communications

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PROPAGATION

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VHF AND UHF PROPOGATION

NOTE: See also Datafile10003-3 and ECP-159 for use with this document.

ABSTRACT

This bulletin is provided for calculating the coverage which a certain VHF or UHF transmitter will provide or for calculating the power which a transmitter must have to cover a certain area. Such factors as path clearance, transmission line losses, antenna gains, and reliability are all taken into account for paths as long as 1000 miles.

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CONTENTS

TABLES

ILLUSTRATIONS

GRAPHS

FORMS

VHF AND UHF PROPOGATION

Calculation of Range and Signal Strength
for
Land Mobile Radio Communication Systems Above 30 MC

This Bulletin is provided for calculating the coverage which a certain VHF or UHF transmitter will provide or for calculating the power which a transmitter must have to cover a certain area. Such factors as path clearance, transmission line losses, antenna gains, and reliability are all taken into account for paths as long as 1,000 miles. This information has been assembled by Mr. N. H. Shepherd of the Advance Engineering Section.

For paths over flat terrain up to about 100 miles and for antenna heights up to a few hundred feet, the G-E Range and Signal Strength Calculator (ECR-16) is useful in making rapid calculations. Beyond the range of the Calculator or where obstructions are present in the path, this Bulletin is most useful.

A convenient Signal Strength Calculation Form (10003-3) has been provided as a guide to the use of the graphs. Additional copies of 10003-3 and ECM-94 (4/3 Earth Curvature Profile Paper) are available in limited quantities from the Technical Publications Section, General Electric Company, Communication Products Department, Mountain View Road, Lynchburg, Virginia.

PROBABILITY OF COVERAGE

One of the first questions a prospective radio communication customer asks when he is considering the purchase of a new system is, "How far will I be able to talk?" Since even the finest radio equipment cannot provide coverage over 100% of the service area for 100% of the time, this customer's question can only be answered on the basis of the percentage of time and locations over which he expects to obtain coverage. For example, calculations might show that a customer could expect a 50-watt, 150-megacycle transmitter and a 100-foot antenna to provide a useable signal to 90% of all locations within a 15-mile radius for 90% of the time. The remaining 10% of the locations would have a useable signal for less than 90% of the time.

The variations in signal strength with time and location can be predicted by applying either theoretically-derived or empirically-derived probability distributions. The theoretically-derived distributions are based on signals traveling between the transmitter and receiver by many different paths and being combined at the receiving antenna to form a single voltage, which is the vector sum of the voltages produced by each path. As the length of each path changes with time or slight movement of either antenna, the total path attenuation follows a Rayleigh probability distribution (see Graph 3A).

Over extended periods of time, seasonal changes or relatively permanent changes alter the basic (average) path loss. The result is a Rayleigh distribution having a constantly changing average value (i.e. the sume of several Rayleigh distributions produces a normal distribution (see Graph 3A). Normal distributions based on empirical data are also shown in Graph 3A.

The basic path loss is the sum of the theoretically-derived transmission losses and the empirically-derived terrain factor losses. For certain paths, empirically-derived transmission losses may be used (Graph 5B).

