9. FORWARD SCATTER

This section gives methods for calculating reference values of long-term median radio transmission loss over paths that extend well beyond the horizon and for combining diffraction and scatter transmission loss estimates where this is appropriate. Empirical estimates of the median values and long-term variability of transmission loss for several climatic regions and periods of time are given in section 10 and annex III.

For long tropospheric paths the propagation mechanism is usually forward scatter, especially during times of day and seasons of the year when ducts and elevated layers are rare. Often, for other periods of time, as scattering becomes more coherent it is more properly called reflection. The examination of transmission loss variation over a particular path during some period for which detailed information about layer heights, tilts, and intensities is available can be very illuminating; see for instance Josephson and Eklund [1958]. Sometimes no distinction can be made between "forward scatter" from a turbulent atmosphere and "incoherent reflections" from patchy elevated layers. The first viewpoint is developed in papers by Pekeris [1947], Booker and Gordon [1950a], Megaw [1950, 1954, 1957], Millington [1958], Staras [1952, 1955], Tao [1957], Troitski [1956, 1957a], Villars and Weisskopf [1955], Voge [1953, 1955], and Wheelon [1957, 1959], while the second viewpoint is emphasized in papers by Beckmann [1957, 1960, 1961a, b], du Castel, Misme, and Voge [1958], Friis, Crawford and Hogg [1957], Starkey, Turner, Badcoe, and Kitchen [1958], and Voge [1956, 1960]. The general prediction methods described here are for the most part consistent with either viewpoint, and agree with long-term median values for all available data. A brief discussion of forward scatter theories is given in annex IV.

The reference value, L_{bsr}, of long-term median basic transmission loss due to forward scatter is

$$L_{bsr} = 30 \log f - 20 \log d + F(\theta d) - F_o + H_o + A_a \quad \text{db} \tag{9.1}$$

For most applications the first three terms of (9.1) are sufficient for calculating L_{bsr}. In (9.1) f is the radio frequency in MHz, and d is the mean sea level arc distance in kilometers. The attenuation function $F(\theta d)$, the scattering efficiency term F_o, and the frequency gain function H_o, are discussed in the following subsections. Atmospheric absorption, A_a, defined by (3.1) and shown on figure 3.6, may be neglected at lower frequencies, but may be more than 2 db over a long path at 1000 MHz, and becomes increasingly important with increasing frequency.

For ground-based scatter links the sea level arc distance, d, and the straight line distance, r_o, between antennas are approximately equal. To estimate transmission loss between the earth and a satellite, where r_o is much greater than d, a term $20 \log(r_o/d)$

should be added to the reference value L_{bsr}. Annex III contains a discussion of transmission loss expected when antenna beams are elevated above the horizon, or directed away from the great circle plane determined by the antenna locations.

The median forward scatter transmission loss, L_{sr}, is the basic transmission loss, L_{bsr}, minus the path antenna gain, G_p. Section 9.4 shows how to estimate the loss in path antenna gain, L_{gp}, when there is a loss in antenna gain due to scatter. Section 9.5 shows how to combine diffraction and scatter losses. Following Arons [1956], the scattering of diffracted fields and the diffraction of scatter fields are ignored.

9.1 The Attenuation Function $F(\theta d)$

The attenuation function $F(\theta d)$ depends upon the most important features of the propagation path and upon the surface refractivity, N_s. The function includes a small empirical adjustment to data available in the frequency range from 100 to 1000 MHz.

For most land-based scatter links figure 9.1 may be used, where $F(\theta d)$ is plotted versus the product θd for $N_s = 400$, 350, 301 and 250. The path distance, d, is in kilometers and the angular distance, θ, in radians. For values of $\theta d \leq 10$ the curves of figure 9.1 are valid for all values of the asymmetry parameter $s = \alpha_o/\beta_o$. For values of θd greater than 10 the curves may be used for values of s from 0.7 to unity. For s greater than 1 use $1/s$ in reading the graph.

For highly asymmetrical paths with $\theta d > 10$, figures III.11 to III.14 of annex III are used to obtain $F(\theta d)$. Annex III also contains analytical functions fitted to the curves $F(\theta d)$ for $0.7 \leq s \leq 1$ for all values of the product θd for $N_s = 301$. A function is also given to adjust these computed values for all values of N_s. Using the analytic functions for $F(\theta d)$ with $N_s = 301$, the reference median basic transmission loss is

For $\theta d \leq 10$:

$$L_{bsr} \cong 135.8 + 30 \log f + 30 \log \theta + 10 \log d + 0.332\, \theta d \qquad (9.2a)$$

For $10 < \theta d \leq 50$:

$$L_{bsr} \cong 129.5 + 30 \log f + 37.5 \log \theta + 17.5 \log d + 0.212\, \theta d \qquad (9.2b)$$

Reference values may be computed in a similar manner for other values of N_s.

The approximations in (9.2) do not make any allowance for the frequency gain function, H_o. For usual cases of transmission at frequencies above 400 MHz the approximations in (9.2) give good results. For the higher frequencies an estimate of atmospheric absorption should be added. For lower frequencies, or lower antenna heights, ground-reflected energy tends to cancel the direct ray and the approximation in (9.2) will underestimate the transmission loss.

9.2 The Frequency Gain Function, H_o

It is assumed that if antennas are sufficiently high, reflection of energy by the ground doubles the power incident on scatterers visible to both antennas, and again doubles the power scattered to the receiver. As the frequency is reduced, effective antenna heights h_{te}/λ and h_{re}/λ in wavelengths become smaller, and ground-reflected energy tends to cancel direct-ray energy at the lower part of the common volume, where scattering efficiency is greatest. The frequency gain function H_o in (9.1) is an estimate of the corresponding increase in transmission loss.

This function first decreases rapidly with increasing distance and then approaches a constant value. For $h_{te}/\lambda > 4\,a/d$ and $h_{re}/\lambda > 4\,a/d$, H_o is negligible. The upper limit of H_o as h_{te} and h_{re} approach zero is $H_o \simeq 6 + A_o$ dB, where A_o is the diffraction attenuation over a smooth earth, relative to free space, at $\theta = 0$. For frequencies up to 10 GHz, A_o may be estimated from the CCIR Atlas of Ground Wave Propagation Curves [1955, 1959]. H_o should rarely exceed 25 dB except for very low antennas.

The frequency gain function, H_o, depends on effective antenna heights in terms of wave lengths, path asymmetry, and the parameter η_s shown on figure 9.2 and defined as

$$\eta_s = 0.5696\, h_o [1 + (0.031 - 2.32\, N_s \times 10^{-3} + 5.67\, N_s^2 \times 10^{-6}) \exp(-3.8\, h_o^6 \times 10^{-6})] \quad (9.3a)$$

$$h_o = s d\,\theta/(1+s)^2 \text{ km.} \quad (9.3b)$$

The parameters r_1 and r_2 are defined as

$$r_1 = 4\pi\theta\, h_{te}/\lambda, \qquad r_2 = 4\pi\theta\, h_{re}/\lambda \quad (9.4a)$$

where θ is the angular distance in radians, and the effective antenna heights h_{te}, h_{re} are in the same units as the radio wave length, λ. In terms of frequency r_1 and r_2 may be written

$$r_1 = 41.92\,\theta f h_{te}, \qquad r_2 = 41.92\,\theta f h_{re} \quad (9.4b)$$

where θ is in radians, f in MHz, and h_{te}, h_{re} are in kilometers.

For the great majority of transhorizon paths, s is within the range $0.7 \le s \le 1$. The effect of very small values of s, with $\alpha_o \ll \beta_o$, may be seen in figures III.15 to III.19, which have been computed for the special case where effective transmitting and receiving antenna heights are equal.

a) For η_s greater than or equal to 1:

Read $H_o(r_1)$ and $H_o(r_2)$ from figure 9.3; then H_o is

$$H_o = [H_o(r_1) + H_o(r_2)]/2 + \Delta H_o \tag{9.5}$$

where

$$\Delta H_o = 6(0.6 - \log \eta_s) \log s \log q.$$

$$s = \alpha_o/\beta_o \qquad q = r_2/sr_1$$

If $\eta_s > 5$ the value of H_o for $\eta_s = 5$ is used. The correction term ΔH_o is zero for $\eta_s = 4$, $s = 1$, or $q = 1$ and reaches a maximum value, $\Delta H_o = 3.6$ db, for highly asymmetrical paths when $\eta_s = 1$. The value of ΔH_o may be computed as shown or read from the nomogram, figure 9.4. A straight line between values of s and q on their respective scales intersects the vertical line marked Ⓘ. This point of intersection when connected by a straight line to the appropriate value of η_s intersects the ΔH_o scale at the desired value.

The following limits should be applied in determining ΔH_o:

If $s \geq 10$ or $q \geq 10$, use $s = 10$ or $q = 10$.

If $s \leq 0.1$ or $q \leq 0.1$, use $s = 0.1$ or $q = 0.1$.

