A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

ESSA RESEARCH LABORATORIES
Institute for Telecommunication Sciences
Boulder, Colorado
August 1969

Effects of Security Fences on VHF/UHF Propagation

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Final Report Phase C Part 8
In Support of Hard Rock Silo Development
Program 125B
Contract F04701-68-F-0072
Task 2.7g

Technical Memorandum ERLTM-ITS 196

U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

BOULDER, COLORADO

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Environmental Science Services Administration
Research Laboratories

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FOREWORD

This document, the final report covering Task 2.7g, is submitted by the Institute for Telecommunication Sciences, Boulder, Colorado, in accordance with contract FO4701-68-F-0072. The Air Force Project Officer was Captain M. Marin of Headquarters Space and Missile Systems Organization, SMQHN, Air Force Systems Command, Norton Air Force Base, California. The study was initiated on 1 February 1969 and completed by 30 June 1969.

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The authors wish to thank Mr. R. E. Wilkerson for his valuable assistance with the computations required for this report.

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EFFECTS OF SECURITY FENCES ON VHF/UHF PROPAGATION

G. D. Gierhart and M. E. Johnson

A method of estimating the basic transmission loss, L_b, for VHF/UHF links that have low or buried antennas surrounded by security fences is presented. Estimates of L_b obtained are compared with experimental data.

Key Words: Buried antennas, knife-edge diffraction, VHF/UHF propagation.

1. INTRODUCTION

Propagation models given by Longley and Rice (1968) and Rice et al. (1967) cannot be used directly to calculate basic transmission loss L_b (Norton, 1953, 1959) for communications links where antennas must be low (< 1 m above ground or buried) and surrounded by close security fences (<90 m from antenna). However, this difficulty can be overcome by making allowances for transmission through and diffraction over such fences.

Transmission through wire grids is discussed in section 2. Values of attenuation associated with transmission through typical chain-link grids are given for frequencies of 225 and 415.9 MHz.

Diffraction over fences is discussed in section 3. Curves showing attenuation associated with diffraction over a fence versus antenna-to-fence distance are given for a 2.13-m (7-ft) fence and various combinations of antenna height, frequency, and ground type. A method of using these curves to determine L_b is also given.

Theoretical estimates made by this technique are compared with experimental transmission loss data in section 4.

2. TRANSMISSION THROUGH WIRE GRIDS

Methods given by Mumford (1961), Wait (1954), and MacFarlane (1946) can be used to calculate the loss associated with transmission through an infinite parallel-wire grid at normal incidence. Experimental data obtained by Decker (1959) for frequencies near 9 GHz are in close agreement (± 1 dB) with values calculated on the basis of Wait's (1954) theory. Since a chain-link fence can be considered as two parallel-wire grids at right angles to each other (45° left and right of vertical), and since a vertically polarized plane wave can be resolved into two plane waves polarized at 45° left and right of vertical respectively (each component is parallel to a wire grid), these methods can be used directly to estimate the loss associated with transmission through a security fence.

Attenuation values for normal incidence on typical steel chain-link grids at 225 and 415.9 MHz calculated in accordance with Wait (1954) or MacFarlane (1946) are essentially identical and within 0.5 dB of those obtained by Mumford's (1961) method. Values of attenuation estimated using these methods for transmission through chain-link grids are given in table 1. These values can be used to estimate the basic transmission loss L_{bft} for transmission through fences where the parameters considered in table 1 are applicable; i. e.,

$$L_{bft} = L_{bnf} + A_{gt} + A_{gr} \text{ dB}, \qquad (1)$$

where

L_{bnf} = basic transmission loss in decibels corresponding to the case where no fences are in the path,

A_{gt} = grid attenuation in decibels associated with a fence at the transmitting terminal, and

A_{gr} = grid attenuation in decibels associated with a fence at the receiving terminal.

Table 1. Attenuation Values for Transmission Through Chain Link

Frequency MHz	Wire Spacing inches*	Wire Gauge W and M**	Attenuation dB
415.9	2	9	14
415.9	2	11	13
415.9	3	9	9
415.9	3	11	8
225	2	9	19
225	2	11	18
225	3	9	14
225	3	11	13

* Chain-link grid sizes are typically specified in inches (1 in = 2.54cm).

** The Washington and Moen wire gauge is typically used to specify steel wire size. In this system No. 9 and No. 11 wire have diameters of 0.1483 and 0.1205 in respectively.

Attenuation values given in table 1 are for an angle of incidence of 0^o (measured relative to normal incidence) and would increase without limit as the angle approaches 90^o. However, the attenuation is not very sensitive to the angle of incidence when it is near 0^o; e.g., an angle greater than 20^o would be required to produce a 1 dB increase in attenuation. Of the methods mentioned, only Wait's (1954) is sufficiently general so that it can be used with large angles (>about 45^o).

The most appropriate of the propagation models discussed by Furutsu et al. (1964), Rice et al. (1967), and Longley and Rice (1968) should be used to calculate L_{bnf}. Methods given by Hufford (1969) can be used if buried antennas are involved.

Calculation of L_b for a particular path accounts for diffraction over the fences, L_{bfd}, as well as L_{bft}. Both L_{bfd} and L_b are discussed in section 3.

3. DIFFRACTION OVER FENCES

The model for "diffraction over a single isolated obstacle with ground reflections" given by Rice et al. (1967, sec. III. 3) was used to develop the fence attenuation-versus-distance curves shown in figure 1 for hard rock (ϵ_r = 5, σ = 3 mmho/m) and in figure 2 for an average ground (ϵ_r = 15, σ = 5 mmho/m). Fence attenuation $A_{ft, r}$ is the attenuation in excess of free space associated with (a) knife-edge diffraction over the fence for the antenna-to-horizon (radio horizon for fence) portion of the path, and (b) a ground reflection between the antenna and fence (or at the antenna for zero antenna height).

These curves can be used to estimate the basic transmission loss L_{bfd} for fence diffraction paths over $\sim$1 km long where the parameters and geometry considered in figures 1 and 2 are applicable; i.e.,

$$L_{bfd} = L_{bff} + A_{ft} + A_{fr} \text{ dB}, \qquad (2)$$

where

L_{bff} = basic transmission loss in decibels when antennas are assumed at fence tops,

A_{ft} = fence attenuation in decibels for transmitting terminal, and

A_{fr} = fence attenuation in decibels for receiving terminal.

This equation can be extended to apply to buried antennas by adding the losses associated with media surrounding the antenna (Hufford, 1969).