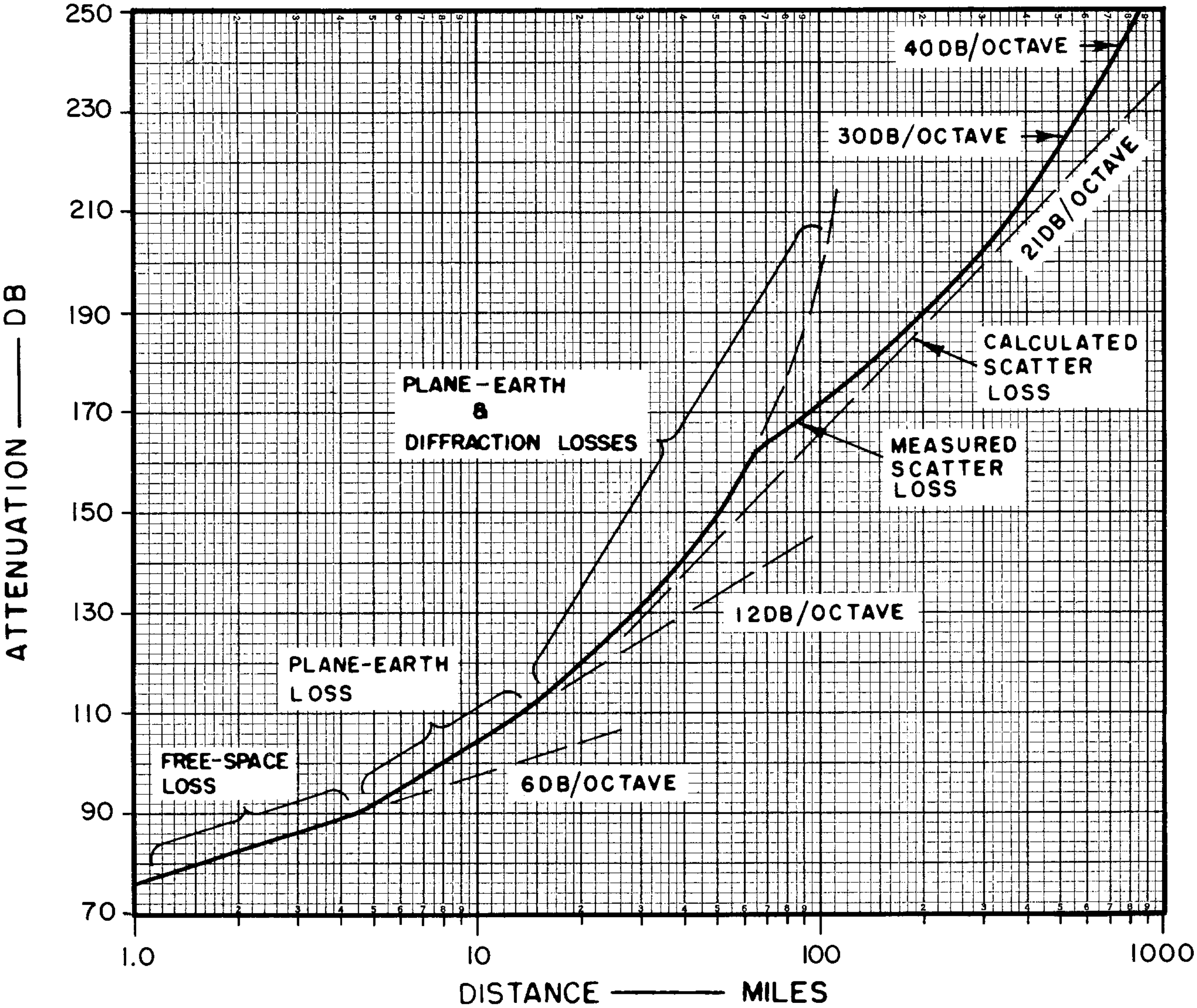
TYPES OF PROPAGATION

VHF and UHF propagation is divided into three main types for calculating path attenuation:

- Free-space propagation (6-db attenuation per octave)
- Plane-earth or smooth-earth propagation (12-db attenuation per octave)
- Scatter propagation (20 to 40-db attenuation per octave)

Each type of propagation contributes attenuation at a different rate, depending upon the path length, the frequency of the signal, and the nature of the path. Figure 1 shows how the attenuation of a signal increases as the range between the antennas is increased over smooth earth (assuming no obstructions). The attenuation values shown are for average time (50% of the time) and for ideal antenna locations. To determine the attenuation for 90%, 99%, or 99.9% useable signal, it is necessary to add 8 db, 19 db, or 29 db respectively for each percentage (as shown on Graph 3A). For base station-to-mobile communication, other losses must be added for terrain factors. Graph 3A can be used to determine the transmission loss to average mobile unit locations for various time percentages.

FIGURE 1 — ATTENUATION BETWEEN HALF-WAVE DIPOLES



CONDITIONS OF MEASUREMENT

FREQUENCY . . . . 160 MEGACYCLES

HEIGHT OF ANTENNAS . . . . 110 FEET

DISTANCE TO HORIZON FROM EITHER ANTENNA (K = 4/3, USING GRAPH 5A) . . . . 15 MILES

DISTANCE FOR 0.6 FRESNEL ZONE CLEARANCE

D_1 . . . . 2.2 MILES

D_2 . . . . 2.2 MILES

TRANSMISSION PATH . . . . SMOOTH EARTH (NO OBSTRUCTIONS)

LOSSES DUE TO EARTH'S CURVATURE NEGLIGIBLE UP TO . . . . APPROX. 10 MILES

FREE-SPACE PROPAGATION (Graph 1A or 1B)

Free-Space propagation is the type of propagation which would take place between a transmitting antenna and a receiving antenna in "empty" space --- where there were no other interfering bodies or atmosphere either between the antennas or close to the path. This type of propagation results in a 6-db attenuation of the signal each time the path is doubled (i.e. 6-db attenuation per octave). Notice in Figure 1 that the attenuation over the first few miles of path is primarily free-space attenuation.