If $\Delta H_o \geq [H_o(r_1) + H_o(r_2)]/2$, use $H_o = H_o(r_1) + H_o(r_2)$.

If ΔH_o would make H_o negative, use $H_o = 0$.

b) For η_s less than 1:

First obtain H_o for $\eta_s = 1$ as described above, then read H_o for $\eta_s = 0$ from figure 9.5. Figure 9.5b shows $H_o(\eta_s = 0)$ for the special case of equal antenna heights. The desired value is found by interpolation:

$$H_o(\eta_s < 1) = H_o(\eta_s = 0) + \eta_s[H_o(\eta_s = 1) - H_o(\eta_s = 0)]. \tag{9.6}$$

The case $\eta_s = 0$ corresponds to the assumption of a constant atmospheric refractive index.

A special case, $h_{te} = h_{re}$, $r_1 = r_2$, occurs frequently in systems design. For this case H_o has been plotted versus r in figures III.15 to III.19 for $\eta_s = 1, 2, 3, 4, 5$ and for $s = 0.1, 0.25, 0.5, 0.75$ and 1. For given values of η_s and s, H_o is read directly from the graphs using linear interpolation. No correction term is required. For $\eta_s < 1$ the value of $H_o(\eta_s = 1)$ is read from figure 9.3 with $r_1 = r_2$ and $H_o(\eta_s = 0)$ is read from figure 9.5 as before.

9.3 The Scattering Efficiency Correction, F_o

The correction term F_o in (9.1) allows for the reduction of scattering efficiency at great heights in the atmosphere:

$$F_o = 1.086(\eta_s/h_o)(h_o - h_1 - h_{Lt} - h_{Lr}) \text{ db} \tag{9.7}$$

where η_s and h_o are defined by (9.3) and h_1 is defined as

$$h_1 = s\,D_s\theta/(1+s)^2, \qquad D_s = d - d_{Lt} - d_{Lr} \tag{9.8}$$

The heights of the horizon obstacles, h_{Lt}, h_{Lr} and the horizon distances d_{Lt}, d_{Lr} are defined in section 6. All heights and distances are expressed in kilometers.

The correction term F_o exceeds 2 decibels only for distances and antenna heights so large that h_o exceeds h_1 by more than 3 kilometers.

9.4 Expected Values of Forward Scatter Multipath Coupling Loss

Methods for calculating expected values of forward scatter multipath coupling loss are given in several papers, by Rice and Daniel [1955], Booker and de Bettencourt [1955], Staras [1957], and Hartman and Wilkerson [1959]. This report uses the most general method available based on the paper by Hartman and Wilkerson [1959].

As explained in section 2, the path antenna gain is

$$G_p = G_t + G_r - L_{gp} \quad \text{db} \tag{9.9}$$

where G_t and G_r are free space antenna gains in decibels relative to an isotropic radiator. The influence of antenna and propagation path characteristics in determining the loss in path antenna gain or multipath coupling loss L_{gp} are interdependent and cannot be considered separately.

This section shows how to estimate only that component of the loss in path antenna gain which is due to phase incoherence of the forward scattered fields. This quantity is readily approximated from figure 9.6 as a function of η_s, defined by (9.3), and the ratio θ/Ω, where $\Omega = 2\delta$ is the effective half-power antenna beamwidth. If the antenna beamwidths are equal, $\Omega_t = \Omega_r$, and if $s = 1$, values of L_{gp} from figure 9.6 are exact. When antenna beamwidths are not equal the loss in gain may be approximated using $\Omega = \sqrt{\Omega_t \Omega_r}$.

The relation between the free-space antenna gain G in decibels relative to an isotropic radiator and the half power beamwidth $\Omega = 2\delta$ was given by (2.5) as:

$$G = 3.50 - 20 \log \delta = 9.52 - 20 \log \Omega \quad \text{db}$$

where δ and Ω are in radians.

Assuming 56% aperture efficiencies for both antennas,

$$\theta/\Omega \cong \theta(\Omega_t \Omega_r)^{-1/2} \cong 0.335\theta \exp\left[0.0576\,(G_t + G_r)\right] \tag{9.10}$$

where θ is the angular distance in radians and G_t, G_r are the free space gains in decibels.

Section 2 shows that the gain for parabolic dishes with 56% aperture efficiency may be computed as (2.7):

$$G = 20 \log D + 20 \log f - 42.10 \quad \text{db}$$

where D is the diameter of the dish in meters and f is the frequency in MHz.

For dipole-fed parabolic antennas where $10 < D/\lambda < 25$, an empirical correction gives the following equation for the antenna gain (2.8):

$$G = 23.3 \log D + 23.3 \log f - 55.1 \quad \text{db.}$$

The general method for calculating L_{gp} requires the following parameters:

$$\nu = \eta_s/2, \quad \mu = \delta_r/\delta_t \tag{9.11}$$

$$\text{For } s\mu \geq 1, \ n = \alpha_o/\delta_t. \quad \text{For } s\mu \leq 1, \ n = \beta_o/\delta_r \tag{9.12a}$$

$$\hat{n} = (n + 0.03\nu)/f(\nu) \tag{9.12b}$$

$$f(\nu) = [1.36 + 0.116\nu]\,[1 + 0.36\,\exp(-0.56\nu)]^{-1} \tag{9.13}$$

where η_s, s, α_o and β_o have been defined, δ_t and δ_r are the effective half-power semi-beamwidths of the transmitting and receiving antennas, respectively, and $f(\nu)$ as defined by (9.13) is shown on figure 9.7.

Figure 9.8 shows L_{gp} versus $\hat{n}$ for various values of the product $s\mu$. For $s\mu < 1$ read figure 9.8 for $1/(s\mu)$ instead of $s\mu$.

9.5 Combination of Diffraction and Scatter Transmission Loss

For transmission paths extending only very slightly beyond line-of-sight, diffraction will be the dominant mechanism in most cases and scattering may be neglected. Conversely, for long paths, the diffracted field may be hundreds of decibels weaker than the scattered field, and thus the diffraction mechanism can be neglected. In intermediate cases, both mechanisms have to be considered and the results combined in the following manner:

Figure 9.9 shows a function, $R(0.5)$, which depends on the difference between the diffraction and scatter transmission loss. Calculate this difference $(L_{dr} - L_{sr})$ in decibels, determine $R(0.5)$ from figure 9.9 and then determine the resulting reference value of hourly median transmission loss, L_{cr}, from the relation

$$L_{cr} = L_{dr} - R(0.5). \tag{9.14}$$

If the difference between the diffracted and the scattered transmission loss values exceeds 15 dB, the resulting value of L_{cr} will be equal to L_{dr} if it is smaller than L_{sr}, or to L_{sr} if this is the smaller value. In general, for most paths having an angular distance greater than 0.02 radians the diffraction calculations may be omitted; in this case, $L_{cr} = L_{sr}$.

9.6 An Example of Transmission Loss Predictions for a Transhorizon Path

Predicted forward scatter and diffraction losses are computed for a 283 km path from Dallas to Austin, Texas. The prediction is compared with measurements at a frequency of 104.5 MHz. Figure 9.10 shows the great circle profile of this path, obtained by the methods of section 6, plotted on a linear scale with allowance for the sea level curvature. The vertical scale in the figure is much exaggerated to show some of the detail of terrain.

The effective earth's radius is determined as described in section 4. From figure 4.1 minimum monthly values of N_o are read at approximate horizon locations. Appropriate terrain heights are used in (4.3) to compute horizon values of N_s, whose average is N_s = 306. From (4.4) the effective earth's radius is then 8580 km.

A reference value, L_{cr}, of basic transmission loss, which corresponds to winter afternoon conditions, is computed as shown below. For each parameter the appropriate equation or figure is referenced.

Path: Dallas to Austin, Texas

d = 283.1 km, f = 104.5 MHz, N_s = 306, a = 8580 km

Parameter	Transmitter	Receiver	Reference
h_{ts}, h_{rs}	280.4 m	243.9 m	figure 9.10
h_{te}, h_{re}	135.0 m	9.8 m	(6.11) and (6.12)
h_{Lt}, h_{Lr}	219.5 m	274.3 m	figure 9.10
d_{Lt}, d_{Lr}	39.6 km	8.8 km	figure 9.10
θ_{et}, θ_{er}	-3.845 mr	+2.933 mr	(6.15)
α_{oo}, β_{oo}	12.777 mr	19.296 mr	(6.18)
θ_{ot}, θ_{or}	0.768 mr	3.961 mr	(6.16)
d_{st}, d_{sr}	130.72 km	103.95 km	(6.20)
$\Delta\alpha_o$, $\Delta\beta_o$	0.057 mr	0.021 mr	figure 6.9
α_o, β_o	12.834 mr	19.317 mr	(6.19)

The angular distance θ = 32.151 mr = 0.032151 radians and the product θd is 9.10. The ratio of α_o/β_o = s = 0.664. Then the function $F(\theta d)$ from figure 9.1 or figures III.12 and III.13 is $F(\theta d)$ = 167.0 db. From (9.3) the height h_o = 2.18 km, and η_s = 1.06. From (9.4) and figure 9.3 the parameters r_1 = 19.01, $H_o(r_1)$ = 0.15 db, r_2 = 1.38, and $H_o(r_2)$ = 13.5 db. From figure 9.4 and (9.5) ΔH_o = 0.61 and H_o = 7.40 db. The correction term F_o defined by (9.7) is negligible. Figure 3.6 shows that the allowance for absorption $A_a \simeq 0.01$ db.