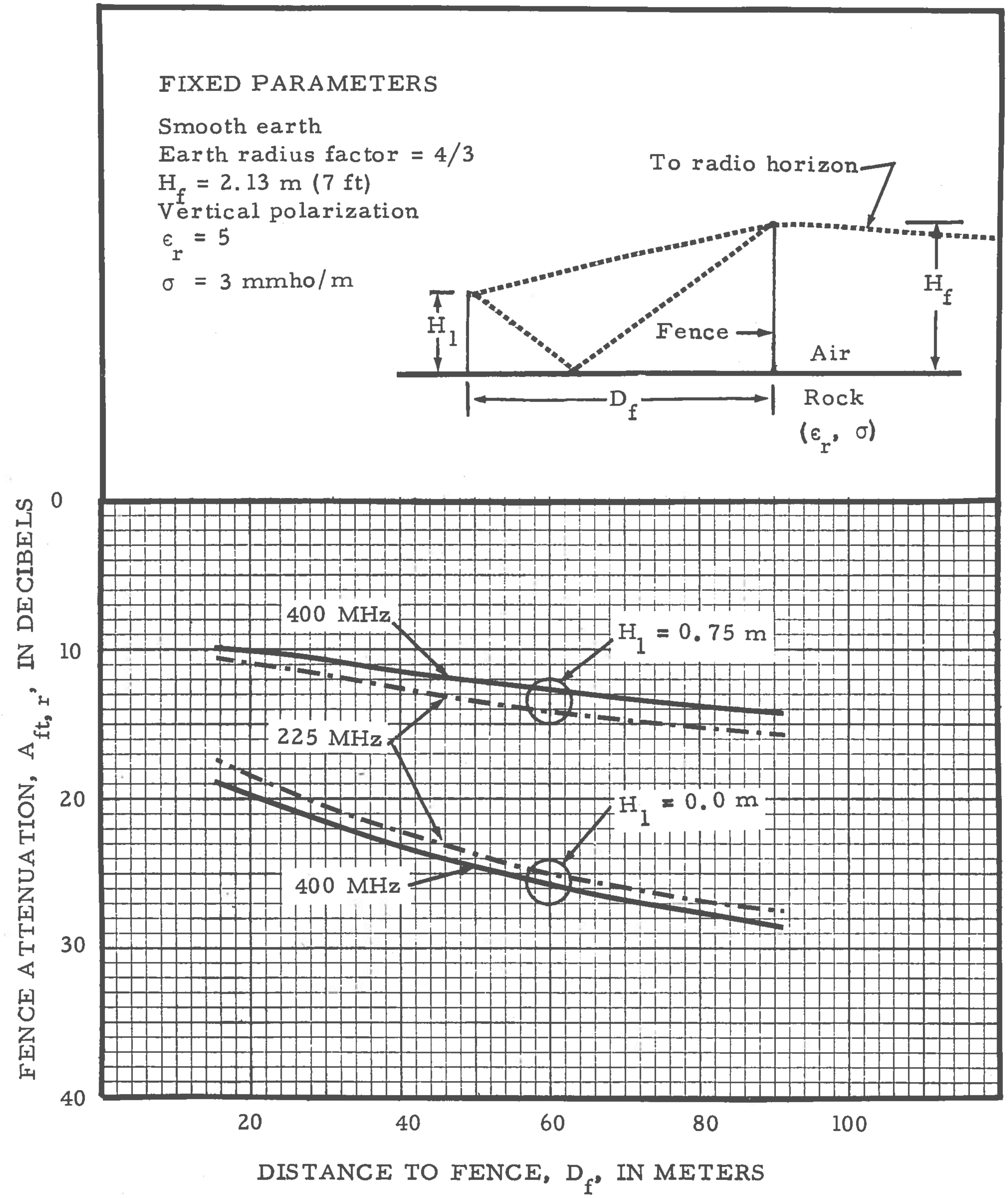

Figure 1. Fence attenuation versus distance for hard rock.

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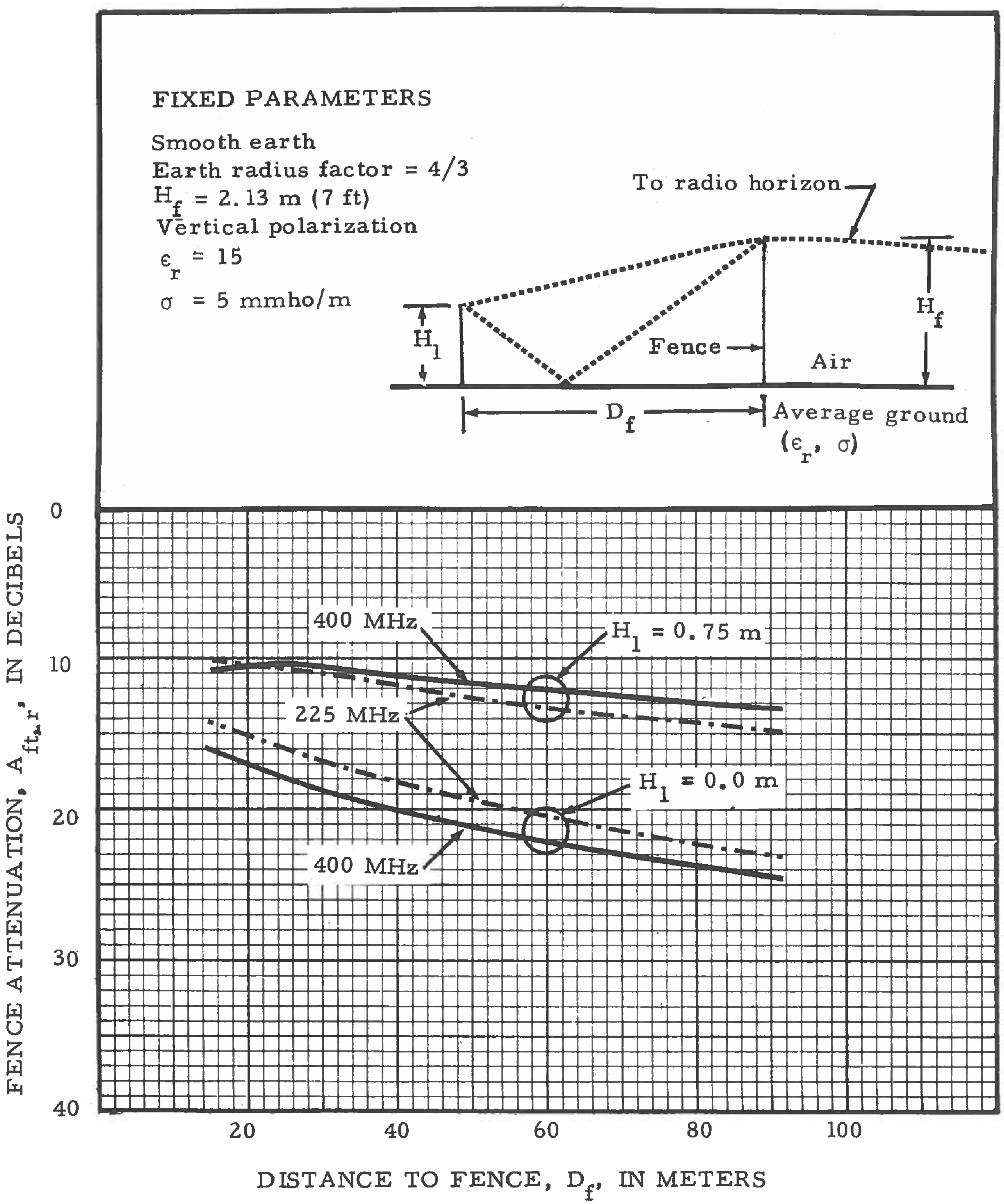

Figure 2. Fence attenuation versus distance for average ground.

Basic transmission loss L_b for a particular path can be estimated from L_{bft} and L_{bfd}; i. e.,

$$L_b \simeq -20 \log_{10} \left| E_{bft} + E_{bfd} (\cos \phi + j \sin \phi) \right| \text{ dB}, \tag{3}$$

where

$$E_{bft} = 10^{-L_{bft}/20}, \tag{4}$$

$$E_{bfd} = 10^{-L_{bfd}/20}, \tag{5}$$

$$\phi = \phi_{ft} + \phi_{fr} \text{ deg}, \tag{6}$$

where ϕ_{ft} = relative phase lag of diffracted component in degrees for the transmitter-to-horizon portion of the path,

ϕ_{fr} = relative phase lag of diffracted component in degrees for the receiver-to-horizon portion of the path, and

$$j = \sqrt{-1}. \tag{7}$$

Estimates of the phase lag $\phi_{ft,r}$ associated with diffraction over a fence are given in figure 3. Obtained by averaging values calculated for ground constants corresponding to hard rock and average ground, these estimates are within $\pm 1^{\circ}$ and $\pm 4^{\circ}$ of the calculated values for $H_1 = 0.0$ and $H_1 = 0.75$ m, respectively.

This method can be used when only one of the terminals has a fence in its proximity. Then $A_{ft,r}$ or $A_{gt,r}$ for the terminal without a security fence is taken as 0 dB, and L_{bff} is calculated for the path from this terminal to the fence.

