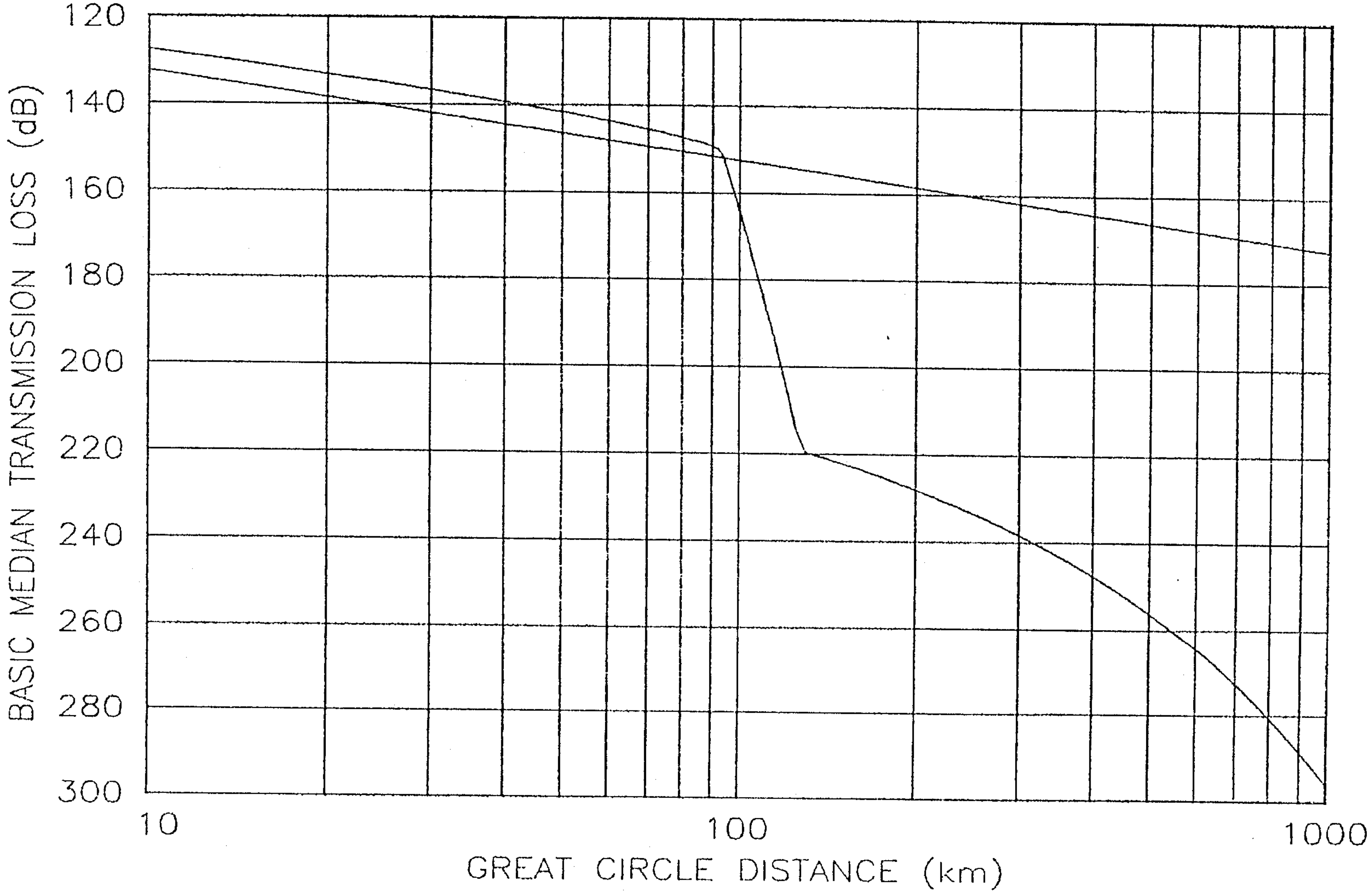

FIGURE A-107. $f=10GHz, h_1=100m, h_2=200m$, V.P., Land and Sea Water

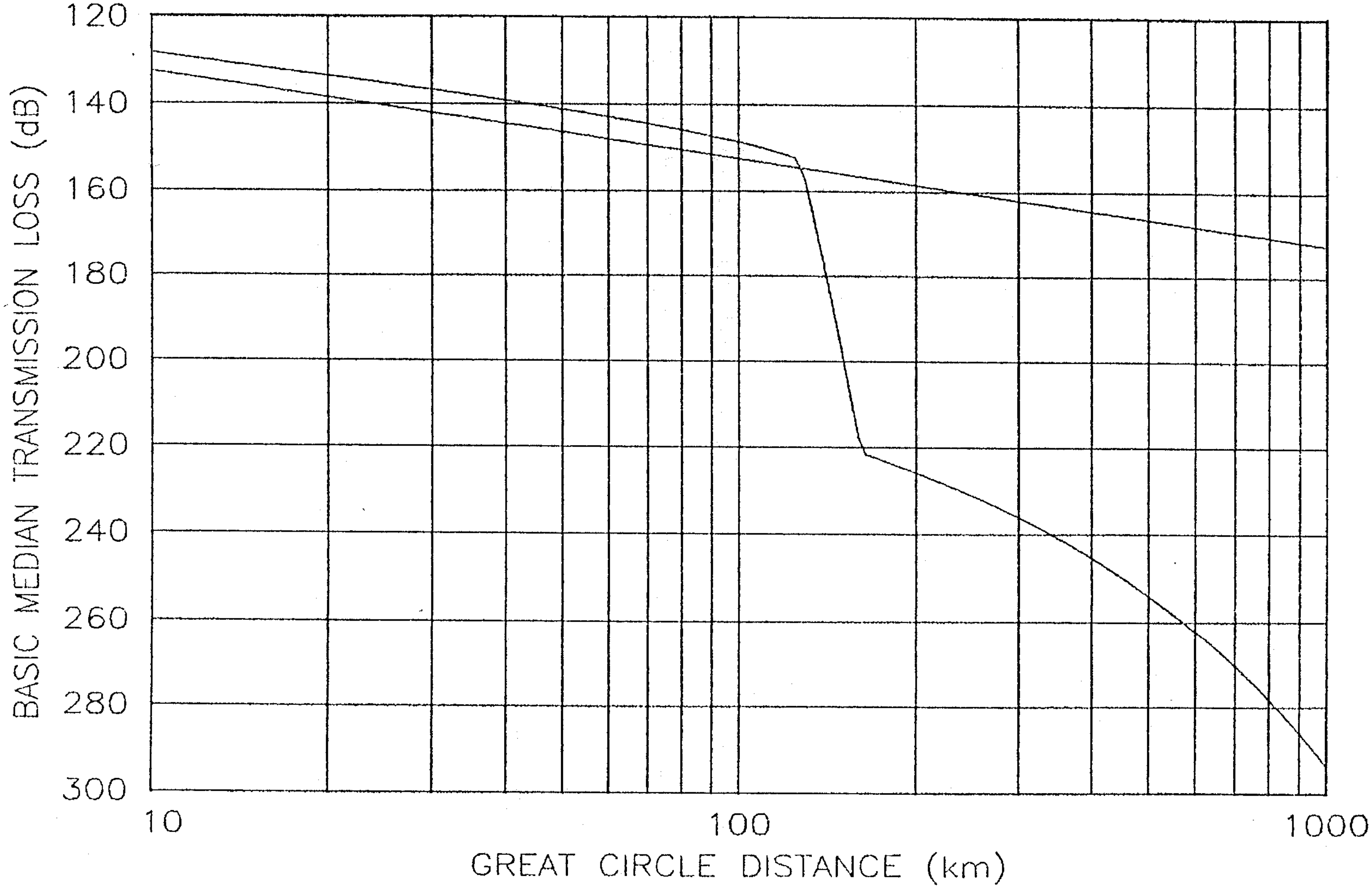

FIGURE A-108. f=10GHz,h_1=100m,h_2=500m,V.P.,Land and Sea Water

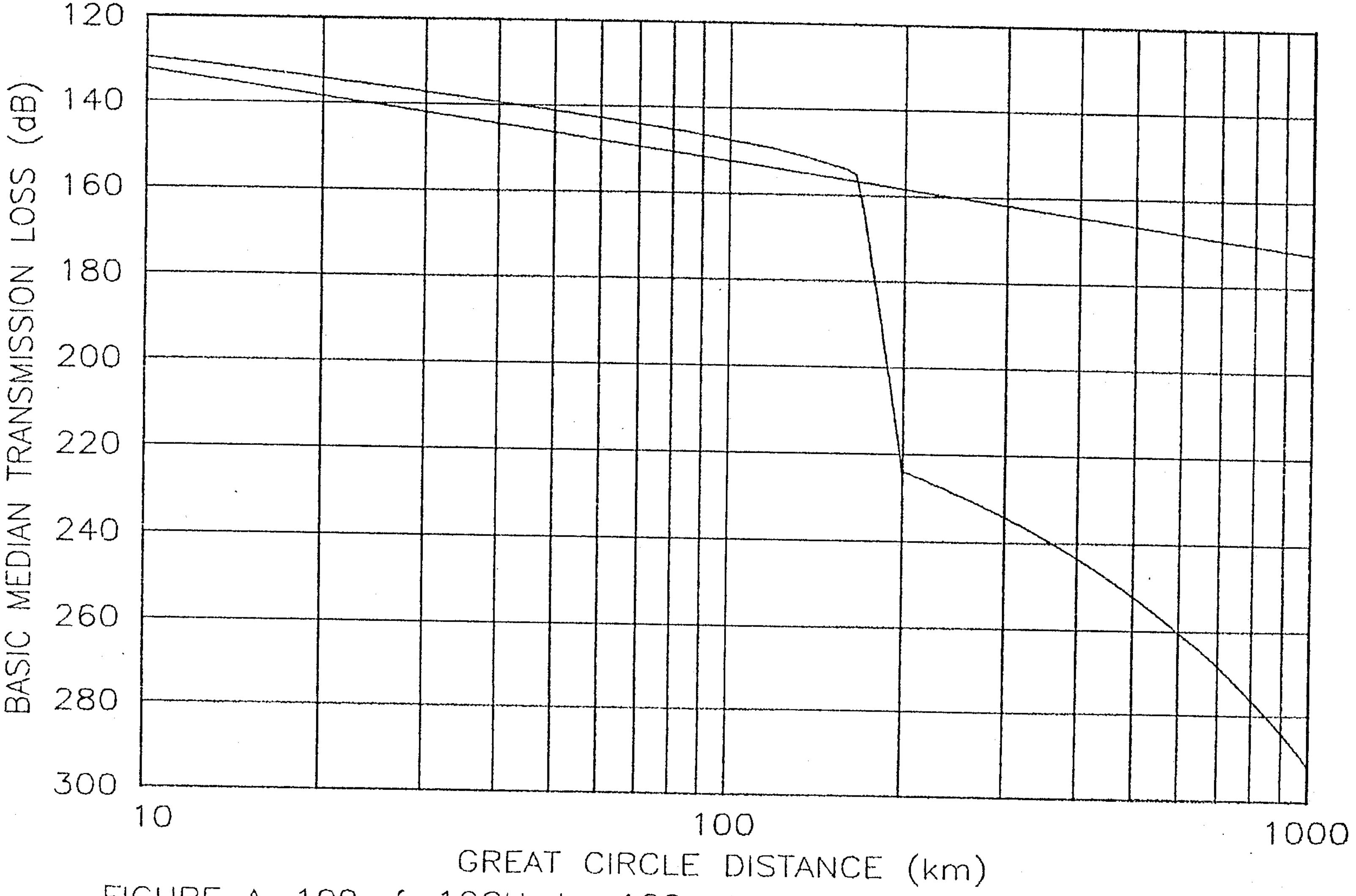

FIGURE A-109. $f=10GHz, h_1=100m, h_2=1km$, V.P., Land and Sea Water