The reference value L_{bsr} of long-term median basic transmission loss due to forward scatter given by (9.1) is then

$30 \log f = 60.573$

$20 \log d = 49.038$

$F(\theta d) = 167.0$ figure 9.1

$F_o = 0$ (9.7)

$H_o = 7.40$ (9.5)

$A_a = 0.01$ figure 3.6

and $L_{bsr} = 186$ db.

Although this is almost certainly a scatter path, the diffraction loss for a transhorizon path is computed as an example. For horizontal polarization over average ground figures 8.1 and 8.2 show $K(a = 8497) = 0.001$ and $b = 93^o$. The following additional parameters are computed:

				Reference
$a_1 = 5808$ km,	$a_2 = 3951$ km,	$a_t = 9179$ km,	$a_r = 5804$	(8.8) and (8.9)
$C_{o1} = 1.135$	$C_{o2} = 1.291$	$C_{ot} = 0.975$	$C_{or} = 1.136$	(8.13)
$K_1 = 0.001135$	$K_2 = 0.001291$	$K_t = 0.000975$	$K_r = 0.001136$	(8.13)
$B_1 = 1.6059$	$B_2 = 1.6058$	$B_t = 1.6062$	$B_r = 1.6059$	figure 8.3
$C_1(K_1) = 20.03$	$C_1(K_2) = 20.03$	$\overline{C}_1(K_{1,2}) = 20.03$		figure 8.4
$x_1 = 385.85$	$x_2 = 112.25$	$x_o = 2452.37$		(8.12) and (8.13)
$F(x_1) = -11.0$	$F(x_2) = -34.5$			figure 8.6
		$G(x_o) = 107.14$		(8.4)

Then from (8.10) the attenuation relative to free space $A = 132.61 + A_a = 132.62$ db. The free space loss (2.16) is $L_{bf} = 121.87$ db and the long-term median median transmission loss due to diffraction $L_{bd} = 254.5$ db. As expected this is much more than the predicted scatter loss and the long-term reference value $L_{cr} = L_{bsr} = 186$ dB.

Long-term variability of hourly median basic transmission loss over this path may be computed using the methods described in section 10. An "effective" distance, d_e, is computed using (10.3). The appropriate value of $V(0.5, d_e)$ is read from figure III.32 of annex III, and subtracted from L_{cr} to obtain the long-term median transmission loss. Variability about the median is then determined as a function $Y(q, d_e)$. The effective distance d_e is computed using (10.1), (10.2) and (10.3b), $d_{s1} = 64.0$ km, $d_L = 62.6$ km, and $d_e = 286.4$ km. From figures 10.14, 10.15, III.32 and from (10.6) the following parameters are:

Parameter	Summer	Winter	All Hours	Reference
$V(0.5, d_e)$	5.0	1.0	3.0	figure III.32
$Y(0.1, d_e, 100$ MHz)	7.75	7.05	7.75	figure 10.14
$Y(0.9, d_e, 100$ MHz)	-6.35	-6.35	-6.35	figure 10.14
$g(0.1, f)$	1.055	1.055	1.055	figure 10.15
$g(0.9, f)$	1.055	1.055	1.055	figure 10.15
$Y(0.1)$	8.18	7.44	8.18	(10.6)
$Y(0.9)$	-6.70	-6.70	-6.70	(10.6)

Using the reference value L_{cr} = 186 db and the ratios given in (10.7) the predicted cumulative distributions for summer, winter and all hours are tabulated below:

		$L_b(q)$ in db	
q	Summer	Winter	All Hours
0.0001	153.8	160.2	155.8
0.001	158.7	164.7	160.7
0.01	164.6	170.1	166.6
0.1	172.8	177.6	174.8
0.5	181.0	185.0	183.0
0.9	187.7	191.7	189.7
0.99	193.2	197.2	195.2
0.999	197.1	201.1	199.1
0.9999	200.4	204.4	202.4

These cumulative distributions are shown graphically on figure 9.11 together with distributions derived from measurements over the path. The data represent more than 23,000 hourly medians from measurements over a period of more than 3 years. The arrows on the curves at 0.001 indicate that losses were less than the values plotted while those at 0.99 and 0.999 indicate that the losses were greater than the values plotted,

An example may be included here of the method of mixing distributions described in subsection III.7.2. The summer and winter distributions of data may be mixed in order to obtain the distribution of hourly median values for all hours. Several levels of transmission loss from 165 to 195 db are chosen and the value q is read from figure 9.11 for each distribution. A weighted average is then obtained at each level to provide the mixed distribution of data corresponding to all hours. The weights are the number of hours of data in each case and the weighted average is $\frac{1}{23,294}(\underset{\text{winter}}{q} \times 12,160 + \underset{\text{summer}}{q} \times 11,134)$.

Level	q_{winter}	q_{summer}	Average q (all hours)
165	<0.0005	0.017	0.0084
170	0.021	0.105	0.061
175	0.083	0.292	0.183
180	0.242	0.590	0.408
185	0.50	0.883	0.683
190	0.86	0.987	0.921
195	<0.9975		>0.9985

The weighted averages of q are plotted on figure 9.11 at each of these levels of transmission loss and show very good agreement with the distribution obtained directly from the data.

THE ATTENUATION FUNCTION, F(θd)
d IS IN KILOMETERS AND θ IS IN RADIANS
(0.75 ≤ S ≤ 1)