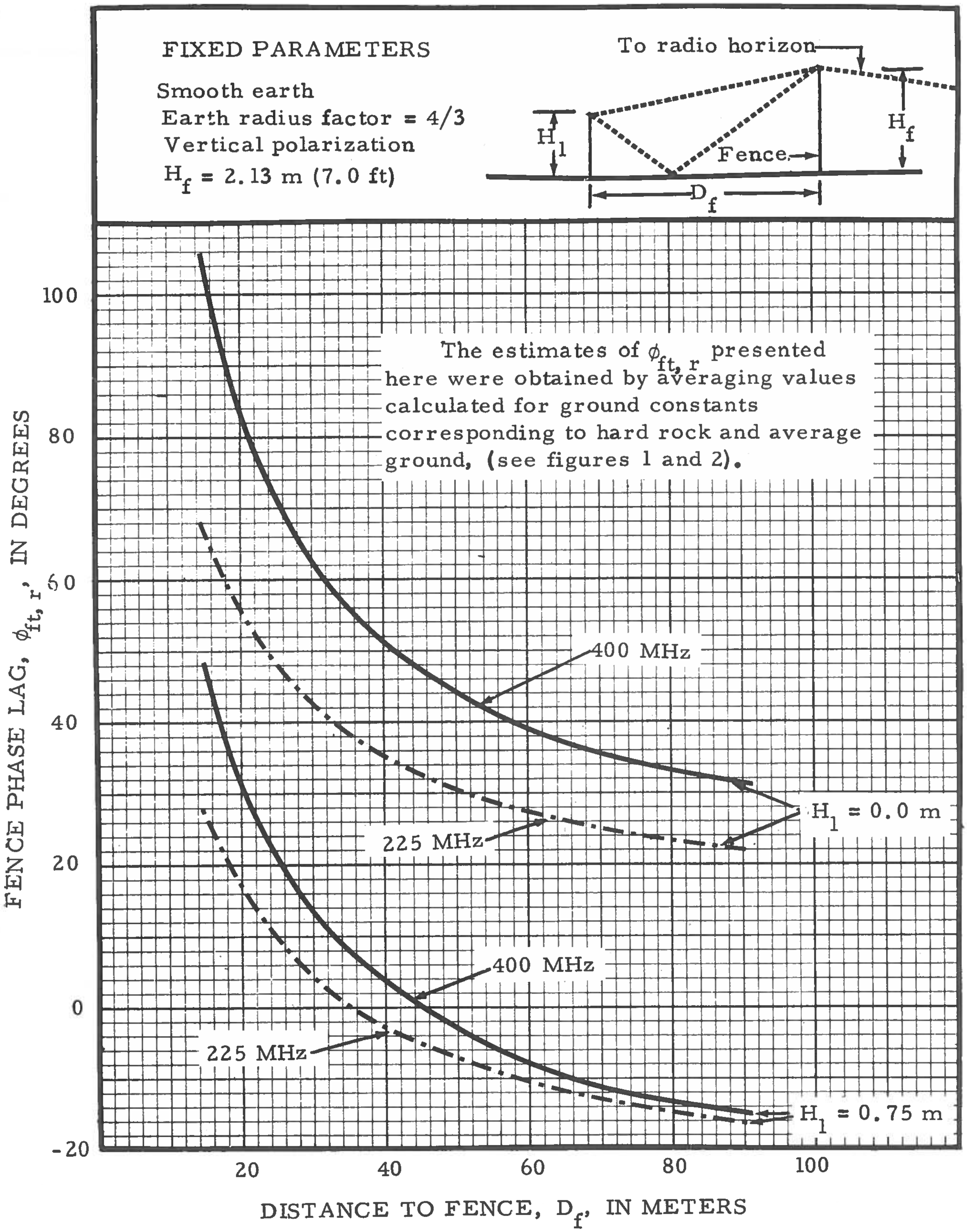

Figure 3. Fence phase lag versus distance.

4. COMPARISON WITH EXPERIMENTAL DATA

Hause and Kimmett (1969) have collected experimental data that can be compared with theoretical calculations based on the methods discussed in sections 2 and 3. Only some of the results of their measurements will be presented here and the reader is referred to their report for details concerning experimental procedures, etc.

The curves for theoretical transmission loss L shown in this section are based on simple ray and/or simple knife-edge diffraction theory. With the exception of the curves labeled "isotropic antennas," allowance is made for the gain characteristics (Rice et al., 1967, sec. 5.2) of the antennas used by Hause and Kimmett (1969). When both antenna heights were less than 0.75 m, an extrapolation was made based on L_b curves obtained with a more complex smooth-earth ground-wave model formulated by Furutsu et al. (1964); i. e., for antenna heights so low that L curves obtained from simple ray theory are not valid, these curves were obtained by assuming that their shape would be the same as the corresponding L_b curve, but with a shift in level. The theoretical L and L_b curves shown in figure 4 for ground with a relative dielectric constant, ϵ_r of 8, illustrate this procedure. Curves for diffraction over a fence were obtained by expanding the four-ray diffraction model presented by Rice et al. (1967, sec. III. 3) to a six-ray model, where rays 5 and 6 account for transmission through the fence via direct and ground-reflected rays.

Figures 4 and 5 show theoretical and experimental transmission loss versus height (height gain) curves for a 15.2-m (50 ft) path, where one antenna H_1 is fixed at 0.0 (fig. 4) and 0.75 (fig. 5). The other antenna height H_2 varies from 0.0 to 3 m. Theoretical curves for ϵ_r values of 4, 8, and 16 are shown in each figure. Good agreement (within 2 dB) between experiment and theory is obtained for