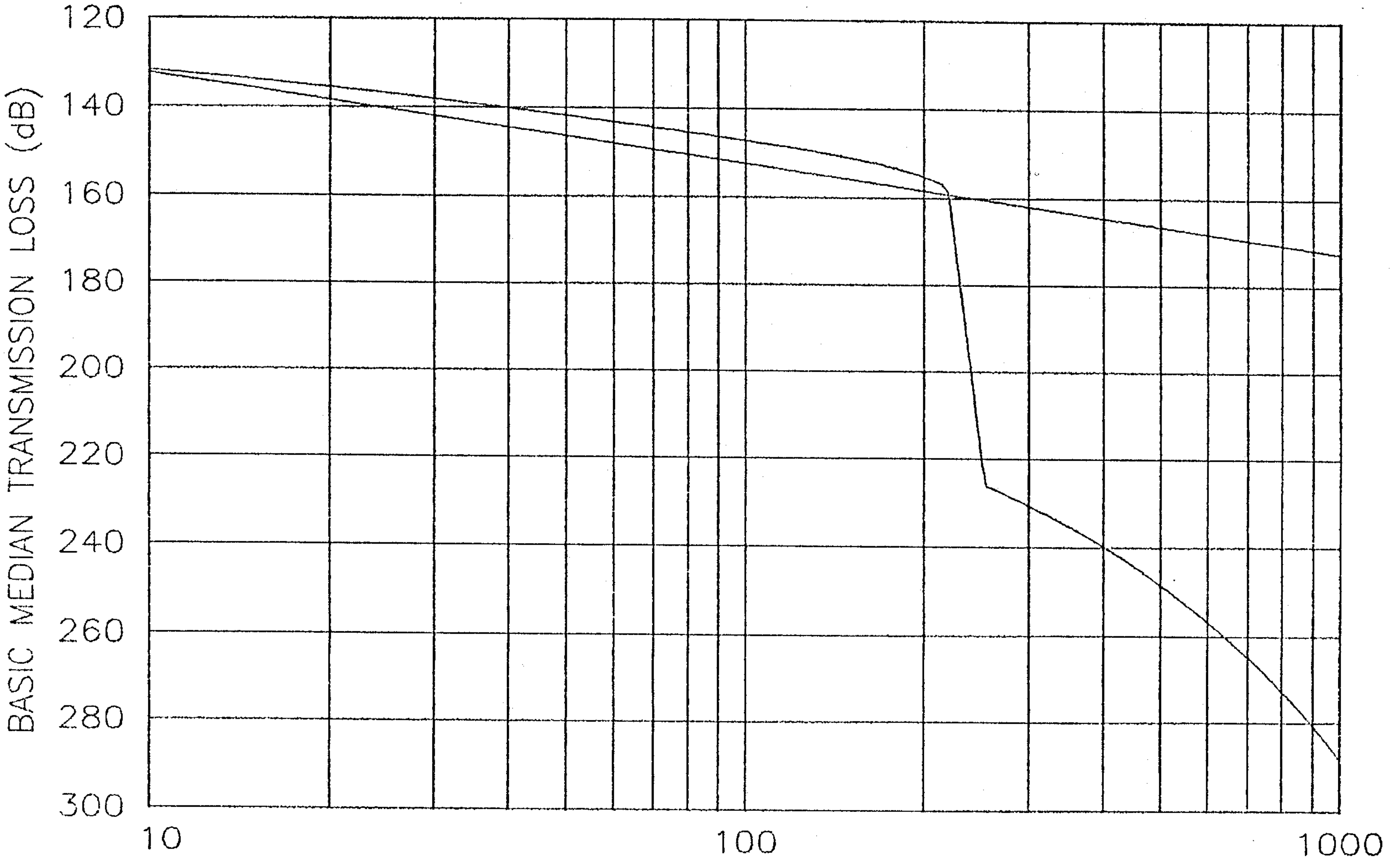

FIGURE A-110. f=10GHz,h_1=100m,h_2=2km,V.P.,Land and Sea Water

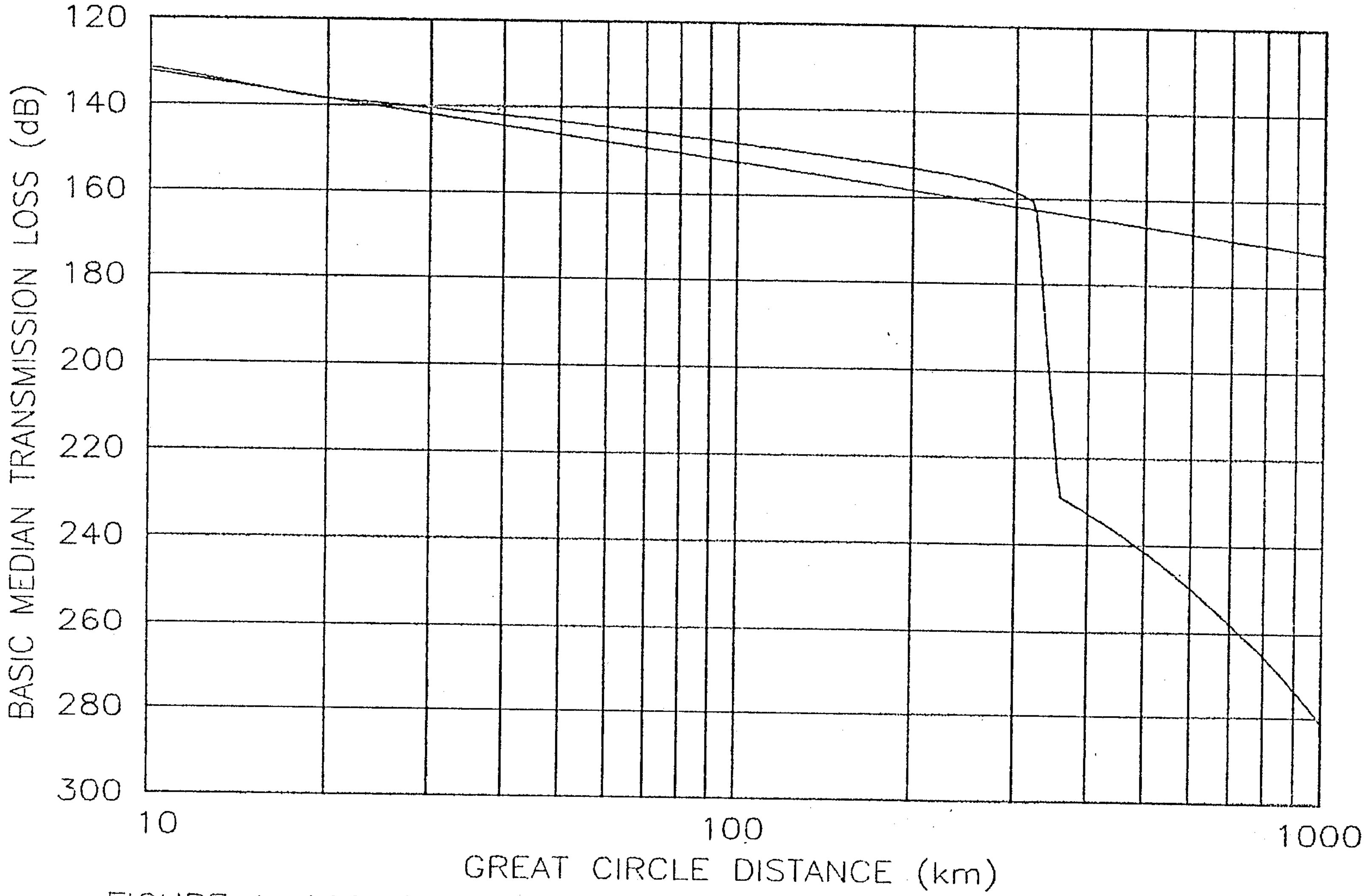

FIGURE A-111. $f=10GHz, h_1=100m, h_2=5km$, V.P., Land and Sea Water

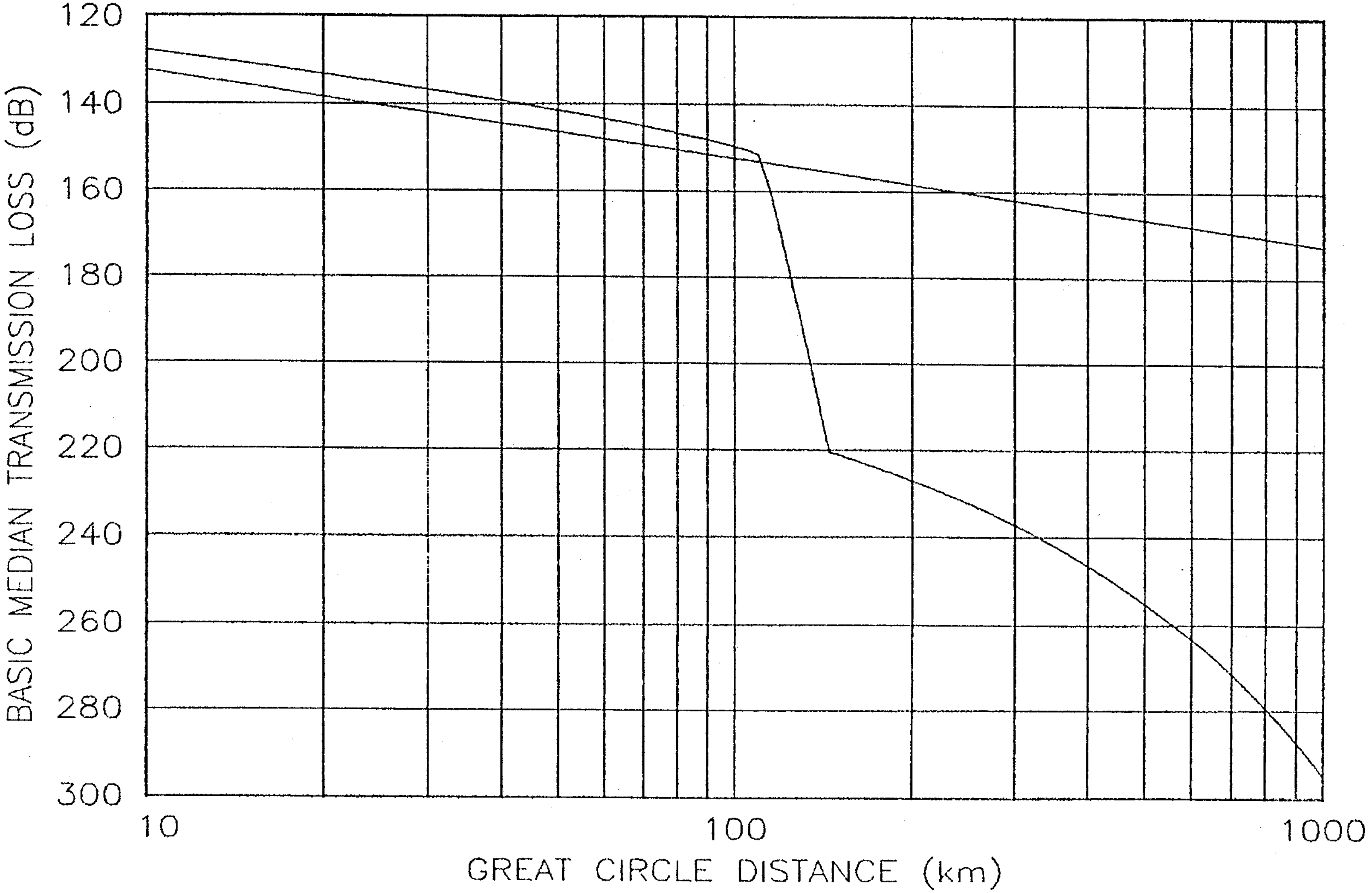

FIGURE A-112. $f=10GHz, h_1=200m, h_2=200m$, V.P., Land and Sea Water