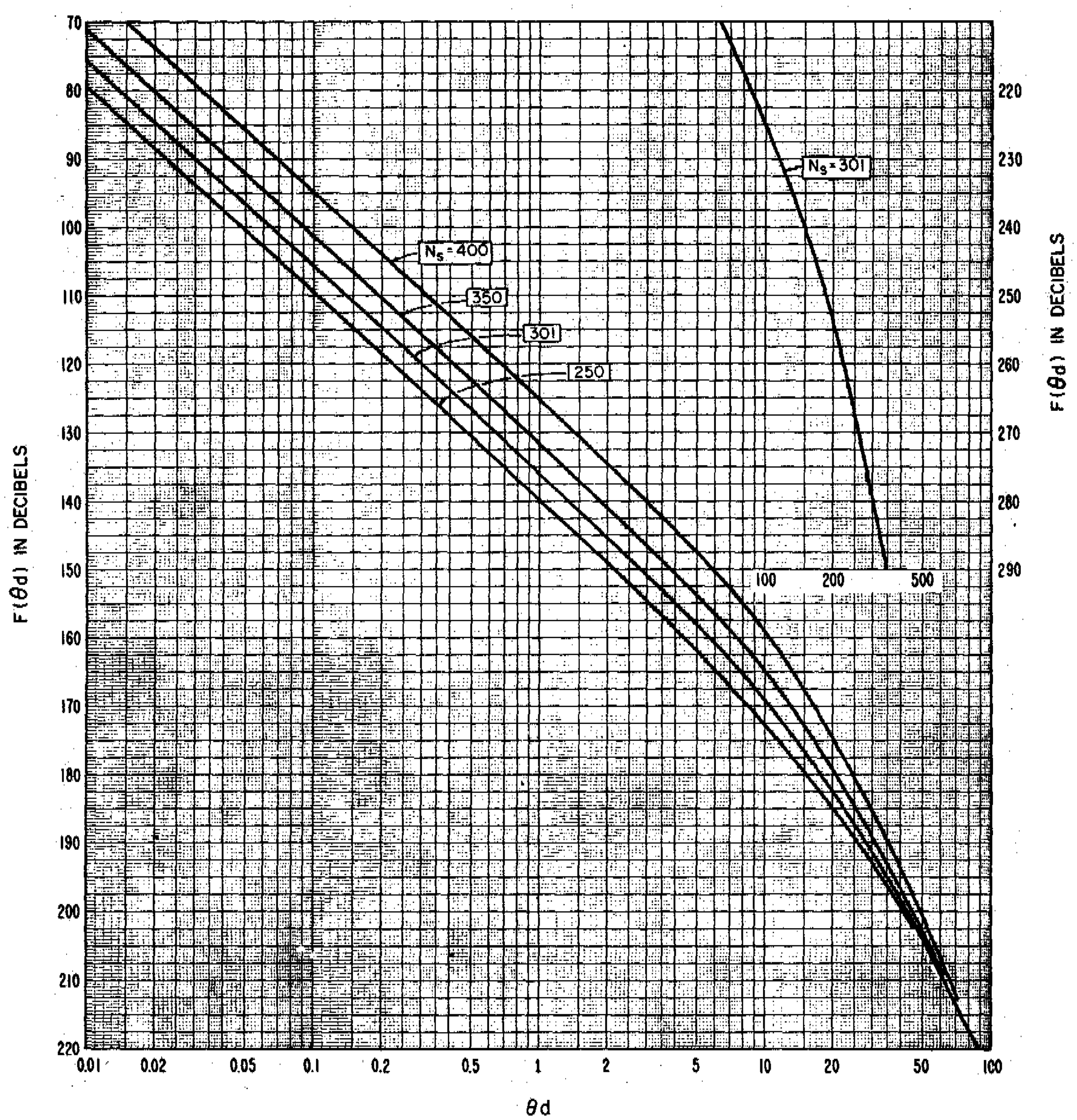

Figure 9.1

THE PARAMETER $\eta_s(h_o)$, USED TO COMPUTE H_o

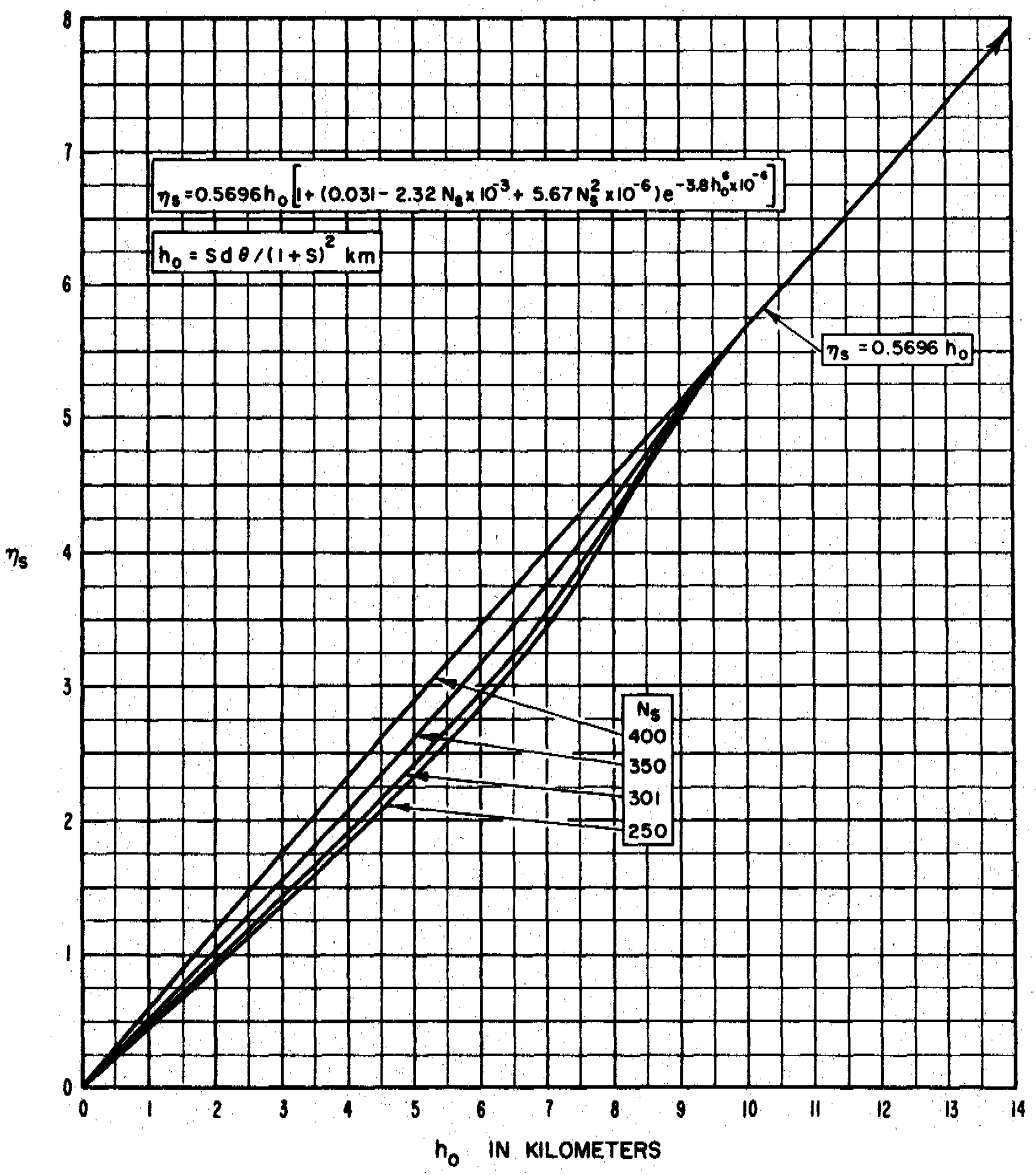

Figure 9.2

THE FREQUENCY GAIN FUNCTION, H_o

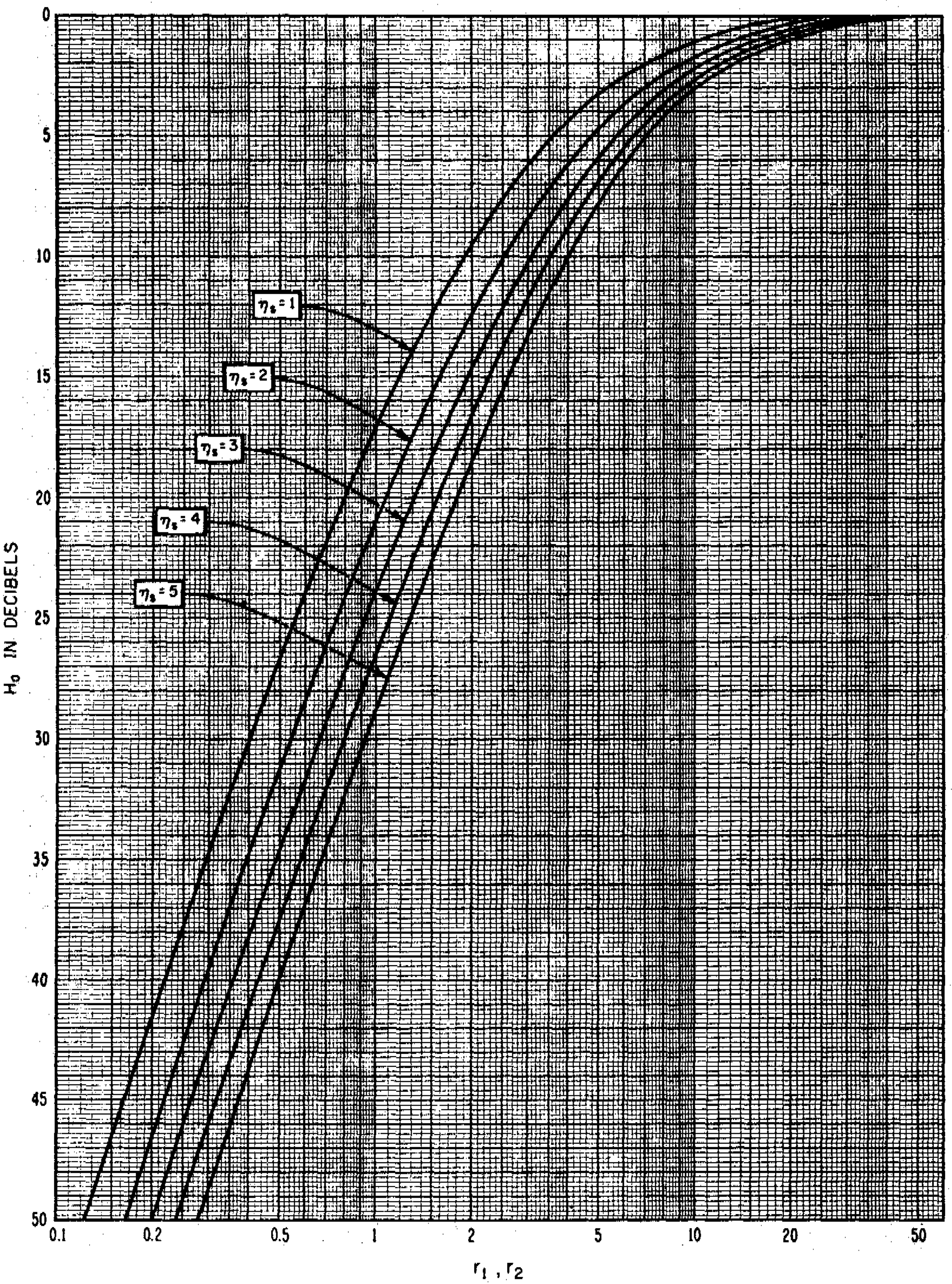