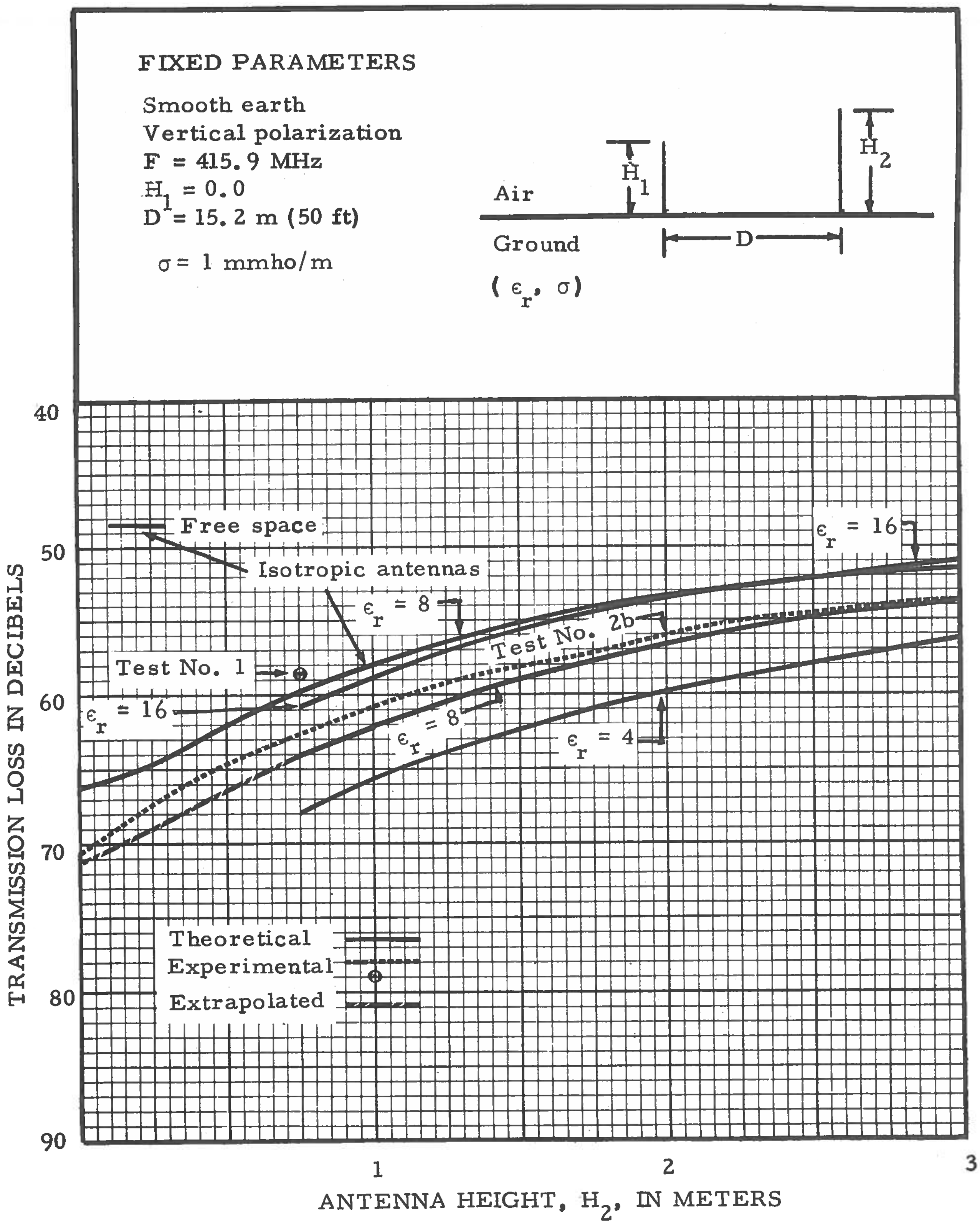

Figure 4. Height-gain curves for 15.2-m path, $H_1 = 0.0$ m.

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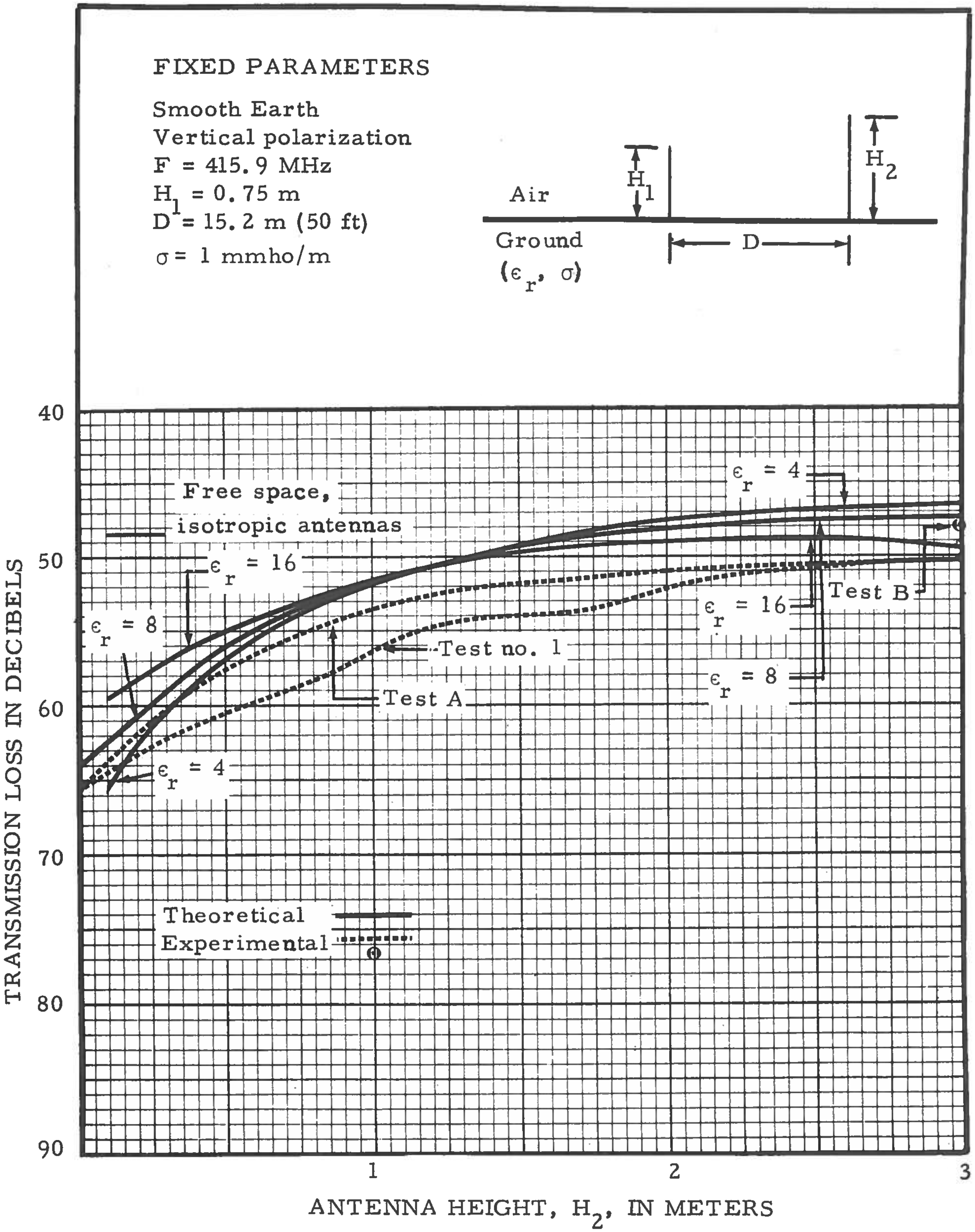

Figure 5. Height-gain curves for 15.2-m path, $H_1 = 0.75$ m.

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the ε_r = 8 curve when H_1 = 0.0 m (fig. 4) and poor agreement (within 6 dB) for any ε_r tried when H_1 = 0.75 m. However, the shape of the ε_r = 8 curve for H_1 = 0.75 m does seem to fit the shape of the experimental curves. An L_b curve for isotropic antennas with ε_r = 8 is also shown in figure 4. Comparison of this curve with the L curve for ε_r = 8 indicates that antenna gain characteristics can be important even when low gain (<4 dB) antennas are used.

Except for Test A and Test B, the test numbers given here correspond to those used by Hause and Kimmett (1969) to report their test results. Tests A and B were made by Hause and Kimmett on July 16, 1969 but are not included in their report. These were special tests made to see if an undetected constant loss, such as internal losses in the antennas, would prevent L values from reaching the L_b level for free space, L_{bf}. Test A is a repeat of Test No. 1 (height gain with H_1 = 0.75 m). Although the Test A data obtained are somewhat closer (~2 dB) to the theoretical curves, the L_{bf} level is not reached. Test B is identical to Test A, except that H_1 = 3 m. Figure 6 shows the height-gain curve resulting from Test B and theoretical curves obtained for ε_r of 4, 8, and 16. The L_{bf} level was reached during this test, and the experimental data agree well (within 2 dB) with the theoretical curve for ε_r= 8.

Figures 7, 8, and 9 show theoretical and experimental height-gain curves for a 30.5-m (100-ft) path with H_1 fixed at -1, 0.0, and 0.75 m respectively. Curves are shown for a smooth-earth path (no fence) and a path where a 2.13-m (7-ft) chain-link fence (2 in.grid of No. 9 wire) is oriented perpendicularly to the path at path center. Figures 8 and 9 include theoretical curves for "diffraction over fence only" and "transmission through fence only", which were used, with relative phase information, to obtain the theoretical "with fence" curves.