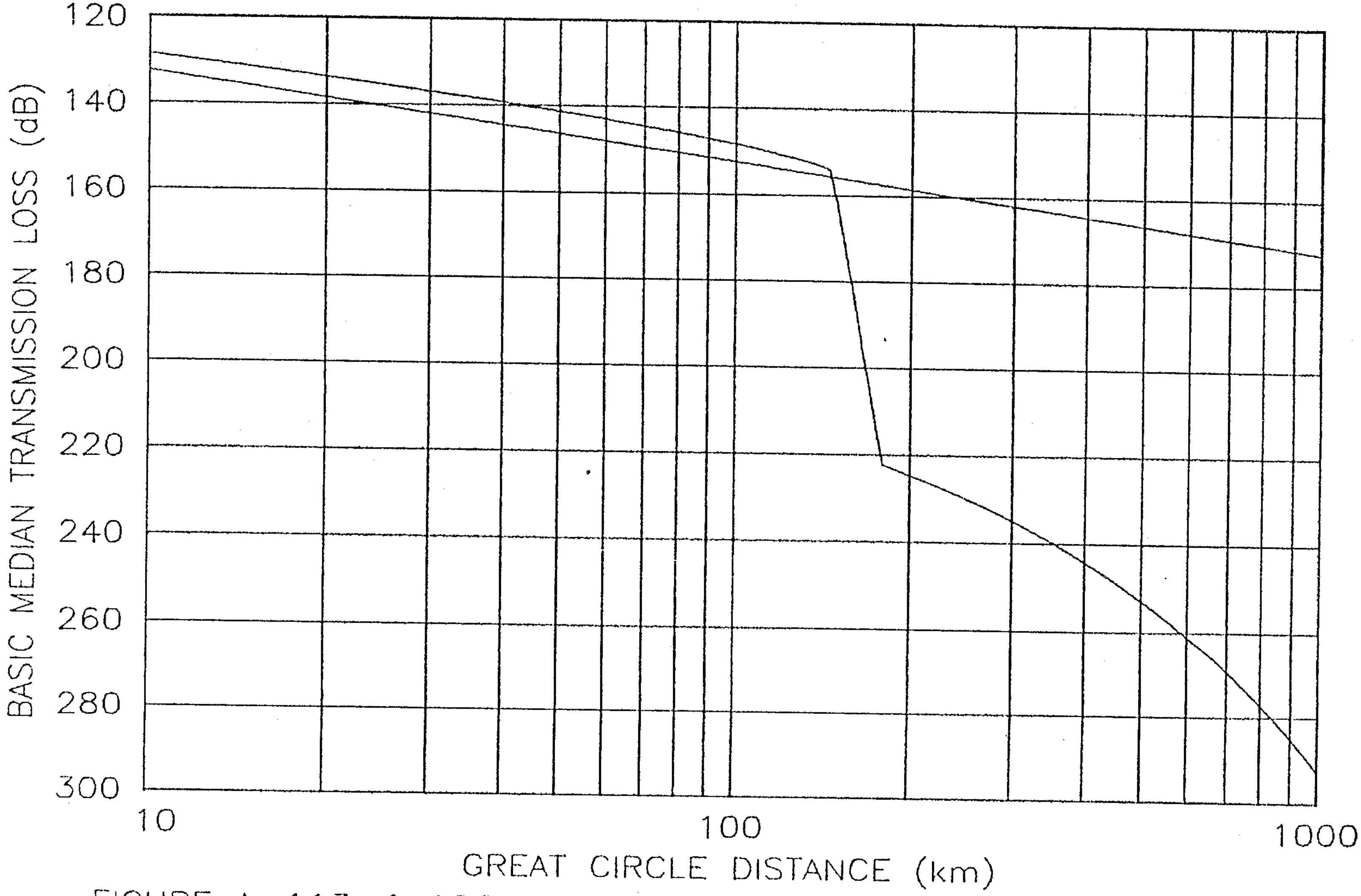

FIGURE A–113. f=10GHz,h_1=200m,h_2=500m,V.P.,Land and Sea Water

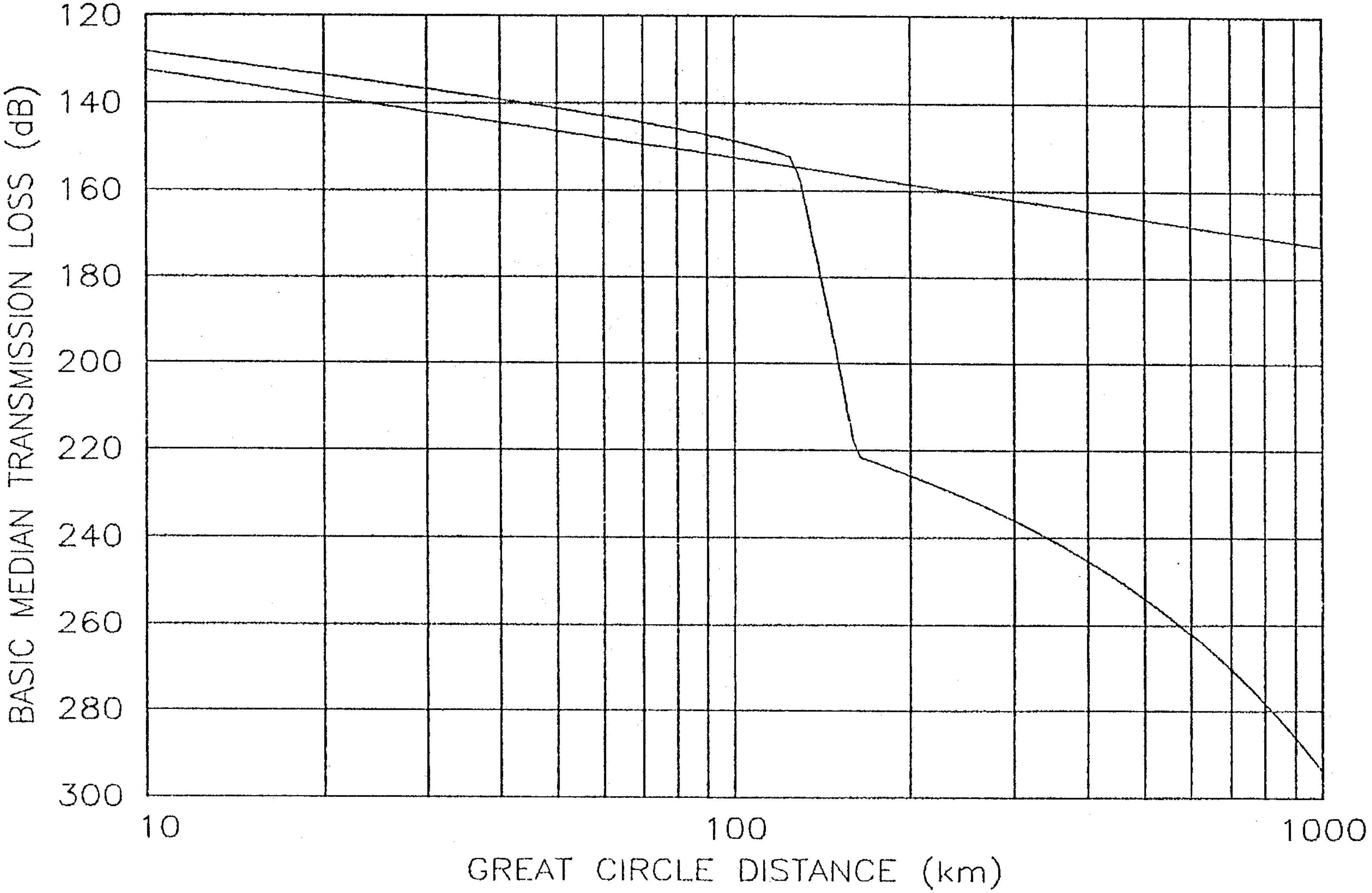

FIGURE A-114. f=10GHz,h_1=200m,h_2=1km,V.P.,Land and Sea Water

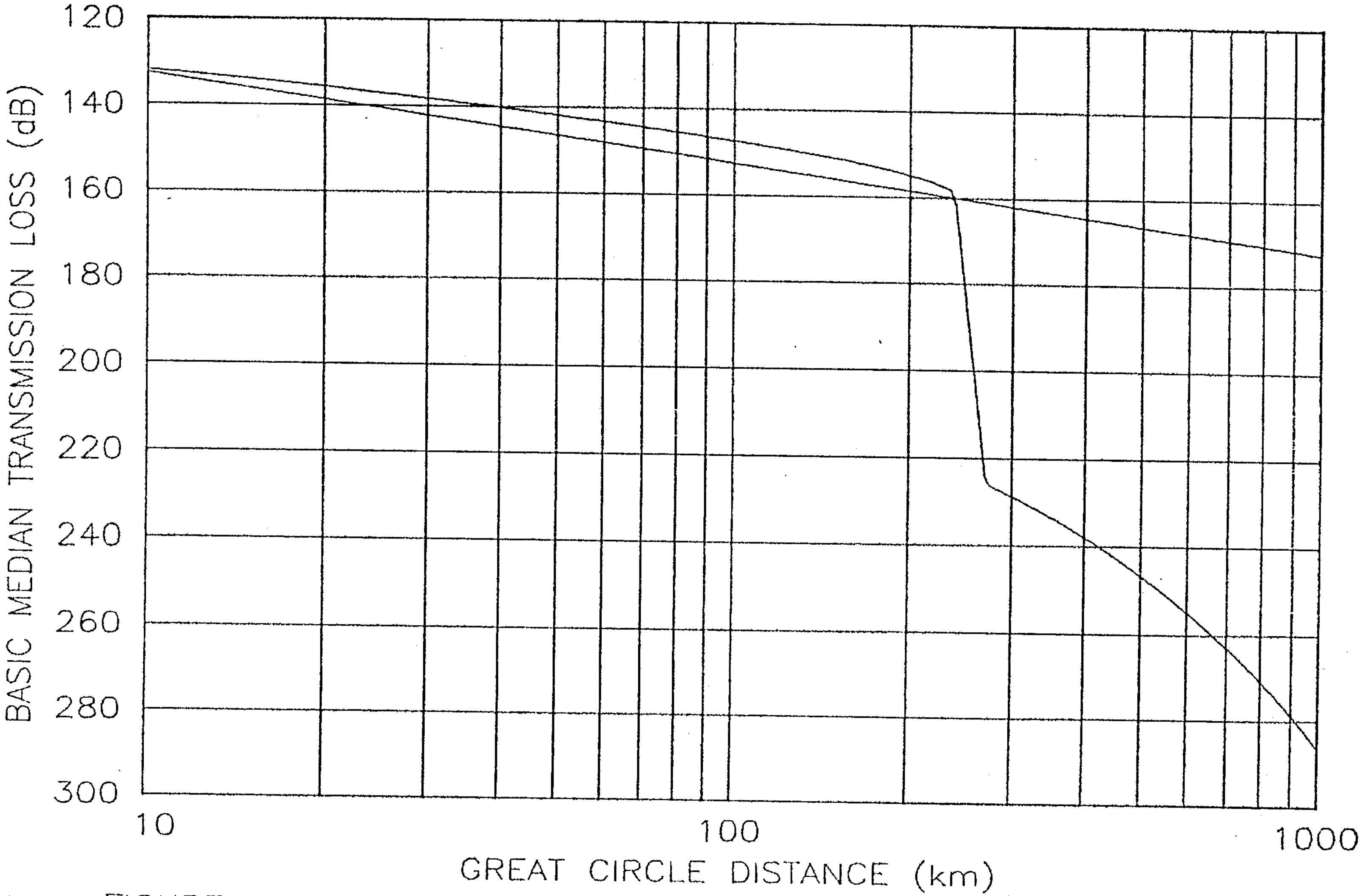

FIGURE A-115. $f=10\mathrm{GHz}, h_1=200\mathrm{m}, h_2=2\mathrm{km}$, V.P., Land and Sea Water