Figure 9.3

NOMOGRAM TO DETERMINE ΔH_o

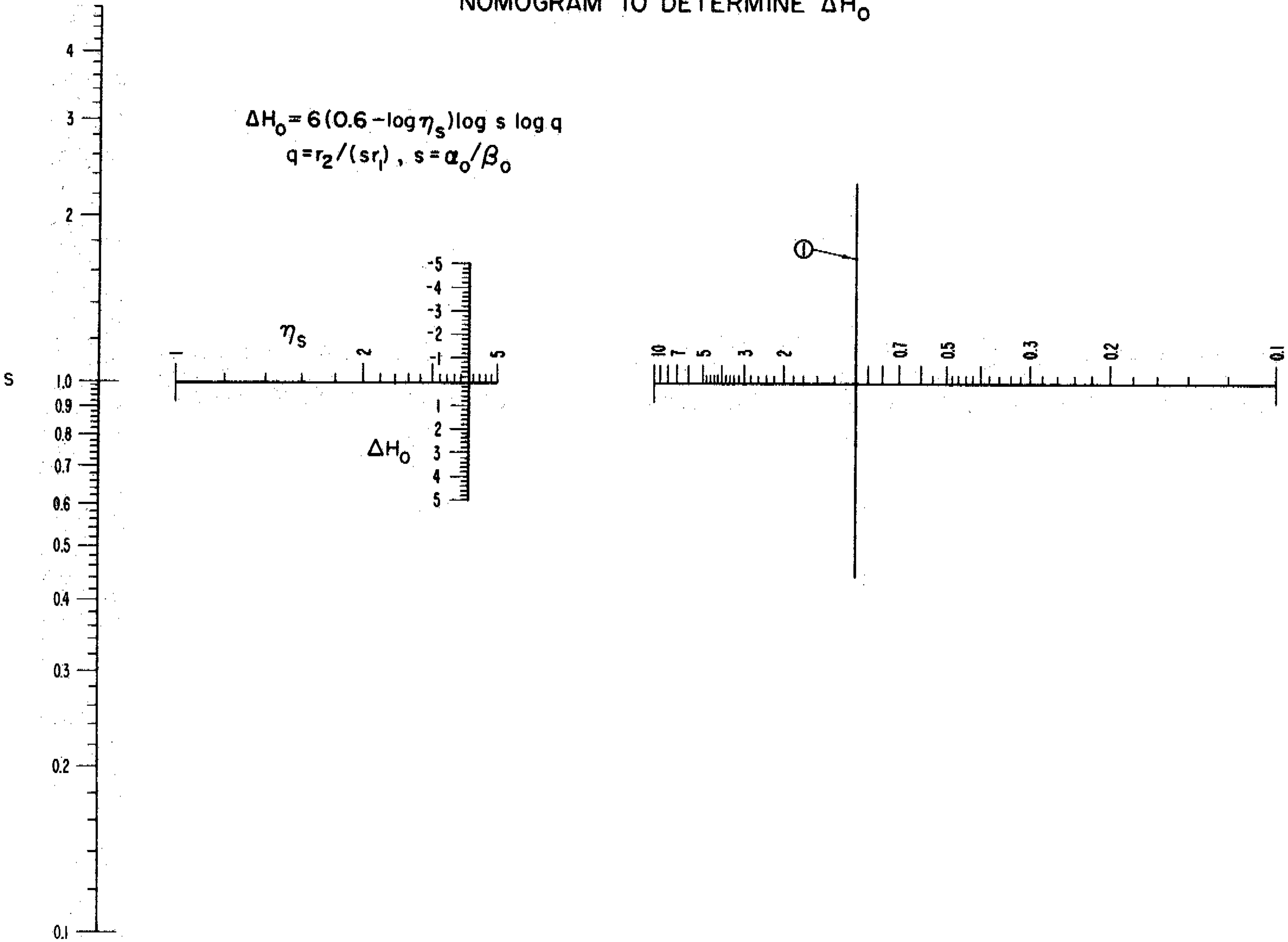

Figure 9.4

THE PARAMETER H_o FOR $\eta_s = 0$

$(0.7 \le S \le 1)$

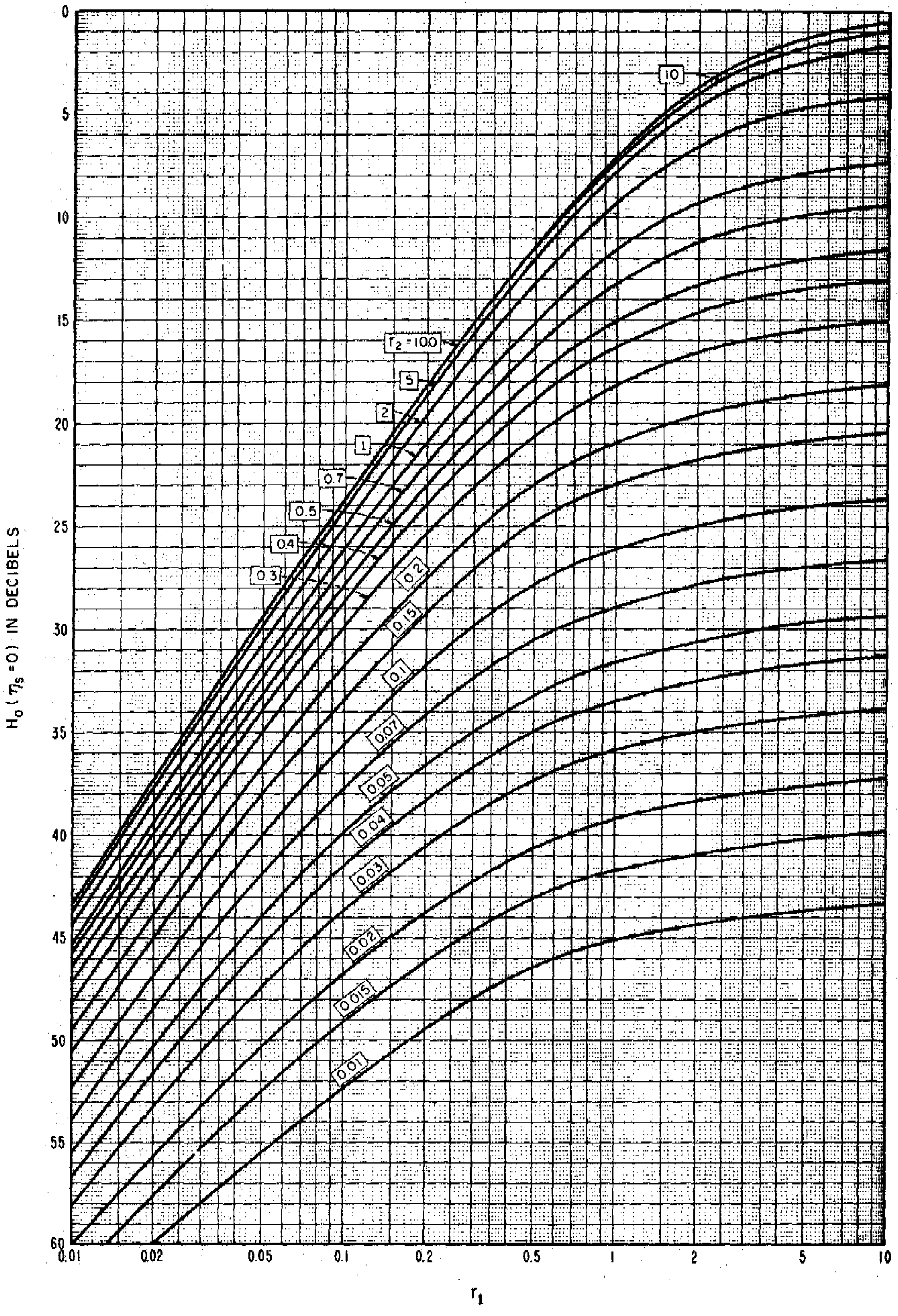

Figure 9.5a