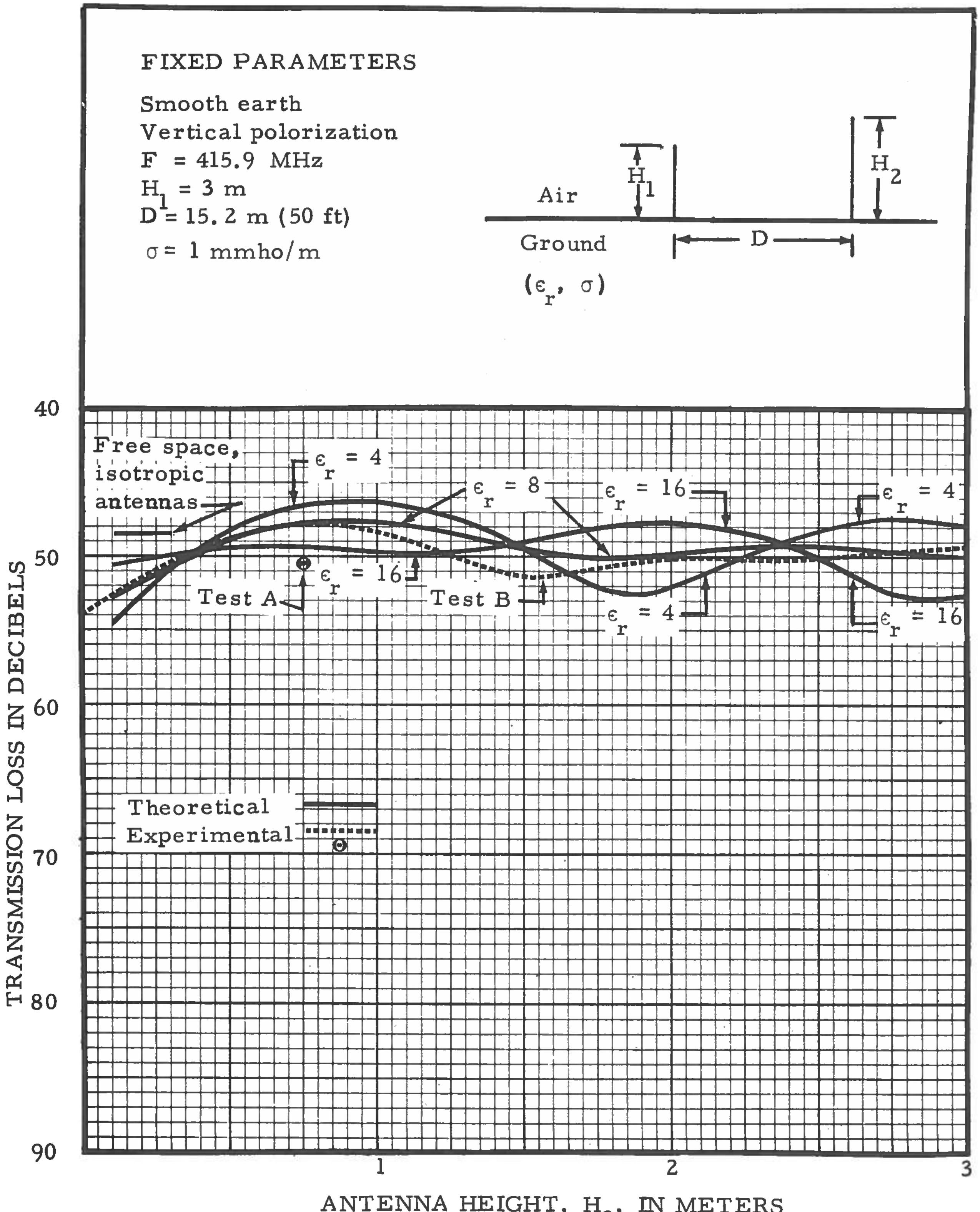

Figure 6. Height-gain curves for 15.2-m path, H_1 = 3 m.

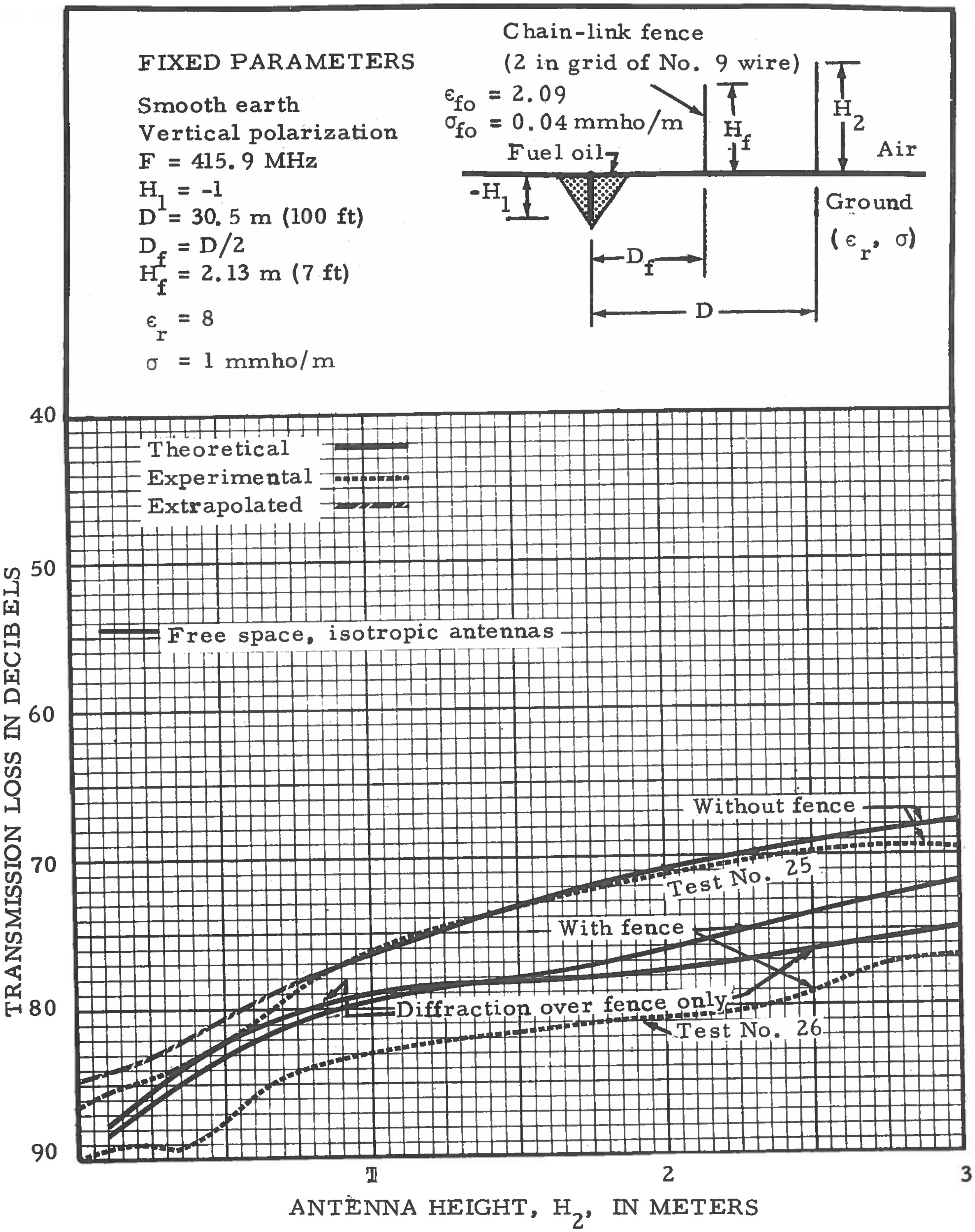

Figure 7. Height-gain curves for 30.5-m path, H_1 = -1 m.