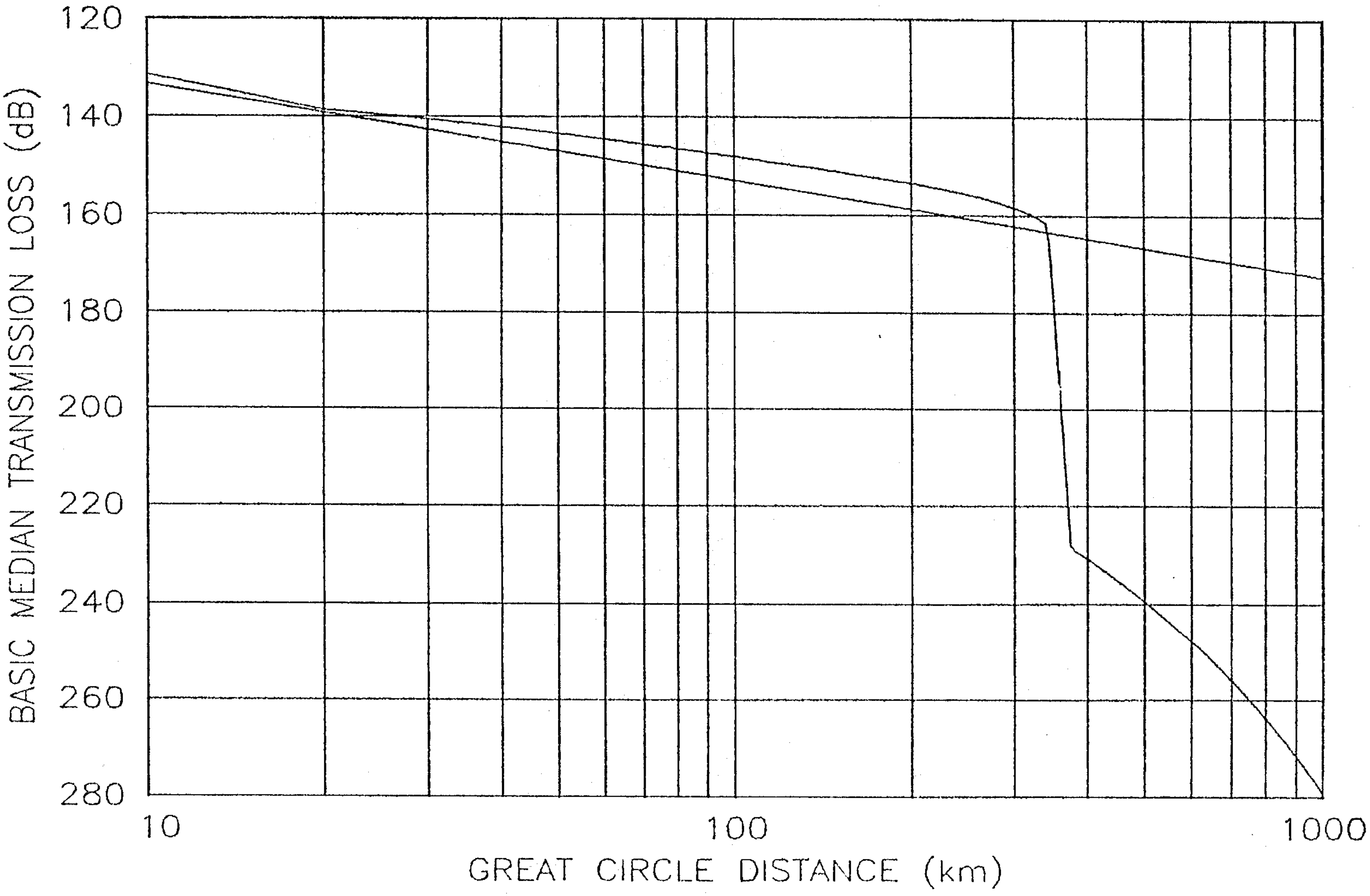

FIGURE A−116. f=10GHz,h_1=200m,h_2=5km,V.P.,Land and Sea Water

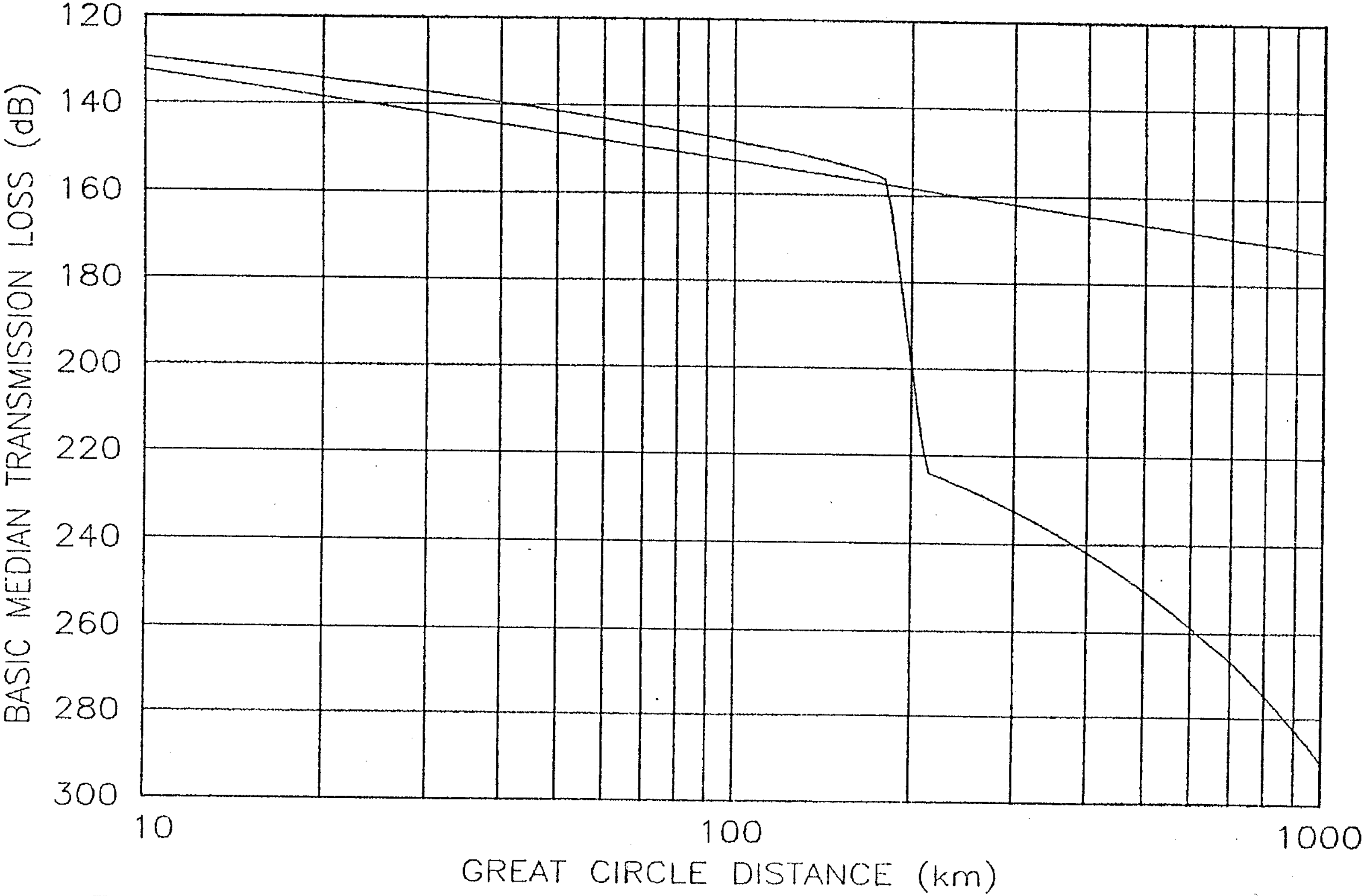

FIGURE A-117. f=10GHz,h_1=500m,h_2=500m,V.P.,Land and Sea Water

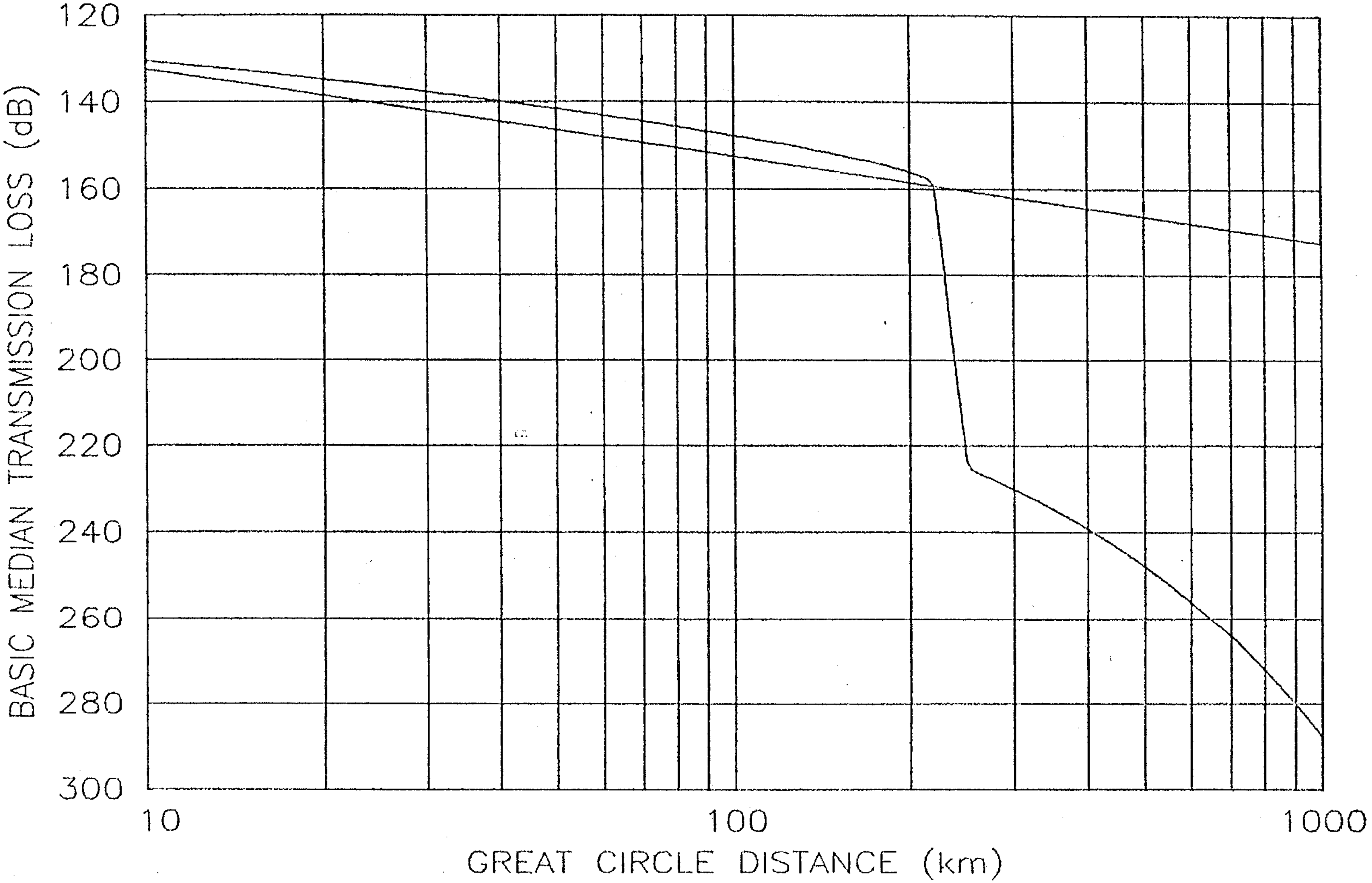

FIGURE A-118. $f=10GHz, h_1=500m, h_2=1km$, V.P., Land and Sea Water

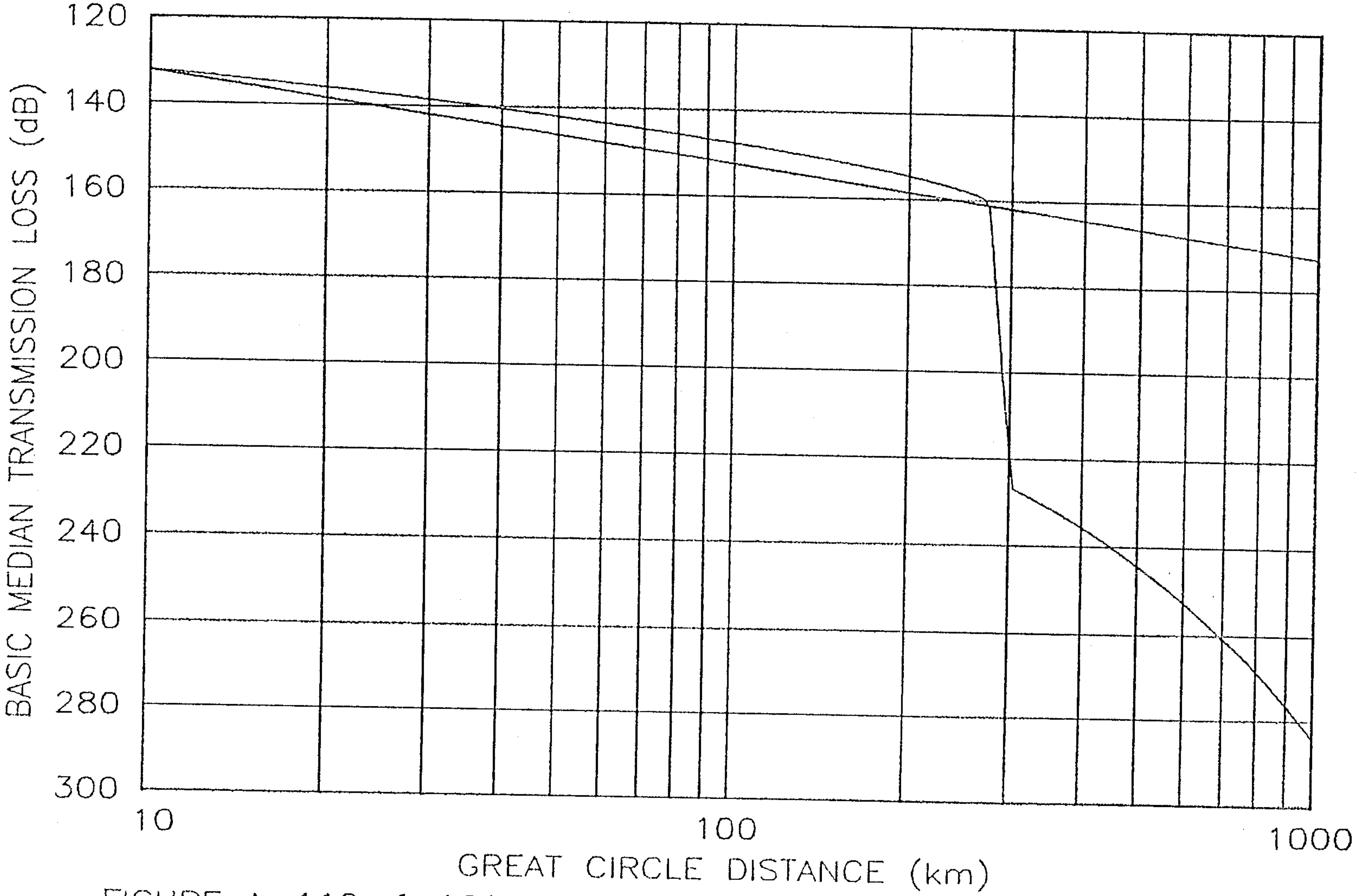

FIGURE A-119. $f=10GHz, h_1=500m, h_2=2km$, V.P., Land and Sea Water

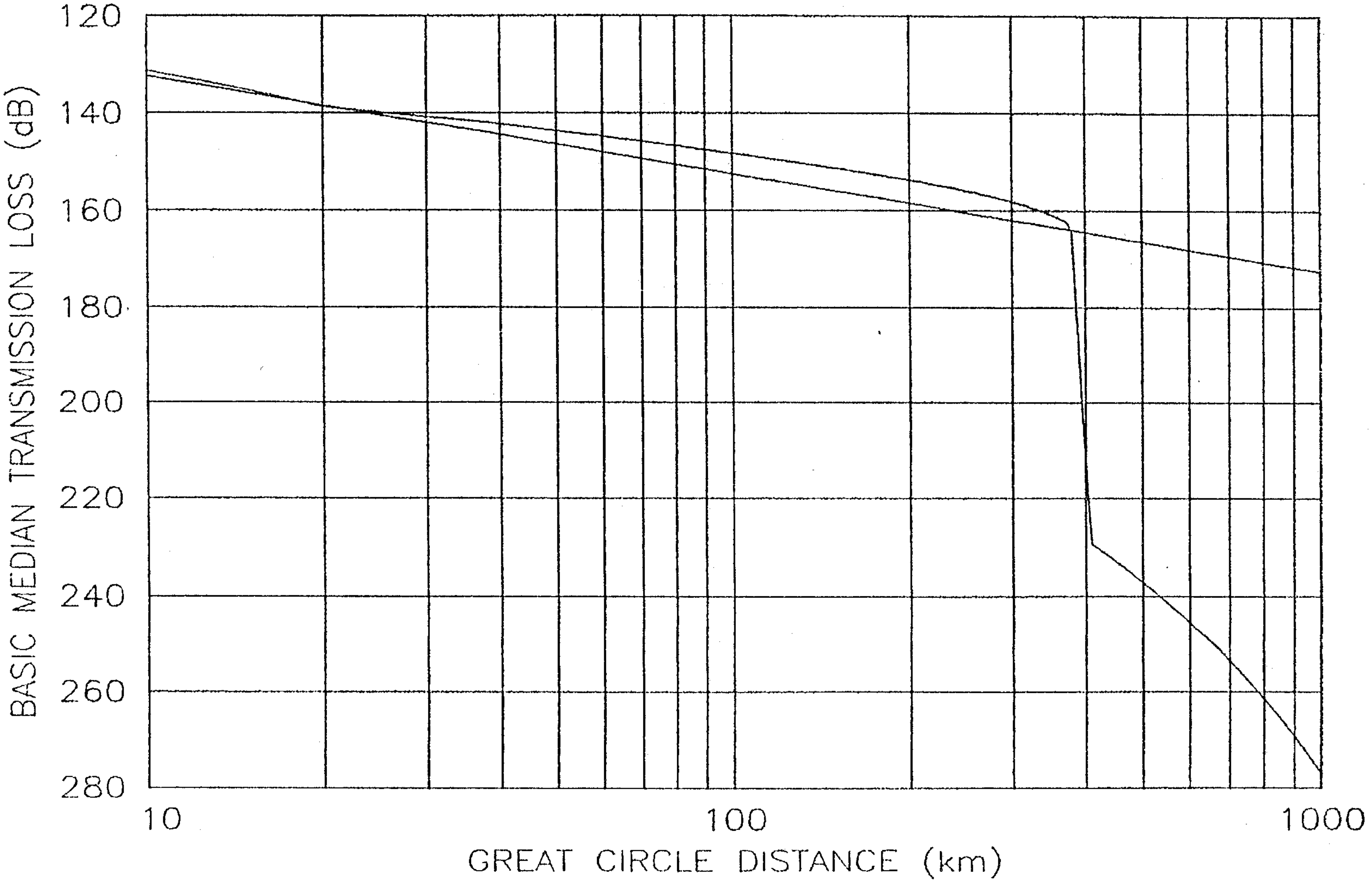

FIGURE A−120. f=10GHz,h_1=500m,h_2=5km,V.P.,Land and Sea Water

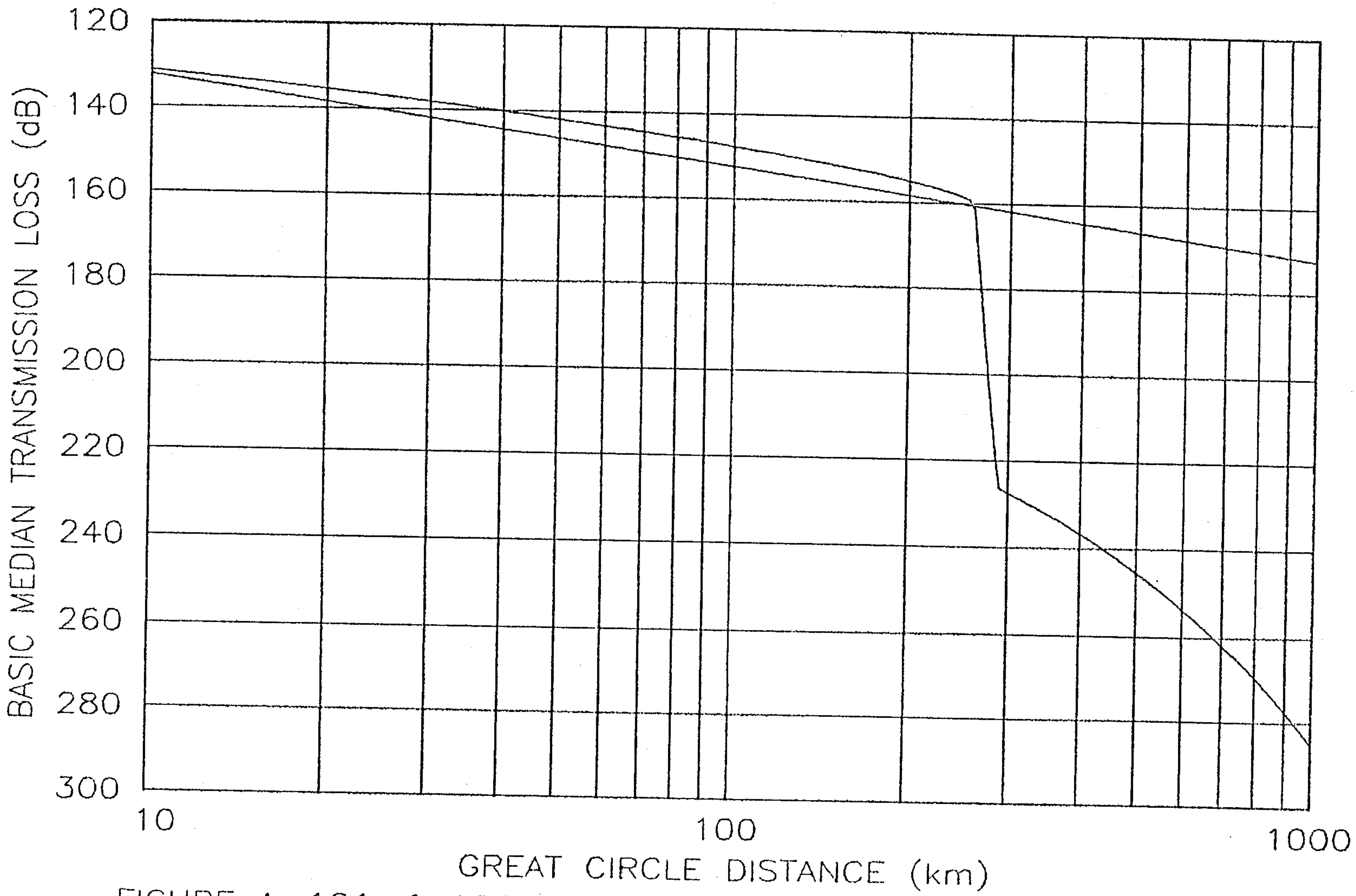