THE PARAMETER H FOR $\eta_s = 0$ AND $h_{te} = h_{re}$

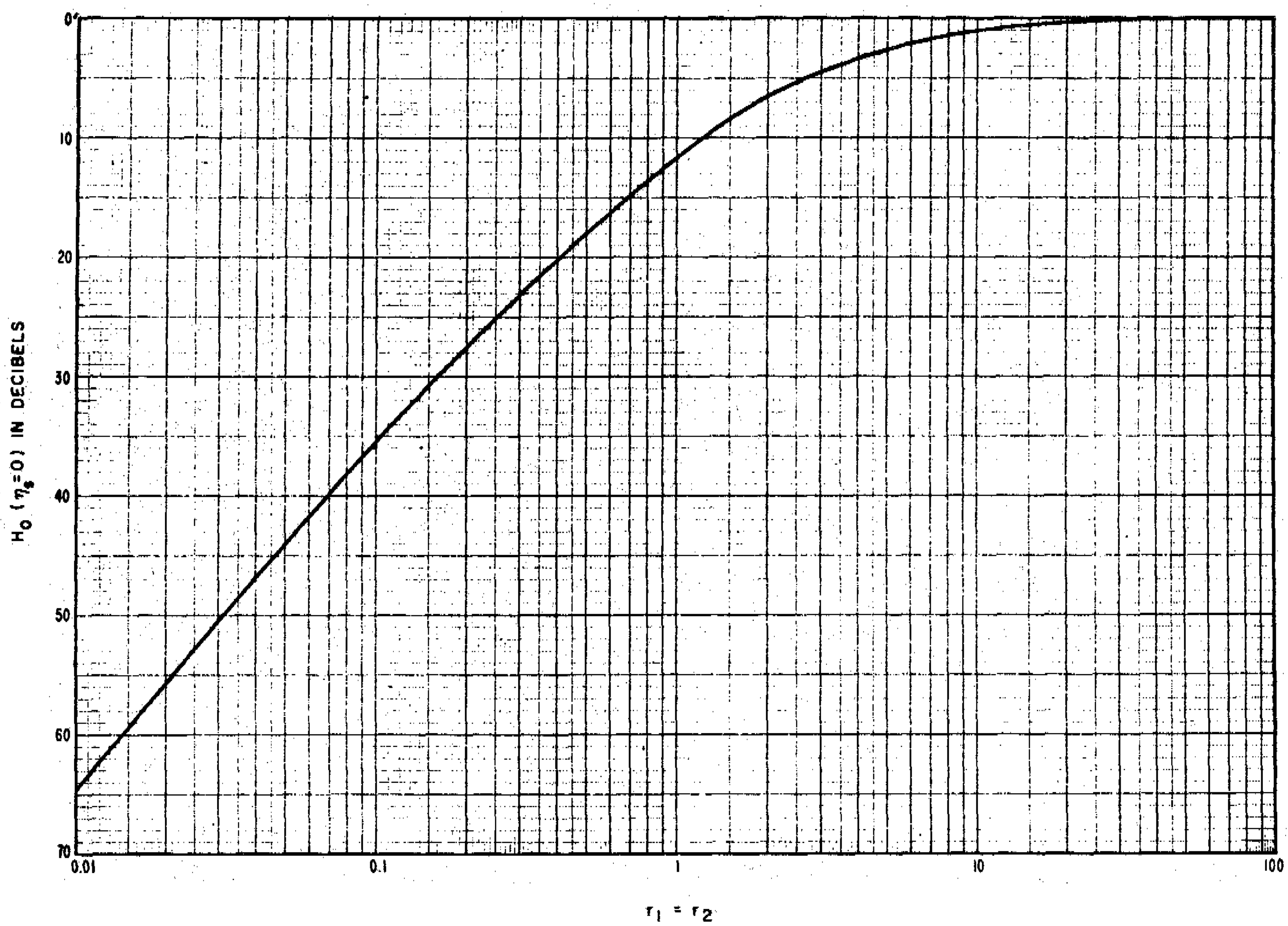

Figure 9.5b

LOSS IN ANTENNA GAIN, L_{gp}
assuming equal free space gains G_t and G_r
at the terminals of a symmetrical path