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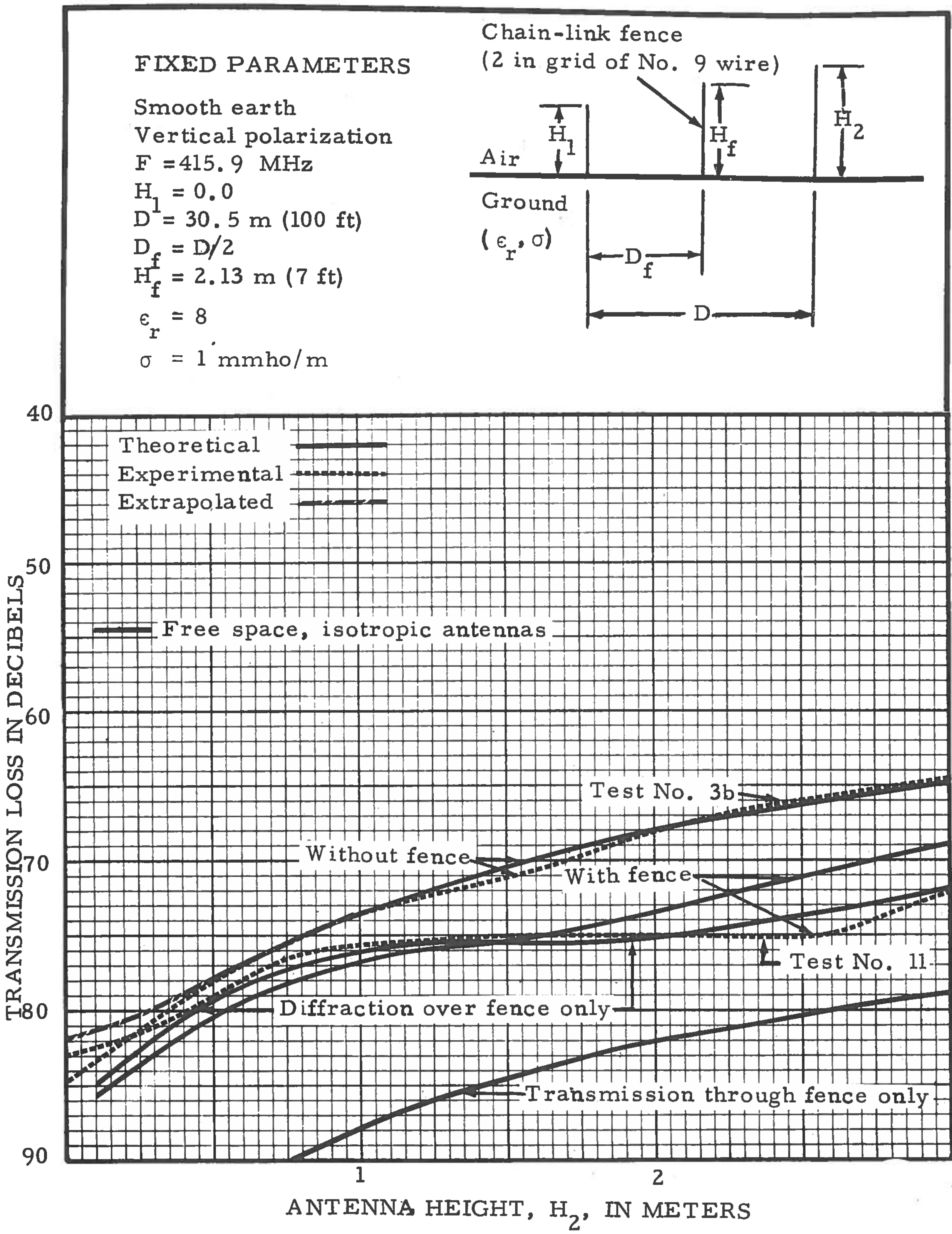

Figure 8. Height-gain curves for 30.5-m path, H_1 = 0.0 m.

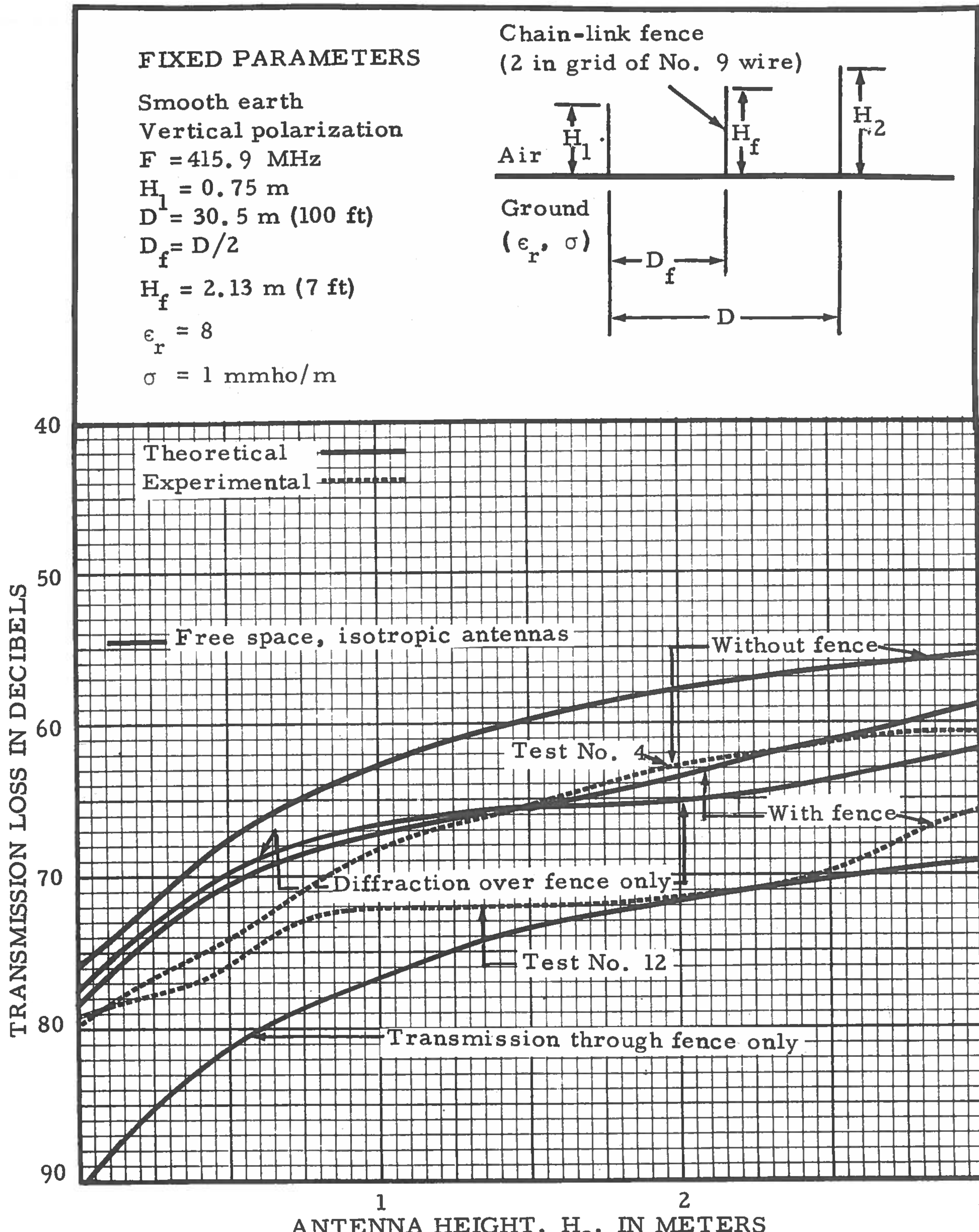

Figure 9. Height-gain curves for 30.5-m path, $H_1 = 0.75$ m.

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Theoretical curves similar to those shown in figures 4 and 5 were developed for the 30.5-m (100-ft) path. According to these curves, not all of which are shown in this report, a value of $\epsilon_r = 8$ gives the best agreement with experimental data. Rice et al. (1967) use ϵ_r values of 15 and 4 to characterize "average" and "poor" ground respectively. Because of the agreement with experimental data, (at least for $H_1 =$ 0.0 or 3 m) and because it seems reasonable to characterize the ground of the test site as being poorer [1] than average, an $\epsilon_r = 8$ was selected as an appropriate value in calculating L for the test paths. Theoretical L curves presented here for a path length of 30.5 m (100 ft) were calculated with $\epsilon_r = 8$.

The method formulated by Furutsu et al. (1964) was used to calculate L for (a) vertical polarization at 415.9 MHz, (b) $H_1 = H_2 = 0.0$ m, (c) $\epsilon_r = 4$, 8, and 16, (d) paths of 15.2 and 30.5 m, and (e) ground conductivities σ from ~0 to 50 mmho/m. Variations of L with σ (other parameters fixed) were less than 1 dB, whereas changing ϵ_r from 4 to 16 (other parameters fixed) resulted in a change of about 10 dB. Because of the minor importance of σ at 415.9 MHz, a value of 1 mmho/m was selected somewhat arbitrarily[2] and used for all theoretical L calculations presented here.