FIGURE A–121. $f=10GHz, h_1=1km, h_2=1km$, V.P., Land and Sea Water

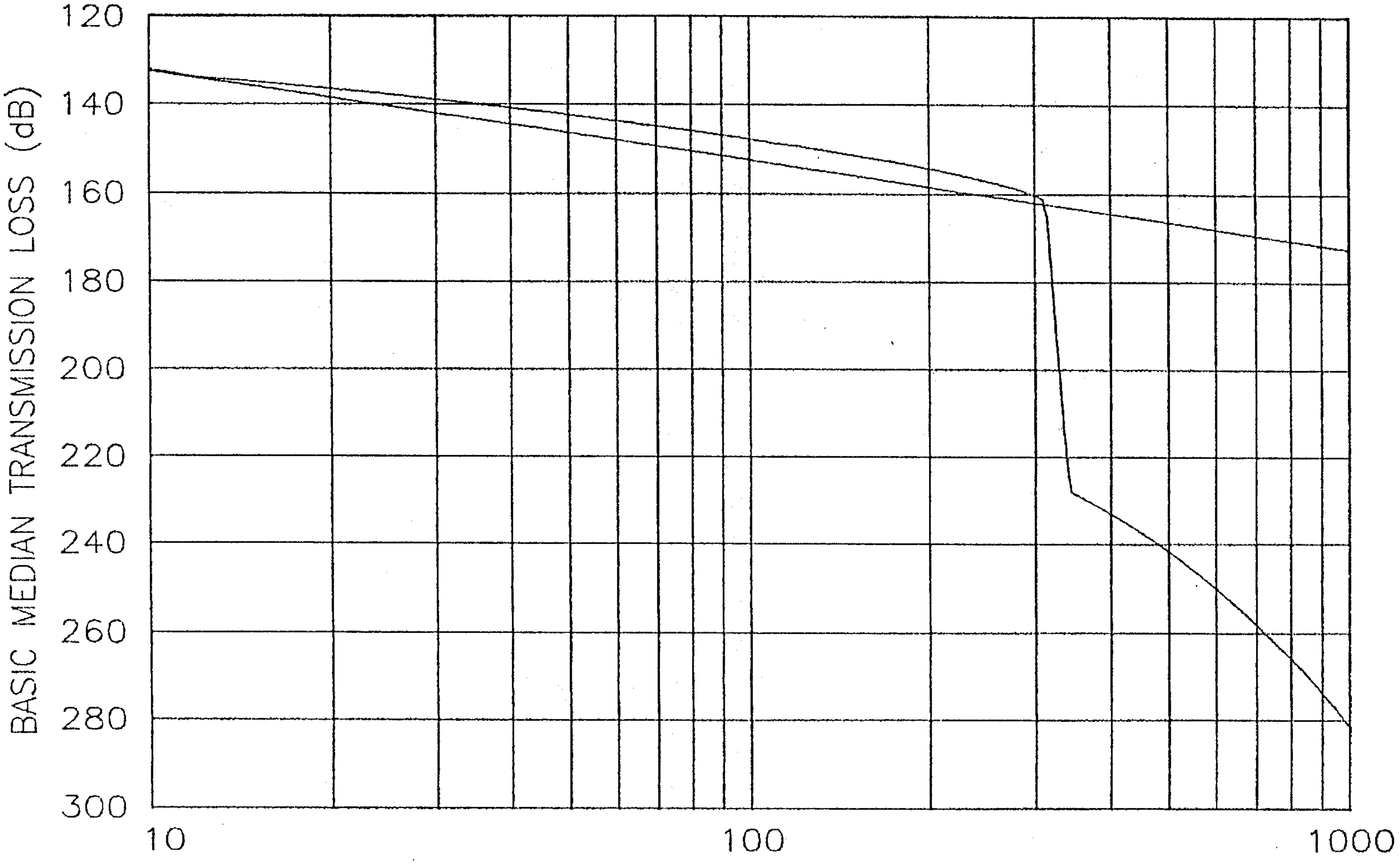

FIGURE A-122. $f=10GHz, h_1=1km, h_2=2km$, V.P., Land and Sea Water

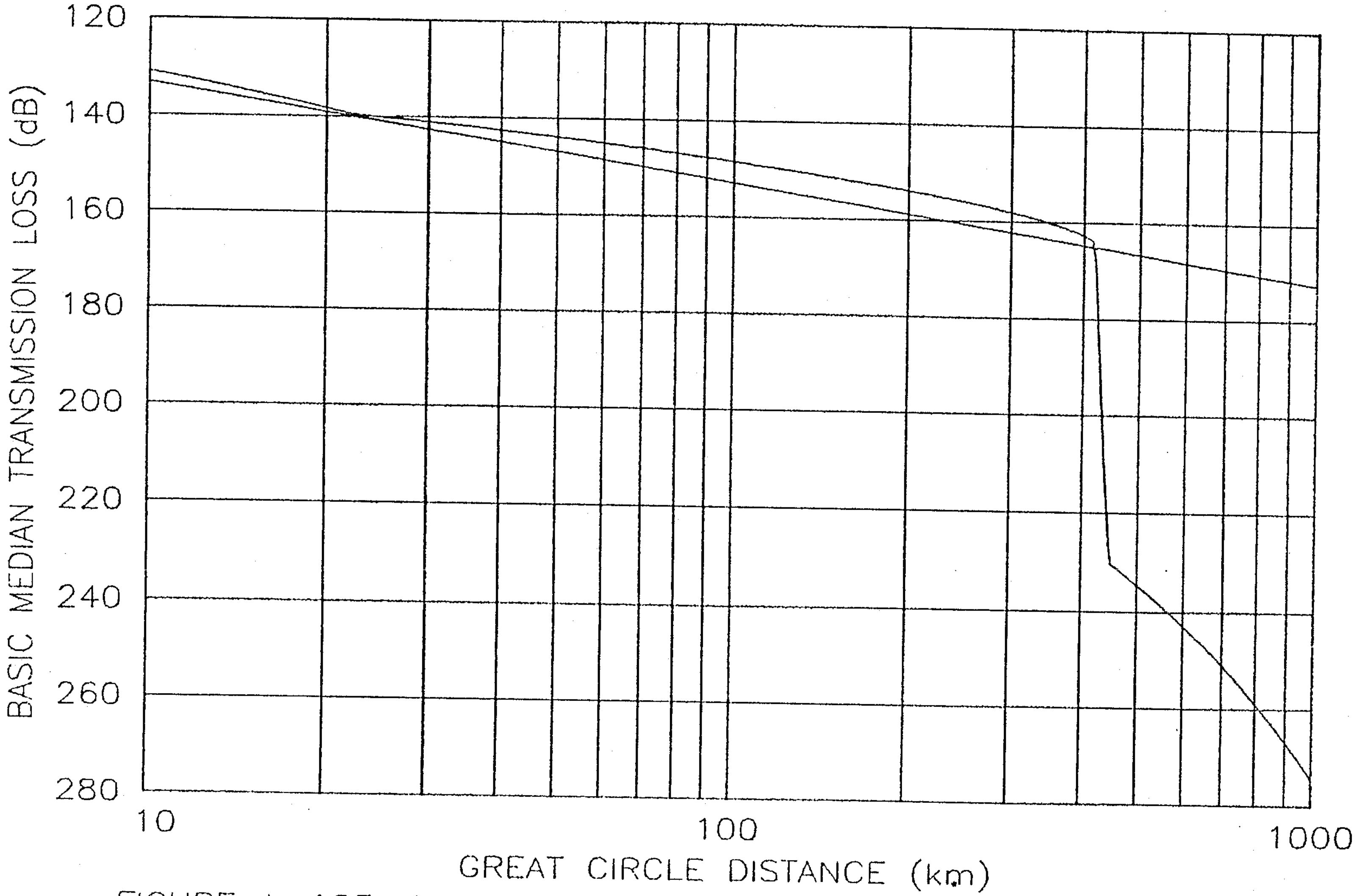

FIGURE A-123. $f=10GHz, h_1=1km, h_2=5km$, V.P., Land and Sea Water

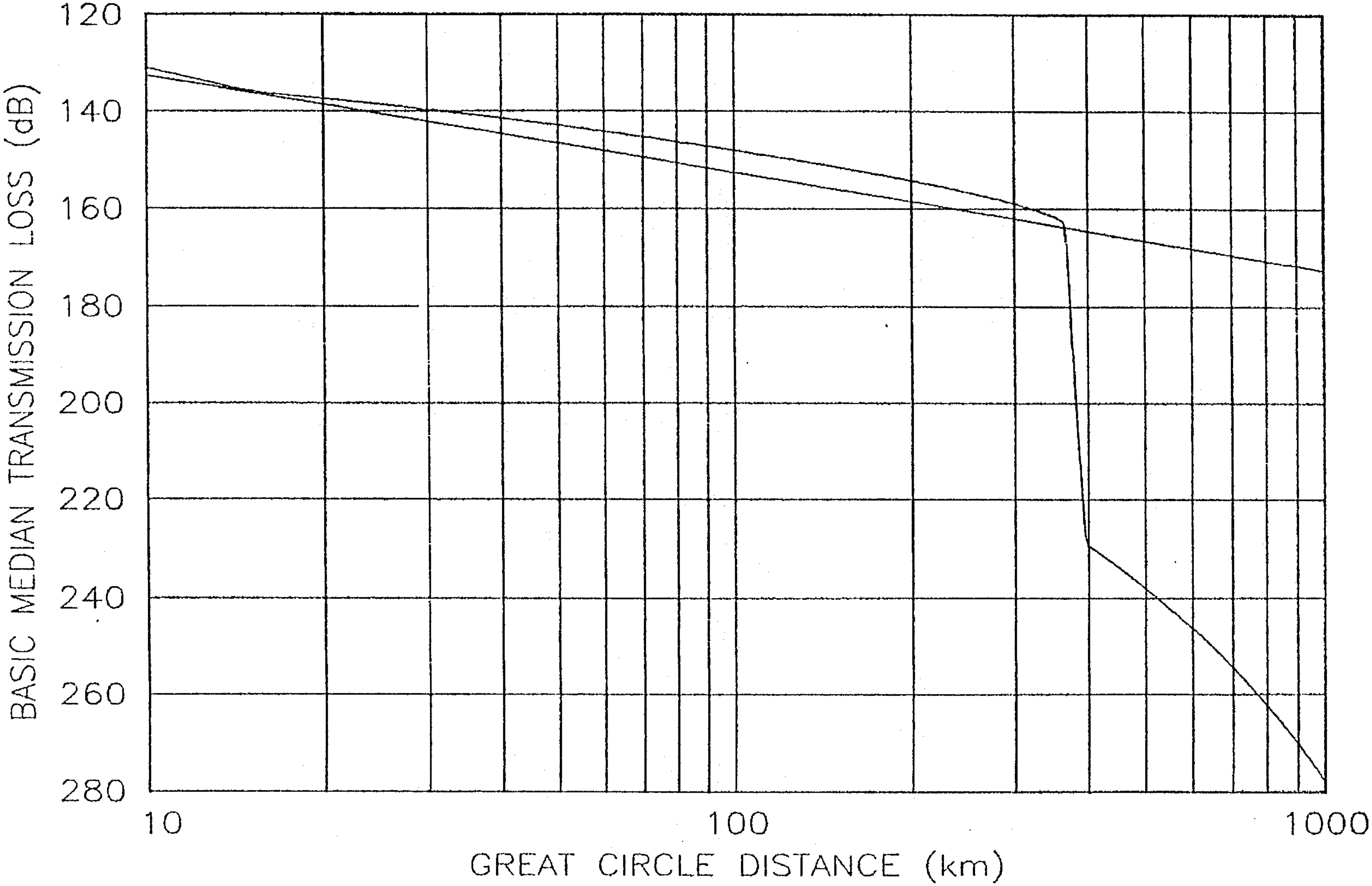

FIGURE A–124. $f=10GHz, h_1=2km, h_2=2km$, V.P., Land and Sea Water

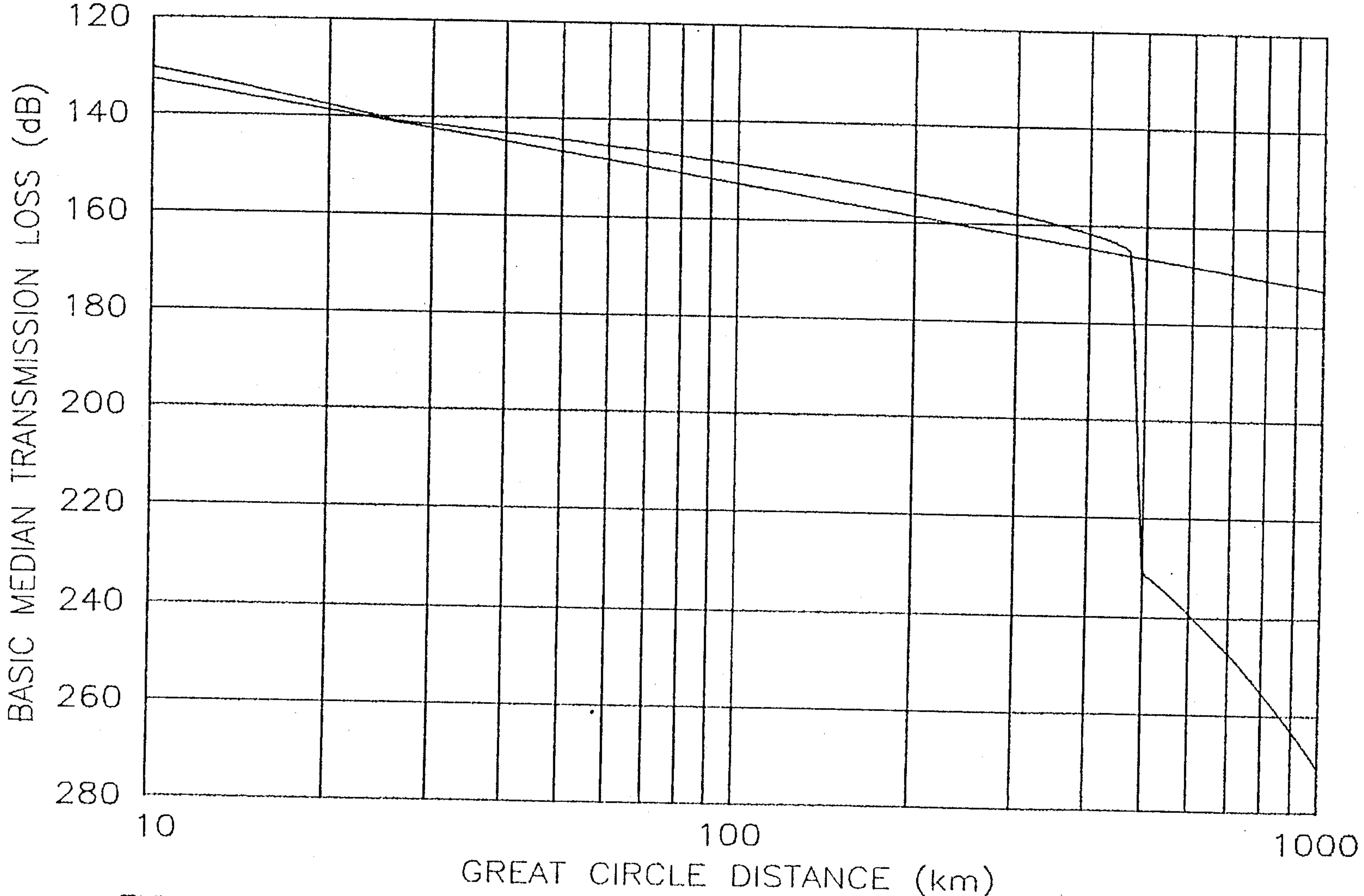

FIGURE A-125. $f=10GHz, h_1=2km, h_2=5km$, V.P., Land and Sea Water

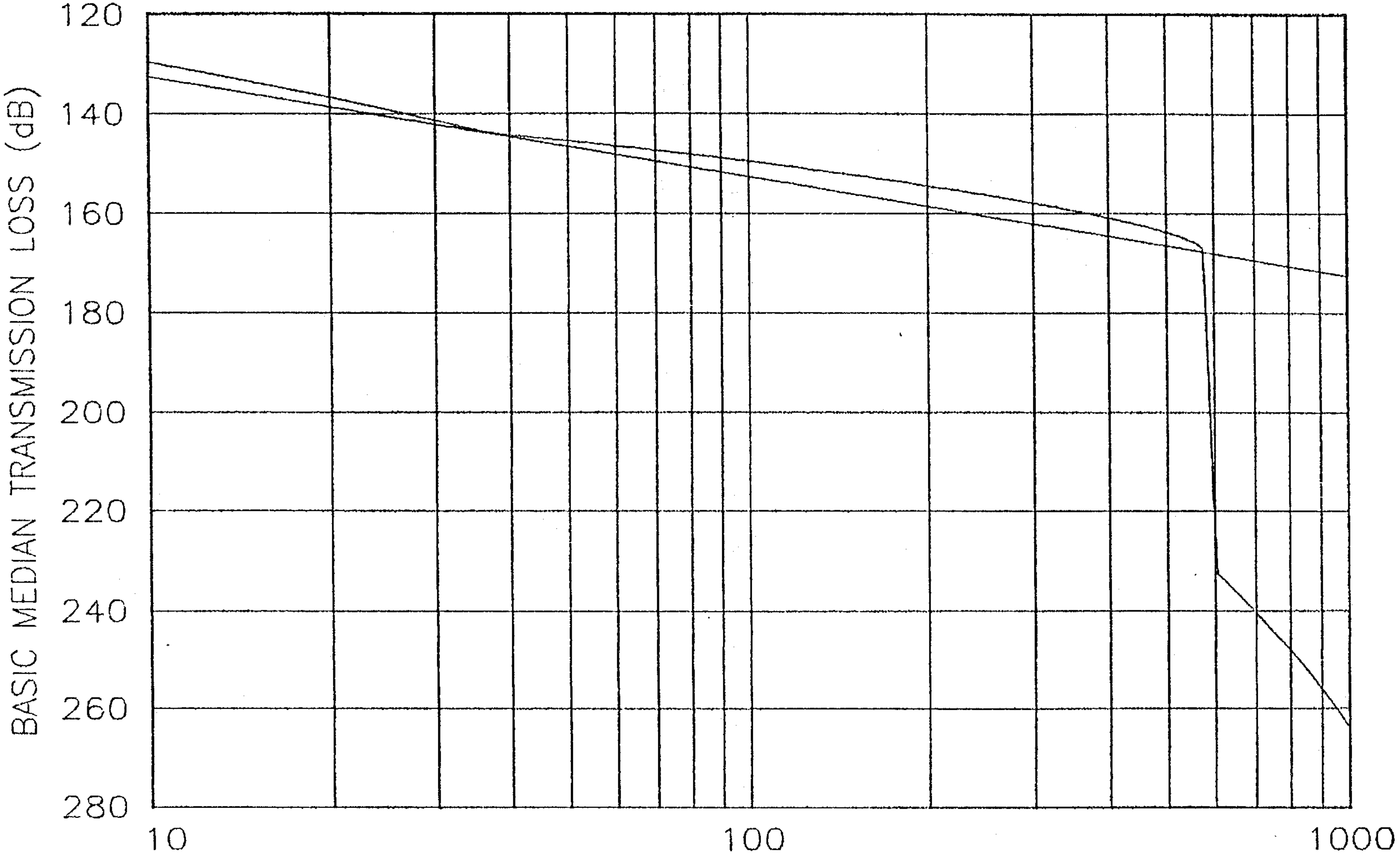

FIGURE A–126. f=10GHz,h_1=5km,h_2=5km,V.P.,Land and Sea Water

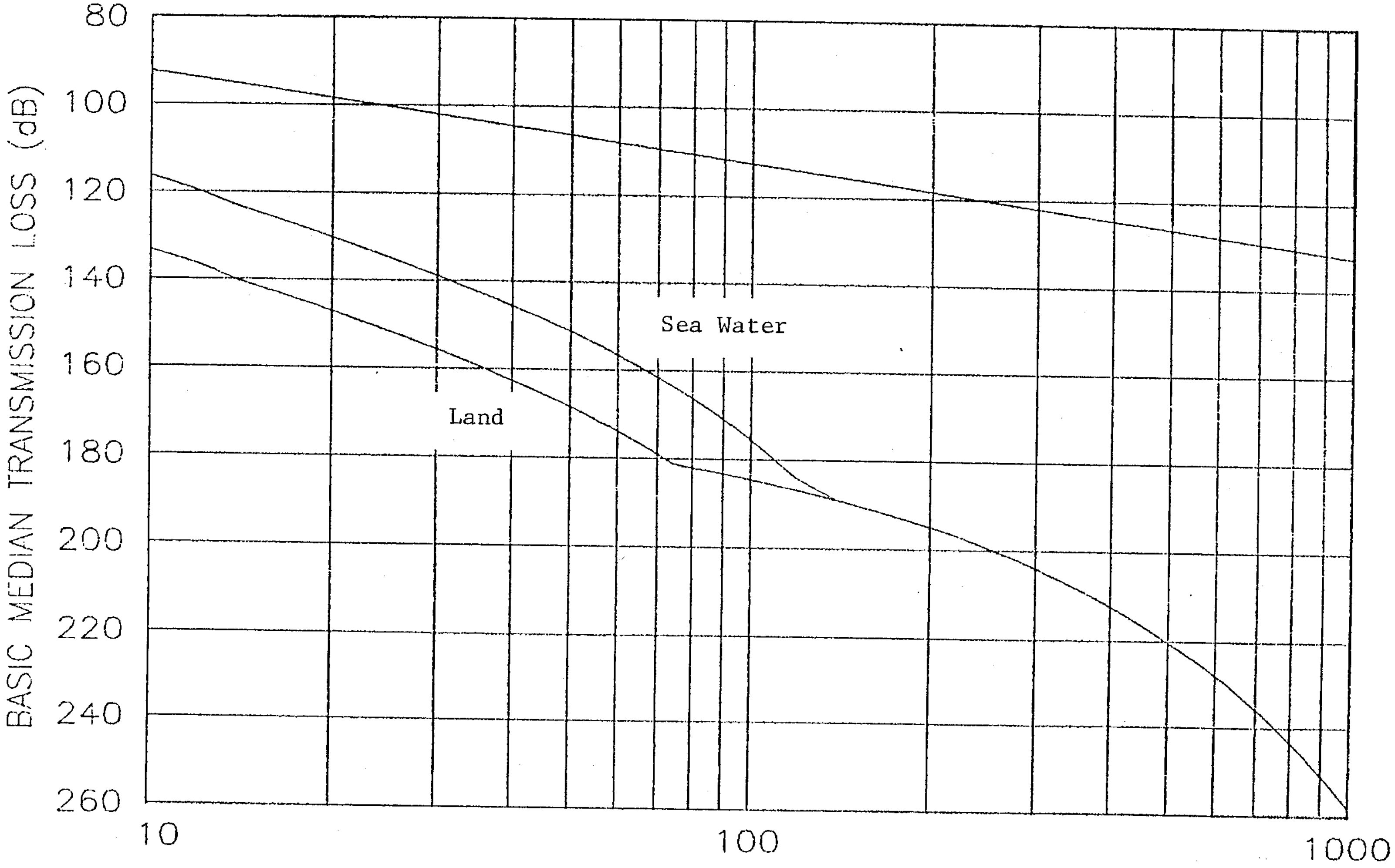