$\Omega_t = \Omega_r$, s=1

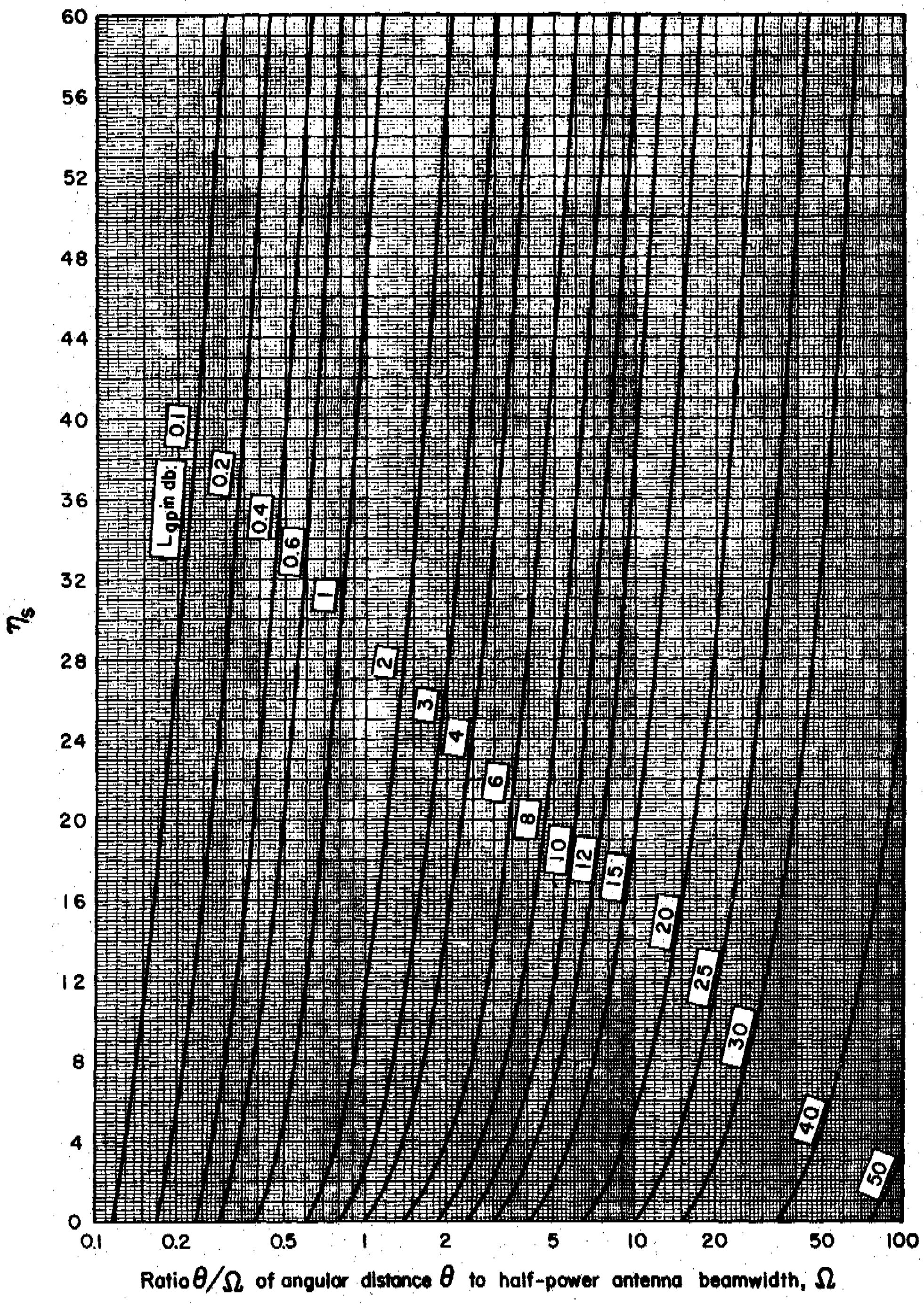

Figure 9.6

THE CONTRACTION FACTOR $f(\nu)$

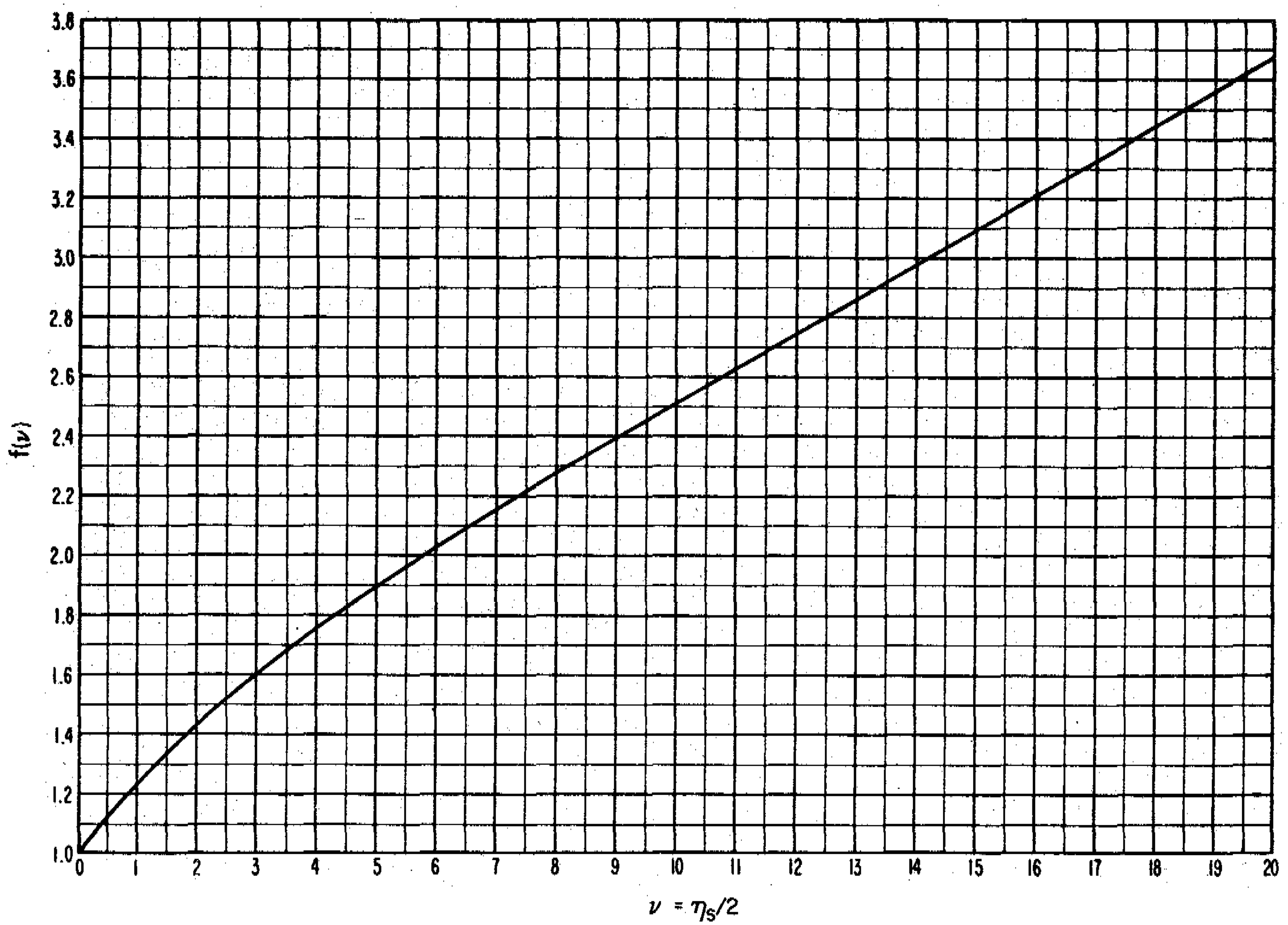

Figure 9.7

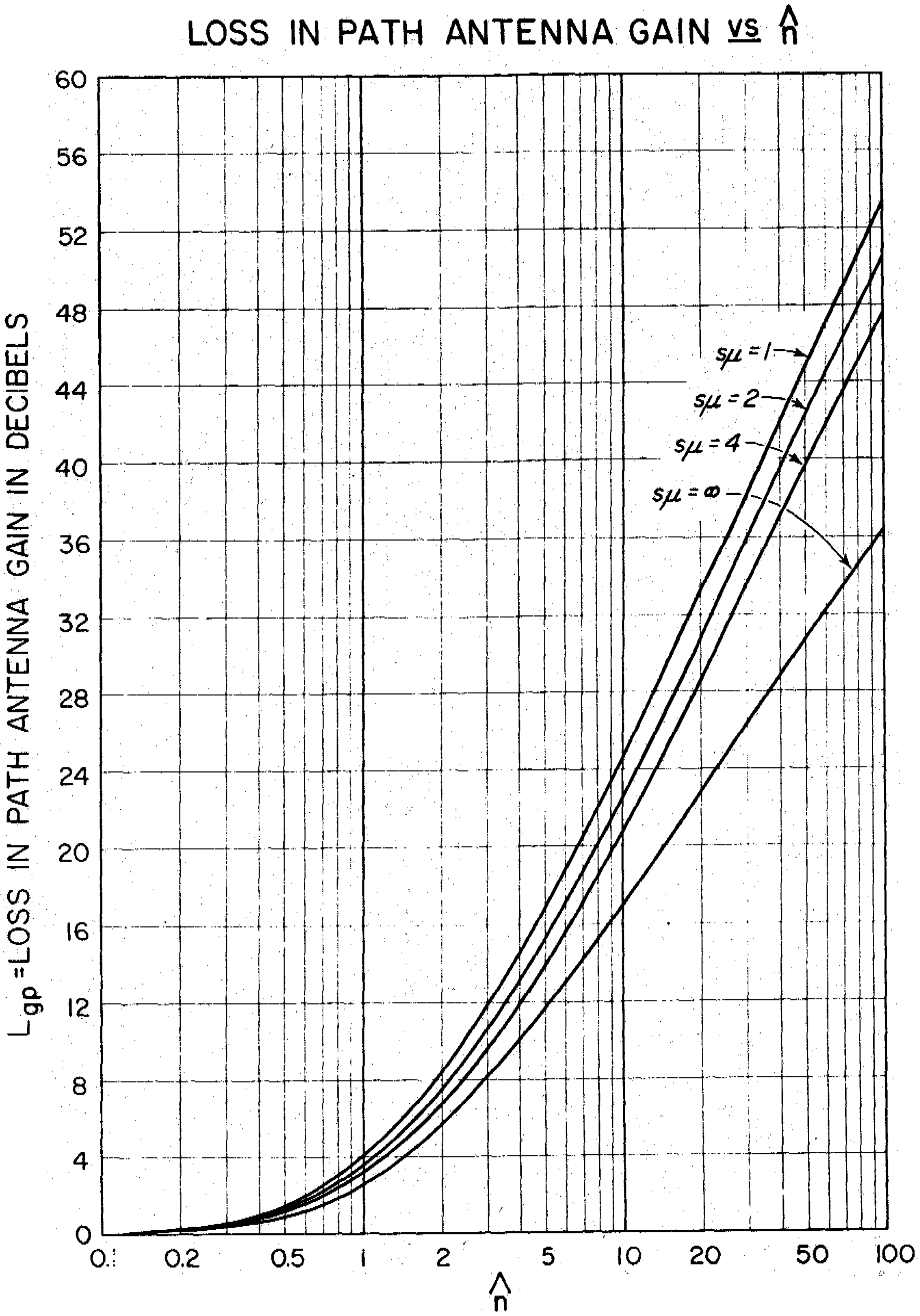
LOSS IN PATH ANTENNA GAIN vs $\hat{n}$
L_{gp} = LOSS IN PATH ANTENNA GAIN IN DECIBELS
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
0.1
0.2
0.5
1
2
5
10
20
50
100
$\hat{n}$
$s\mu = 1$
$s\mu = 2$
$s\mu = 4$
$s\mu = \infty$

Figure 9.8

THE MEDIAN, $R_{0.5}$, FROM THE CUMULATIVE DISTRIBUTION OF THE RESULTANT AMPLITUDE OF A CONSTANT DIFFRACTED FIELD PLUS A RAYLEIGH DISTRIBUTED SCATTERED FIELD