Height-gain curves for a transmitting antenna submerged in fuel oil ($H_1 = -1$ m) are shown in figure 7. Theoretical curves were obtained by increasing the L values for $H_1 = 0.0$ m (fig. 8) by 2.8 dB, a value obtained by subtracting the gain of the submerged antenna

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[1]Kerr (1964, p. 398) give ϵ_r values of 2, 4, 3.2, and 2.8 for "very dry sandy loam", "very dry ground, "Arizona soil", and "Austin, Tex., soil, very dry", respectively.

[2]Rice et al. (1967) use $\sigma = 1$ mmho/m to characterize "poor" ground.

(-2.7 dB) from the loss associated with propagation through the fuel oil (0.1 dB). An antenna gain of -2.7 dB corresponds to that measured by Hause and Kimmett (1969, fig. A.7) with the antenna in air (gain in fuel oil would be somewhat different) for an angle (46°) obtained (90° - 44°) from the critical angle (44°) calculated by Hufford's (1969, eq. 7.2) method, and an attenuation of 0.1 dB corresponds to the antenna-to-surface critical ray length ($1/\cos(44^{\circ})$ = 1.4 m) multiplied by the attenuation rate (0.05 dB/m) for fuel oil obtained from data given by the Massachusetts Institute of Technology (1953, p. 65) for jet fuel type JP-1 at a frequency of 300 MHz. This method of estimating L is based on a simple interpretation of Hufford (1969, sec. 7) method, and values determined using it are in good agreement with experimental data (within 2 dB) for the case without fence and in poor agreement (within 6 dB) for the case with fence.

The relative agreement between experiments and theory implied by figures 8 and 9 (30.5-m path) is similar to that implied by figures 5 and 6 (15.2-m path); i. e., experimental data obtained for H_1 = 0.0 m (figs. 5 and 8) agree better with theoretical values than data obtained for H_1 = 0.75 m (figs. 6 and 9). Experimental L values for H_1 = 0.75 m with ϵ_r = 8 are always greater than those obtained theoretically.

Experimental and theoretical L values obtained for the 30.5-m path are shown in table 2 for the special cases where the same antenna heights are involved in more than one test; i. e., tests for (a) H_1 = 0.0 m and H_2 = 0.75 m, and (b) H_1 = 0.75 m and H_2 = 0.0 m involve the same antenna heights. Theoretical values do not change with an interchange of antenna heights, because it is assumed in the model used that the antenna patterns are identical and that the reflection coefficients do not change with an interchange of antenna heights. The lack of agreement with the experimental data indicates that these assumptions may not be valid.

Table 2. Transmission Loss Values for 30.5 km Path

H_1 in meters	H_2 in meters	L Values in Decibels			
		Without fence		With fence	
		Experimental	Theoretical	Experimental	Theoretical
0.00	0.75	75.5	75.5	76.6	78.2
0.75	0.0	79.8	75.5	79.1	78.2

Experimental and theoretical L_b values for the 2.41-km path tested by Hause and Kimmett (1969, tests 5 and 8) are tabulated in table 3. Theoretical values were calculated by (a) the Longley and Rice (1968) computer method, with input parameters appropriate for the test path; (b) the Furutsu et al. (1964) smooth-earth model, with an effective earth radius of 8493 km; and (c) the smooth-earth model, with a radius of 200 km. A circle with a 200-km radius that passes through the test path terrain profile (Hause and Kimmett, 1969, fig. 3) is within ± 1 m of the other profile points. Losses used in the theoretical calculations and those in excess of L_{bf} are also given.

The theoretical losses tabulated in table 3 are from 2 to 11 dB greater than the corresponding experimental values. The loss estimates considered most appropriate, by the authors, for the signal component associated with propagation via diffraction over the great-circle portion of the terrain between terminals (smooth earth with 200-km radius) are greater by 8 to 11 dB. This is a strong indication that propagation via the great-circle path is not the primary mode. Hause and Kimmett (1969, sec. 4) performed tests to see if reflections from terrain not on the great-circle path could be important. Since their results indicate

Table 3. Basic Transmission Loss Values for 2.41-km Path

Conditions and/or Items	L_b or A Values in Decibels*			
F = 415.9 MHz		Theoretical		
$H_1 = H_2 = 0.75$ m	Experimental**	Irregular terrain	Smooth earth	Smooth earth
Effective earth radius in km		8066	8493	200
L_{bf}		92	92	92
Without fences, L_{bnf}	137	142	139	145
$L_{bnf} - L_{bf}$	45	50	47	53
With fences,*** L_b	137	142	142	148
$L_b - L_{bf}$	45	50	50	56
$A_{gt} + A_{gr}$		28	28	28
L_{bft}		170	167	173
L_{bff}		122	122	128
$A_{ft} + A_{fr}$		20	20	20
L_{bfd}		142	142	148

* Correspond to those discussed in sections 2 and 3.

** Estimated from L-data by subtracting the sum of the most relevant antenna gains (2 x -0.37 = -0.74 dB).

*** When in place 2.13-m (7-ft) high chain-link (2-in grid of number 9 wire) fences are located on, and perpendicular to, the path at a distance of 15.2 m (50 ft) from each antenna.

that propagation over the test path is strongly influenced (perhaps dominated) by reflections from terrain not on the great-circle path, a detailed comparison of experimental data taken over this path with theoretical predictions that consider only the great-circle terrain is not justified.

5. CONCLUSIONS

The following conclusions can be drawn from this work:

(1) Surface conductivity can usually be neglected in L-calculations for positive antenna heights at frequencies above 200 MHz. Calculations made in this study at 415.9 MHz indicate that a change of less than 1 dB in L would be expected for a change in σ from 0 to 50 mmho/m with an ϵ_r as low as 4. The importance of σ decreases with increase in frequency, larger ϵ_r values, and/or a change from vertical to horizontal polarization.

(2) Electrical constants of the fuel oil used in the submerged antenna tests should and are being measured at a frequency close to 415.9 MHz. Values for ϵ_{fo} and σ_{fo} used in the theoretical calculations were based on measurements for a specific type of jet fuel at 300 MHz. These values resulted in an attenuation rate of 0.05 dB/m, and absorption associated with propagation through the fuel oil could therefore be considered negligible. However, an absorption rate of 2 dB/m was calculated for 415.9 MHz based on the conductivity measured at 3,000 MHz for the same jet fuel. The extent to which the fuel oil used in the experiment is similar to the jet fuel assumed in the theoretical calculations is unknown.

(3) Ray theory can be used to calculate L even though one antenna height is zero. For the calculations reported here for the 15.2-m path with H_1 = 0.0 m, ray theory and a more complex ground wave model (Furutsu et al., 1964) were used. Values of L_b obtained by the two

methods agreed within 1 dB when H_2 was elevated to 0.75 m. This corresponds to an angle of 2.8° between the reflected ray and the surface (grazing angle, ψ). The ψ value below which ray theory becomes inadequate would be expected to decrease with increasing antenna heights, increasing path length, increasing frequency, and/or a change in polarization from vertical to horizontal. An angle of 2.8° is about 20 times as large as the angle given by Reed and Russell (1964, table 6) as the value that limits the validity of ray theory at 300 MHz. Restrictions placed on the use of ray theory by Rice et al. (1967, sec. 5.2 and III.1) imply that ray theory should not be used for an antenna height of zero. All these authors seem to be concerned about propagation where the curvature of the earth becomes important (Norton, 1941).