FIGURE A–127. f=100MHz,h_1=1m,h_2=10m,V.P.,Land and Sea Water

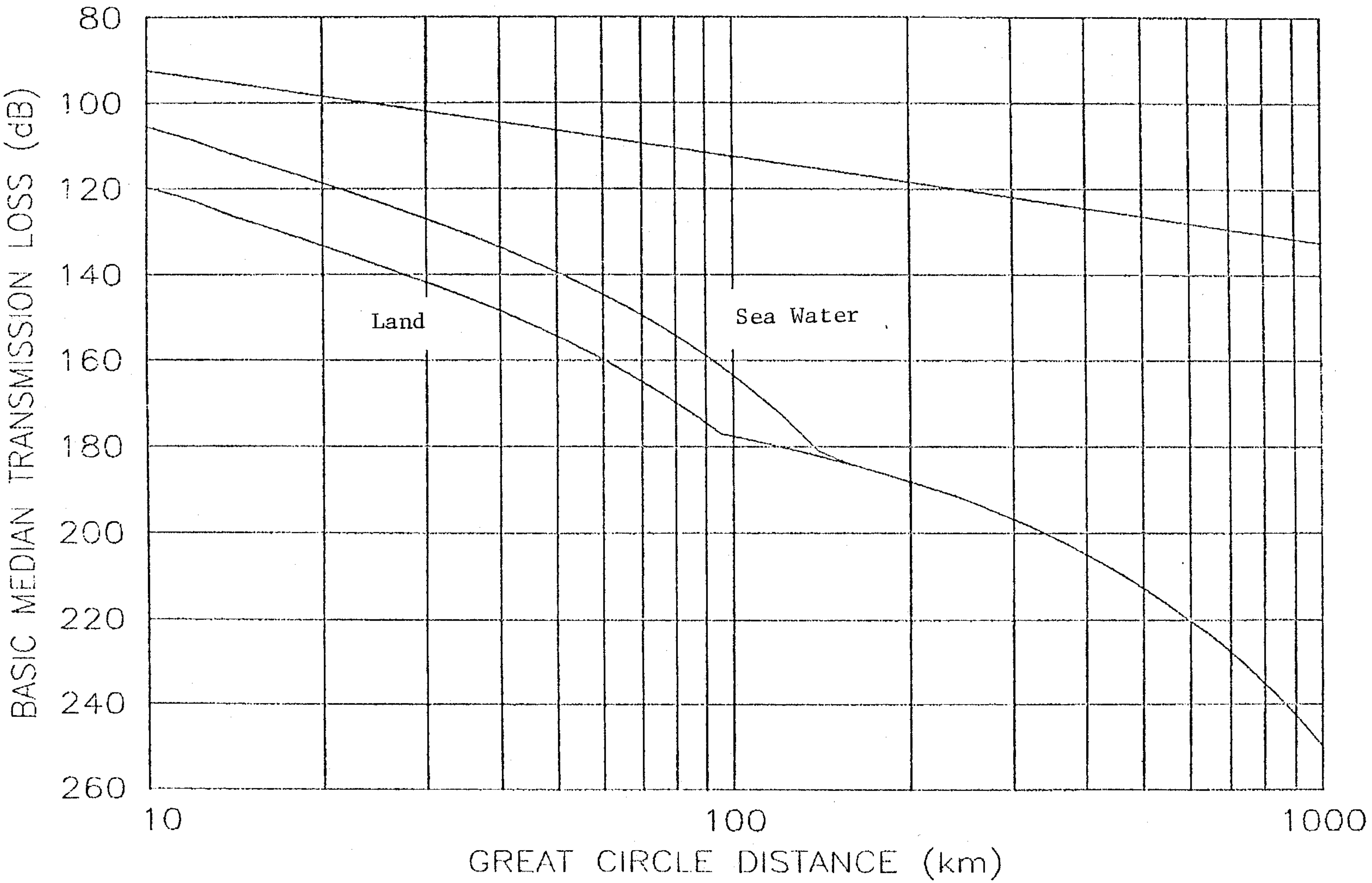

FIGURE A–128. f=100MHz,h_1=1m,h_2=50m,V.P.,Land and Sea Water

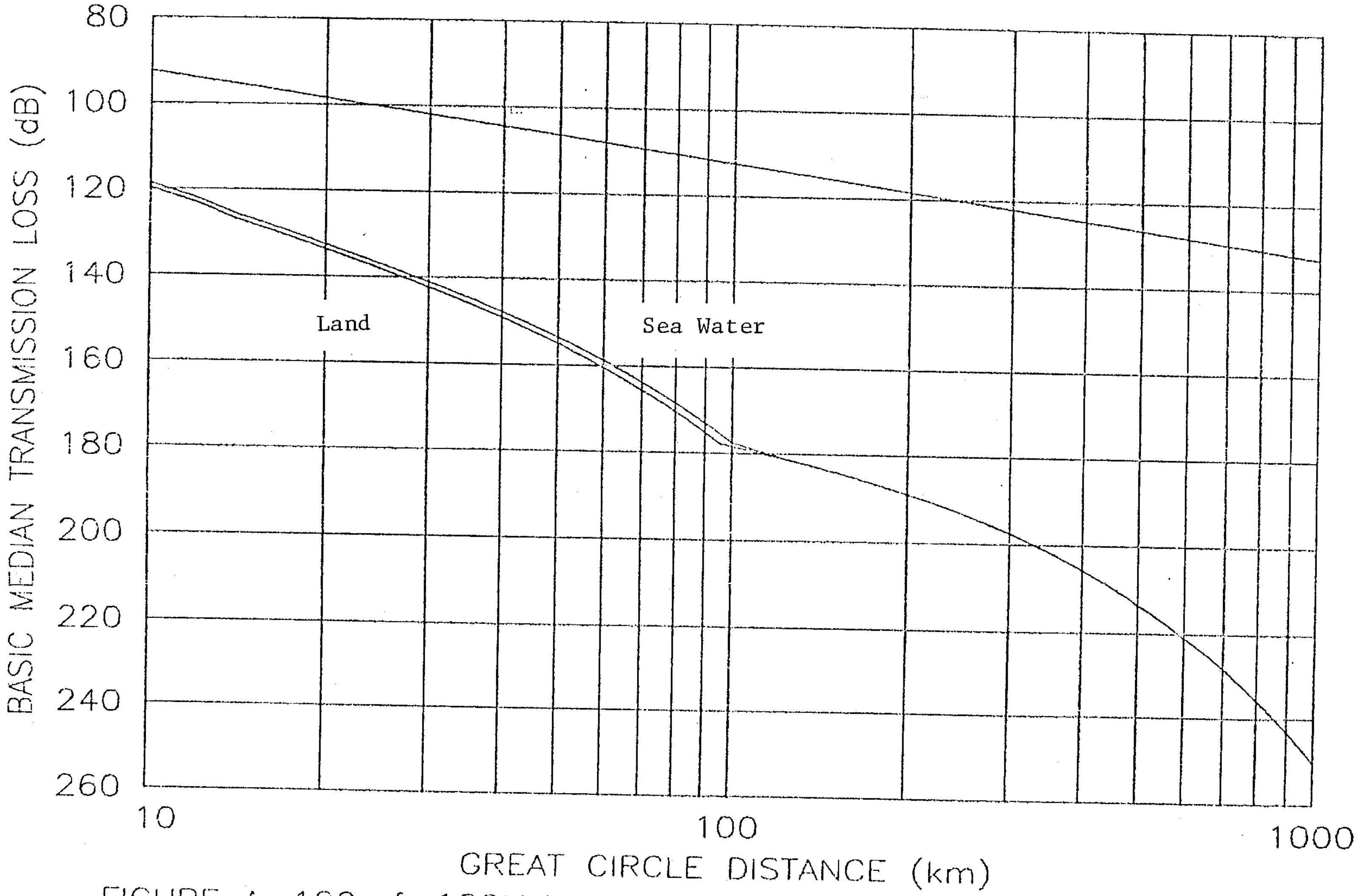

FIGURE A-129. $f=100MHz, h_1=10m, h_2=10m$, V.P., Land and Sea Water

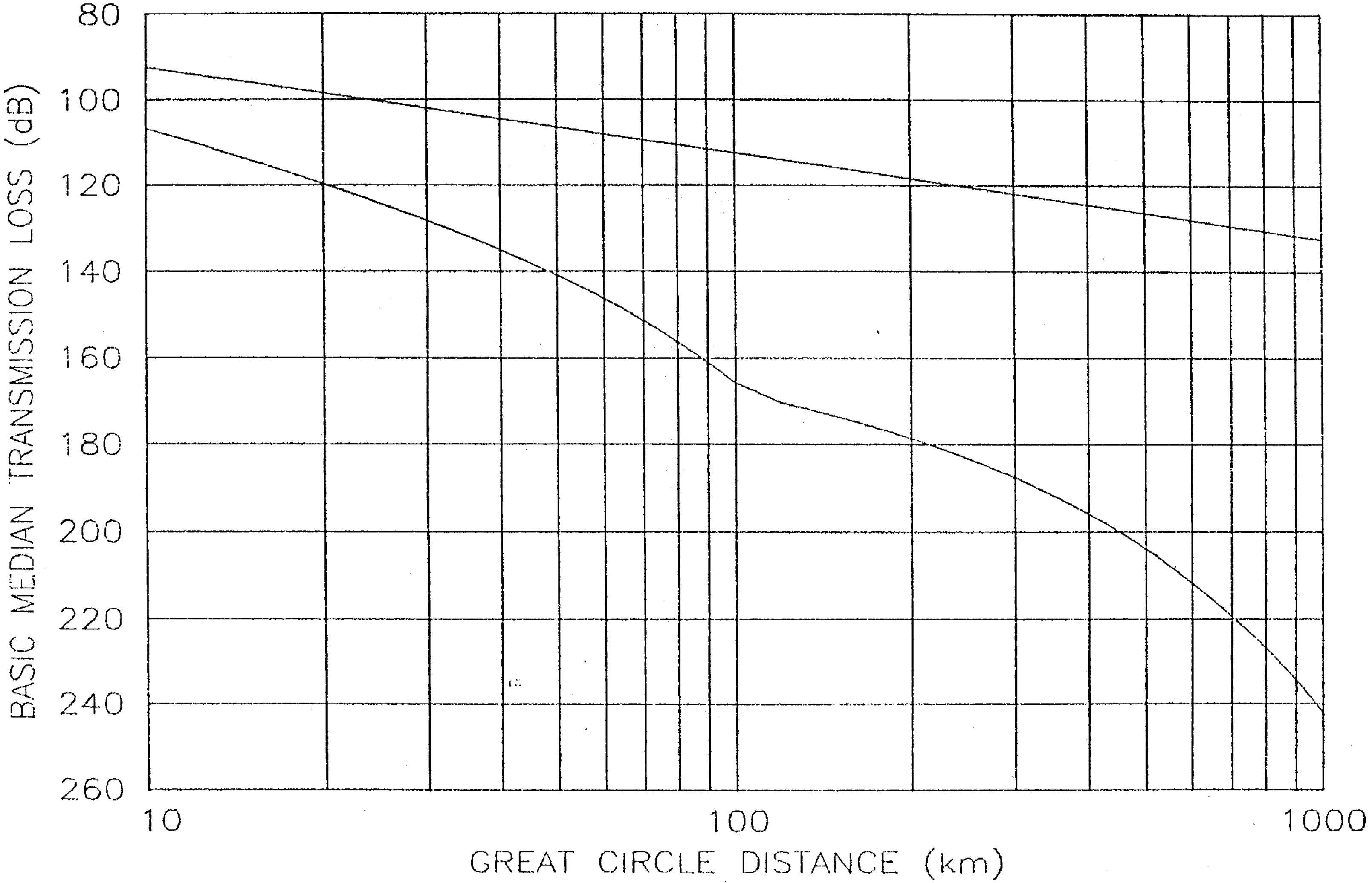

FIGURE A—130. $f=100MHz, h_1=10m, h_2=50m$, V.P., Land and Sea Water

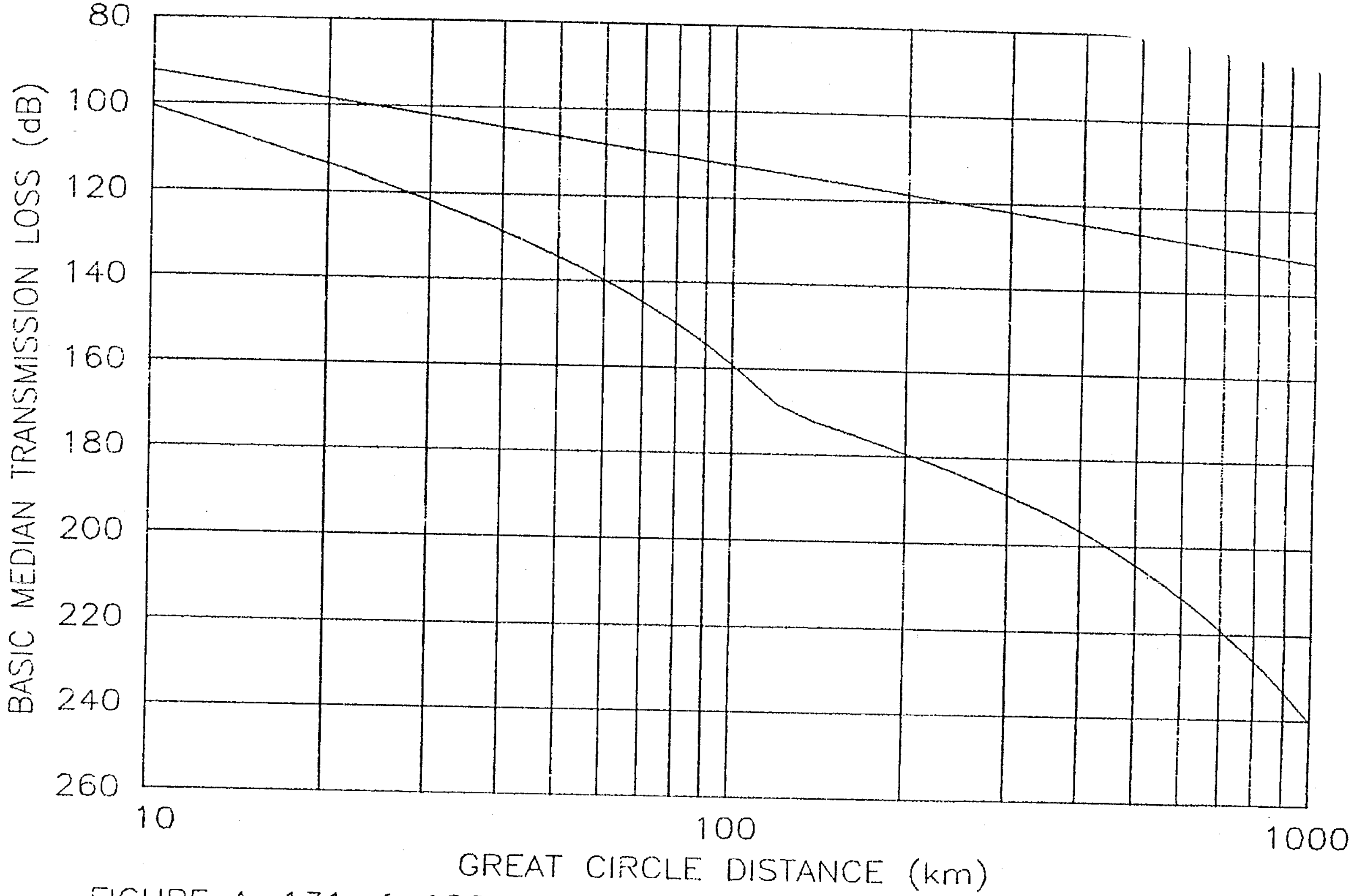

FIGURE A–131. f=100MHz,h_1=10m,h_2=100m,V.P.,Land and Sea Water

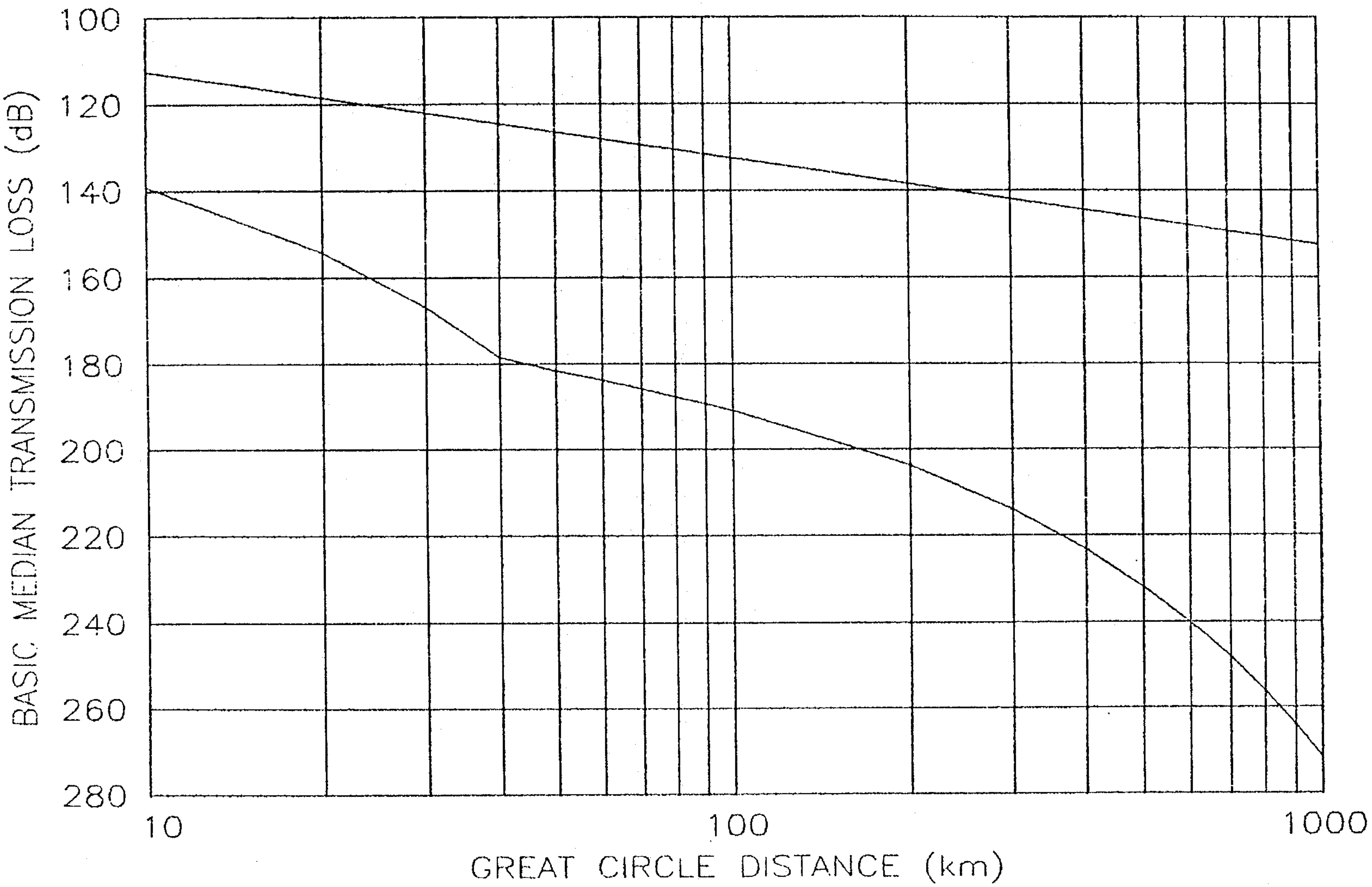

FIGURE A–132. $f=1\text{GHz}, h_1=1\text{m}, h_2=10\text{m}$, V.P., Land and Sea Water

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This handbook is intended to assist in manual analysis techniques that must be used when an automated analysis is not possible. It provides estimates of radio wave propagation loss between transmitting and receiving antennas above the assumed smooth-earth surface that were calculated using the Integrated Propagation System (IPS) computer model. For many cases involving electromagnetic compatibility analysis, the included curves of transmission loss predictions may be used for estimating transmission loss for the desired signal and the undesired signal. These loss values are given in dB as BASIC MEDIAN TRANSMISSION LOSS for antennas with effective heights up to 5000 meters, operating in the 100 to 10,000 MHz frequency range, over land or sea, at great circle earth surface distances up to 1,000 kilometers. This handbook is an initial document that will be supplemented by additional curves to be provided on an ongoing basis.

16. Key Words *(Alphabetical order, separated by semicolons)*

Basic Median Transmission Loss; Electromagnetic Compatibility; Radio Wave Propagation; Transmission Loss

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