$$L_{cr} = L_{dr} - R(0.5)$$

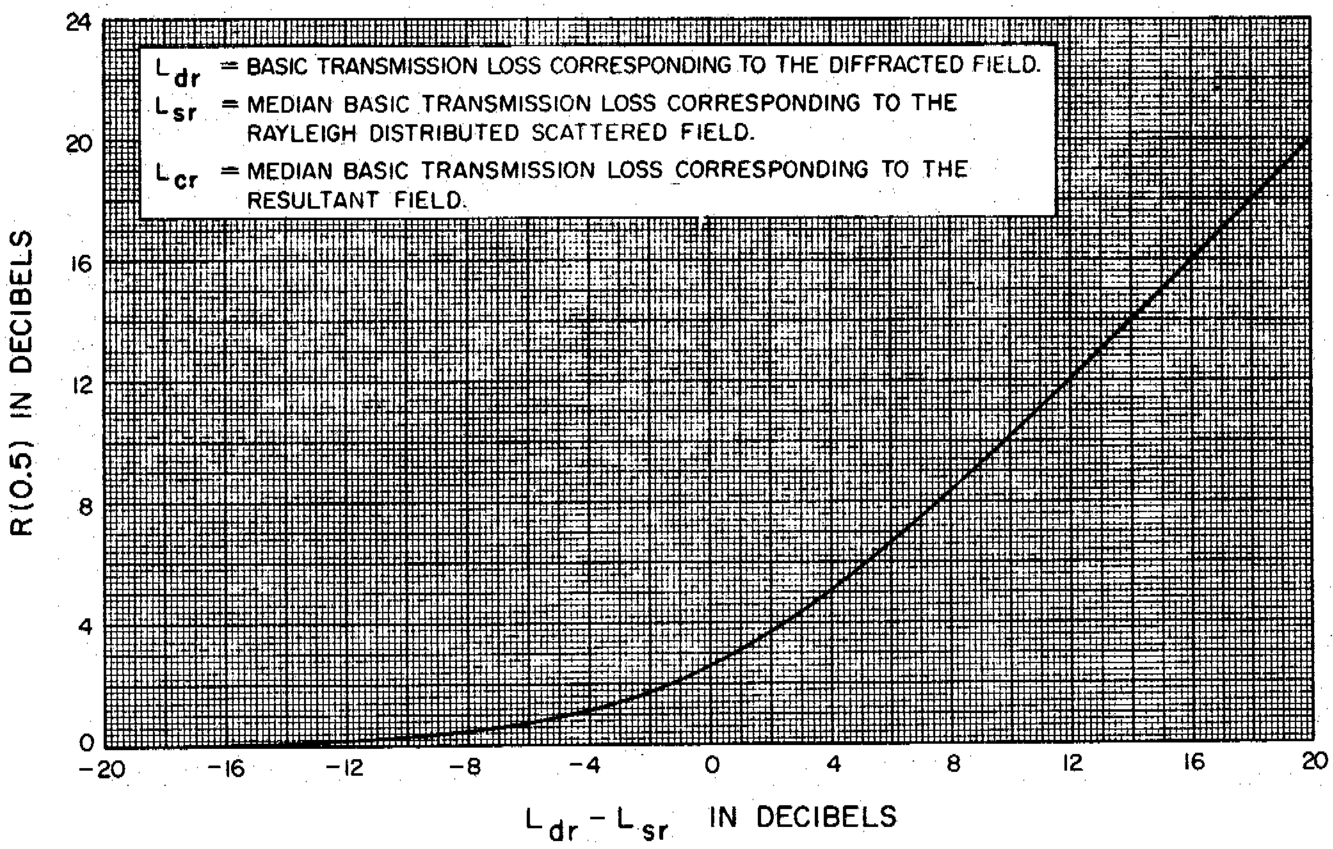

Figure 9.9

PROFILE OF A TRANSHORIZON PATH
DALLAS TO AUSTIN, TEXAS

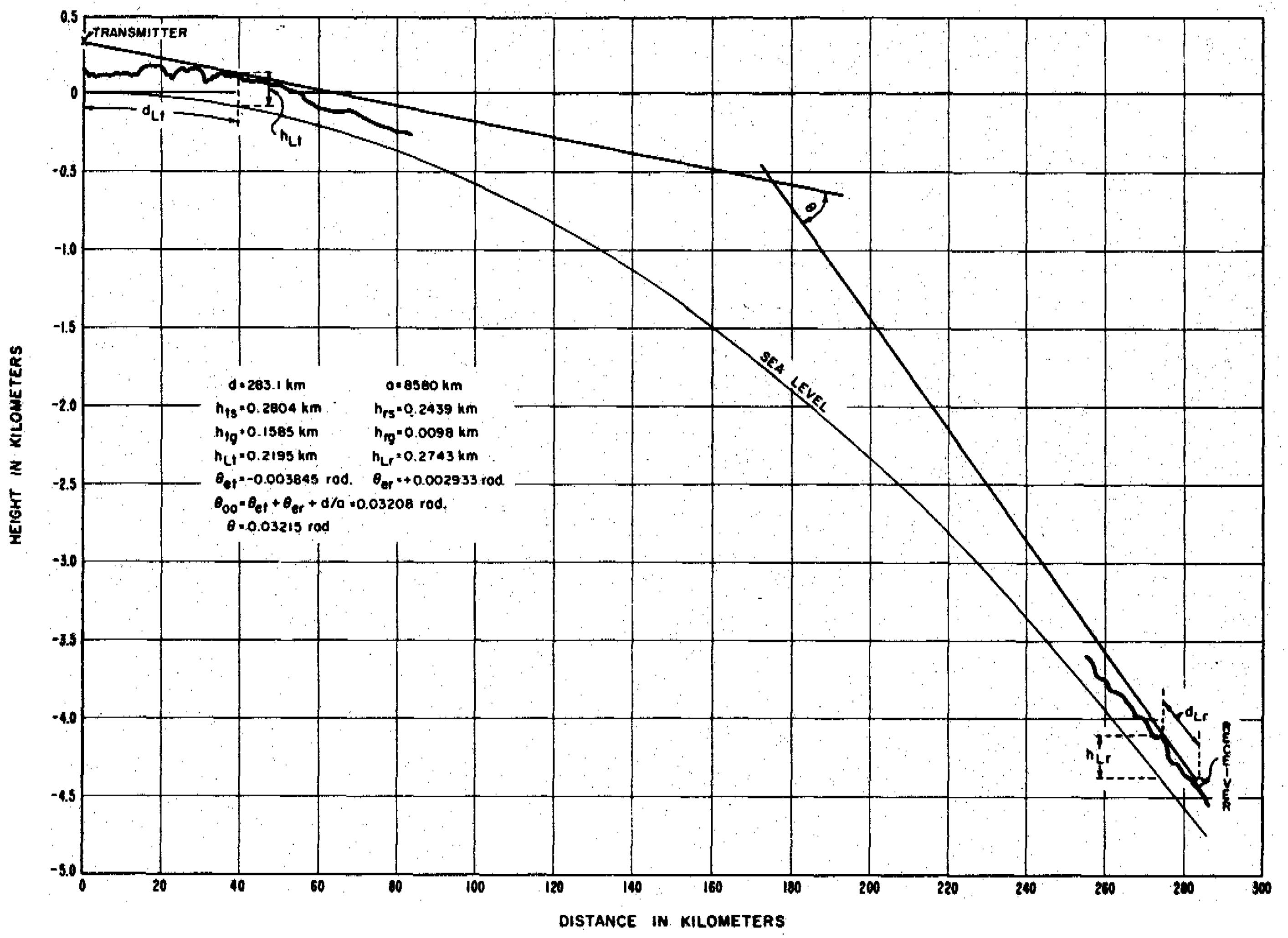

Figure 9.10

CUMULATIVE DISTRIBUTIONS $L_b(q)$ OBSERVED AND PREDICTED vs q
SUMMER, WINTER, AND ALL HOURS
DALLAS TO AUSTIN, TEXAS

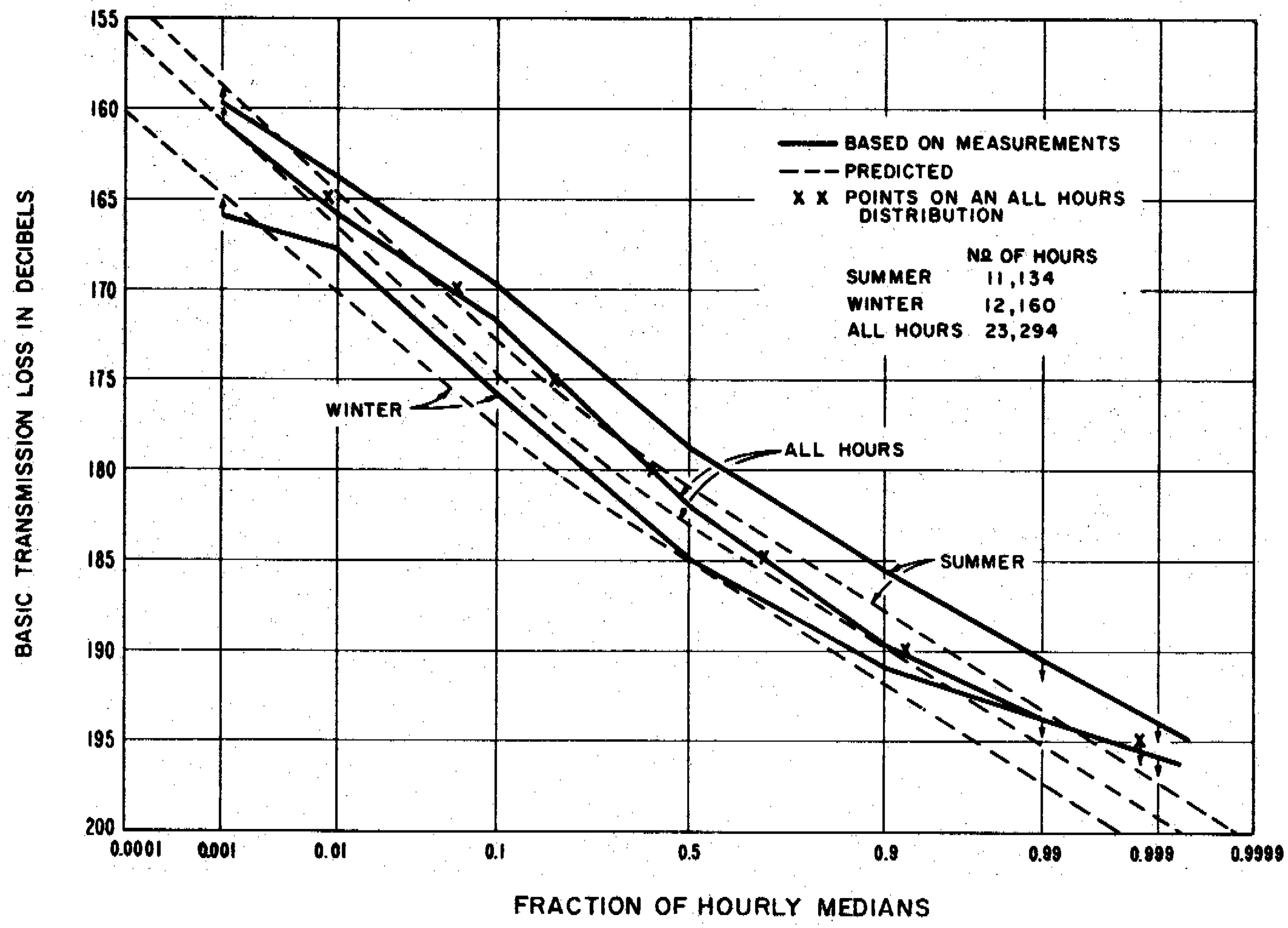

Figure 9.11