(4) Antenna vertical patterns of low gain antennas can be very important in cases where the reflection coefficient is near unity and where the relative phase of direct and reflected rays is near 180°. Then a change in the effective reflection coefficient, R_e, (Rice et al., 1967, sec. 5.2) caused by a slight change in the antenna gains applicable to the direct and reflected rays can change L by several decibels. Antennas designed to reduce the effects of ground reflections (lower L's for low ψ's) by providing a higher antenna gain for the direct ray are in use (Casabona, 1956), and have been recommended for use with the VORTAC air navigation aid by Kirby and Hause (1963). Comparison of the curves given in figure 4 shows that L-values calculated for $\epsilon_r = 8$ from the measured antenna pattern (Hause and Kimmett, 1969, fig. 7) for each antenna are higher than those calculated from isotropic patterns and that the curve calculated from the measured pattern agrees well (within 2 dB) with experimental data. This increase in L would be expected, since the transmitting antenna orientation is such that its vertical gain pattern increases R_e. The same transmitting antenna (H_1) operated

upside down in a test similar to Test 2 b (fig. 4) would be expected to result in a decrease of L of several decibels as compared with values obtained for Test 2 b.

(5) Poor agreement between experiment and theory for some of the short paths is probably the result of using an inappropriate antenna pattern for the receiving antenna (H_2) in the theoretical calculations. Theoretical L values were determined from the antenna pattern measured by Hause and Kimmett (1969, fig. A. 7) for both antennas. Actually their pattern is for the transmitting antenna, and although the receiving antenna is of similar construction, it is not identical, since a coaxial cable is attached to the side of the housing. Poor agreement between experimental data obtained under similar conditions (Tests 1 and 2 b in fig. 4; Tests 1 and A in fig. 5; Tests A and B in fig. 6) could also be explained by a receiving antenna pattern that differs from the transmitting antenna pattern because of the cable. The effective reflection coefficient is independent of the receiving antenna pattern for Tests 2 b (fig. 4), 25 (fig. 7), and 3 b (fig. 8), since both the direct and reflected rays have the same angle of arrival at the receiving antenna. These tests provide the only experimental data that agree well (within 2 dB) with theoretical calculations.

(6) A simple interpretation of Hufford's (1969) method can be used for submerged antennas. This simple method was used to obtain the theoretical curves given in figure 7 (H_1 = -1 m) from the theoretical curves given in figure 8 (H_1 = 0.0 m) which agree well with experimental data for the case without fence. However, uncertainty concerning the conductivity of the fuel oil and the receiving antenna pattern makes it difficult to be more specific.

(7) Theoretical estimates of fence attenuation A_g may be low. Theoretical curves (figs. 7, 8, and 9) in which the fence is assumed to be

opaque to radiation at 415.9 MHz (diffraction over fence only) seem to agree better with experimental data than those that include transmission through the fence (with fence). However, uncertainty concerning the receiving antenna pattern makes it again difficult to be more specific.

(8) Curves such as those given by Hufford (1969, fig. 9) can be used to extend the Longley and Rice (1968) method to antenna heights below 0.5 m. The degree to which the extrapolated curves shown in figures 4, 7, and 8 agree with experimental data is an indication of the potential of such an extension. The agreement is good.

(9) Propagation via reflections from terrain not on the great-circle path is likely to be an important mode at VHF/UHF when attenuation relative to free space for propagation over the great circle exceeds 45 dB and off-path terrain is illuminated by both antennas. The 45 dB comes directly from the experimental data given in table 3, and a more appropriate value could probably be obtained from an extensive analysis of available propagation data. In their discussion of "communication by diffuse ground reflections without direct visibility" Beckmann and Spizzichino (1963, sec. 17.2) quote a figure of 20 dB for propagation in mountainous terrain at 50 MHz and give equations for calculating the scattered field.

(10) Simple ray and knife-edge diffraction may be used to account for the effect of a fence on propagation over the 30.5-m path, provided one antenna height is greater than 0.75 m. Better agreement between experimental and theoretical L-values could probably be obtained by including a more accurate pattern for the receiving antenna in the theoretical calculations.

(11) Information given in table 1 and figures 1, 2, and 3 may be useful in estimating the effects of security fences on propagation at VHF/UHF.

It is difficult to be more positive, since propagation via strong off-path reflections on the 2.41-km test path prevent a valid comparison of experimental data with theoretical values based on propagation via the great-circle terrain.

(12) Estimates of L_b can be made with L_{bft} neglected in most situations,

$$L_b \simeq L_{bfd} \text{ dB,} \qquad (8)$$

within the range of parameters considered in sections 2 and 3, and the phase lag ϕ is usually small enough to be neglected in those cases where L_{bft} is important,

$$L_b \simeq -20 \log_{10} (E_{bft} + E_{bfd}) \text{ dB.} \qquad (9)$$

The values tabulated in table 3 for the smooth-earth case show that L_{bft} can exceed L_{bfd} by a margin of 25 dB. By changing the chain-link to a 3-in.grid of number 11 wire (table 1), and increasing the antenna-to-fence distances to 90 m (fig. 1) this margin can be reduced to 5 dB. It could then be reduced to 3 dB by removing one fence. However, an increase in antenna-to-fence distance and/or the removal of a fence will reduce ϕ. The assumption made in (9) that E_{bft} and E_{bfd} can be added in phase will usually result in an error of less than 2 dB.

6. REFERENCES

Beckman P. and A. Spizzichino (1963), The Scattering of Electromagnetic Waves From Rough Surfaces, International Series of Monographs on Electromagnetic Waves, 4 (Pergamon Press, New York, N.Y.).

Casabona, A. M. (1956), Antenna for the AN/URN-3 TACAN beacon, Elec. Commun. 33, No. 1, 35-59.

Decker, M. T. (1959), Transmission and reflection by a parallel wire grid, J. Res. NBS 63D (Radio Prop.), No. 1, 87-90.

Furutsu, K., R. E. Wilkerson, and R. F. Hartman (1964), Some numerical results based on theory of radio wave propagation over inhomogeneous earth, Radio Sci. J. Res. NBS 68D. No. 7, 827-846.

Hause, L. G. and F. G. Kimmett (1969), UHF buried antenna path loss measurements, ESSA Tech. Memo. (to be published).

Hufford, G. A. (1969), UHF Propagation from buried antennas, ESSA Tech. Memo. ERLTM-ITS 191.

Kerr, D. E. (1964), Propagation of short radio waves, MIT Radiation Laboratory Series 13 (Boston Technical Publishers, Inc., Lexington, Mass.).

Kirby, R. S. and L. G. Hause (1963), Siting factors for VORTAC, NBS Rept. 7690.

Longley, A. G. and P. L. Rice (1968), Prediction of tropospheric radio transmission loss over irregular terrain a computer method-1968, ESSA Tech. Rept. ERL 79-ITS 67 (U.S. Government Printing Office, Washington, D. C.).

MacFarlane, G. G. (1946), Surface impedance of an infinite parallel-wire grid at oblique angles of incidence, Proc. Inst. Elec. Engrs. (London) Pt. IIIA 93, 1523-1527.

Massachusetts Institute of Technology (1953), Tables of dielectric materials, IV, Tech. Rept. 57, Laboratory for Insulation Research, MIT.

Mumford, W. W. (1961), Some technical aspects of microwave radiation hazards, Proc. IRE 49, No. 2, 427-447.

Norton, K. A. (1941), The calculation of ground-wave field intensity over a finitely conducting spherical earth, Proc. IRE 29, No. 12, 623-639.

Norton, K. A. (1953), Transmission loss in radio propagation, Proc. IRE 41, No. 1, 146-152.

Norton, K. A. (1959), System loss in radio wave propagation, J. Res. NBS 63D (Radio Prop.), No. 1., 53-73.

Reed, H. R. and C. M. Russell (1964), Ultra High Frequency Propagation (Boston Technical Publishers, Inc., Lexington, Mass.).

Rice, P. L., A. G. Longley, K. A. Norton, and A. P. Barsis (1967), Transmission loss predictions for tropospheric communication circuits, NBS Tech. Note 101, I and II (revised).

Wait, J. R. (1954), Reflection at arbitrary incidence from a parallel wire grid, Appl. Sci. Research B. 4, No. 6, 393-400.