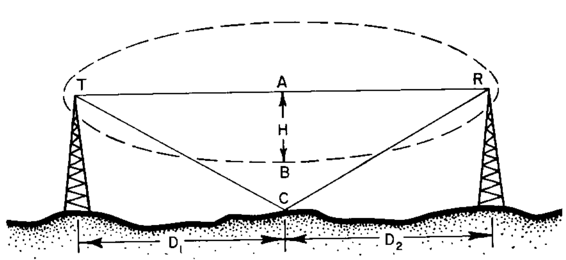


FIGURE 2 - 0.6 FRESNEL ZONE CLEARANCE (H)

To provide only free-space loss between the transmitter and receiver antennas, the direct path between the two antennas must clear obstructions by at least 0.6 of the first Fresnel zone (illustrated in Figure 2). When the distance TCR is equal to TAR plus half a wavelength, then AC is the height required for the first Fresnel zone clearance. For 0.6 Fresnel zone clearance (H), AB is six-tenths of AC. The actual zone of clearance is an ellipsoid, with one of the antennas at each of the focal points. The following equations can be used to calculate H:

$$AB = H = 1316\sqrt{\frac{D_1 \quad D_2}{F\ (D_1 + D_2)}} \qquad (1)$$

When D_1 is less than 1% of D_2:

$$AB = H = 1316\sqrt{\frac{D_1}{F}} \qquad (2)$$

D_1 = distance to obstruction in miles from one antenna.

D_2 = distance to obstruction in miles from other antenna.

D_1 and D_2 are chosen so that D_1 is less than or equal to D_2.

F = frequency in megacycles.

H = 0.6 Fresnel zone clearance in feet.

Graph 5C can be used to rapidly determine 0.6 Fresnel zone clearance, as described by Equations (1) and (2). A correction factor must be used where D_1 does not equal D_2. Notice that D_1 must be chosen so that it is equal to or smaller than D_2.

For transmission paths more than a few miles in length, earth curvature can have a noticeable effect on 0.6 Fresnel zone clearance. Equations (1) and (2) do not take earth curvature into account, but this can be determined by plotting the path on earth curvature profile paper (ECM-94) or by using Graph 5A for K = 4/3. Due to the greater bending of RF waves than light waves by the earth's atmosphere, the effect of earth curvature for RF waves is less. The K - 4/3 calculations use an earth curvature for an earth diameter one third larger than the physical diameter.

PLANE-EARTH OR SMOOTH-EARTH PROPAGATION (Graph 1D)

As the path clearance becomes less than 0.6 Fresnel zone, signal attenuation increases rapidly until it is at least twice the free-space attenuation. Notice in Figure 1 that the attenuation is approximately 12 db per octave (i.e., 12 db each time the path length is doubled) from approximately 5 miles to 15 miles. This is due to the lack of 0.6 Fresnel zone clearance in the example.

Beyond approximately 10 miles, diffraction losses, due to the earth's curvature, begin to increase the attenuation of the signal. The sum of plane-earth and diffraction losses reaches an attenuation of about 20 db per octave at about 50 miles.

SCATTER PROPAGATION (Graph 1C)

Until relatively recently, it was thought that the attenuation curve (see Figure 1) continued to rise more and more steeply beyond 50 miles. Actual measurements, however, showed that the attenuation over paths hundreds of miles long was consistently less than expected, due to a third type of propagation -- scatter propagation. Scatter propagation starts with an attenuation slope of approximately 20 db per octave and increases to beyond 30 db per octave at a range of 500 miles. Notice in the example in Figure 1 how the slope of the attenuation curve <u>decreases</u> beyond the point where scatter propagation begins.

SIGNAL STRENGTH CALCULATIONS[1]

The received power for base-to-base, base-to-mobile or mobile-to-base communication can be calculated by subtracting the transmission loss from the system gain. To calculate base-to-base signal strength, use Signal Strength Calculation Form 10003-3. As a guide for determining transmission losses, use Figure 3 or Table I.

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[1] Calculations made using this Bulletin should be sufficiently accurate for most estimates. For very high accuracy, refer to NBS Report 6767, Ground Telecommunication Performance Standards, 15 June 1961, U.S. Dept. of Commerce, National Bureau of Standards, Bolder, Colorado.

TABLE I - CALCULATING TRANSMISSION LOSSES

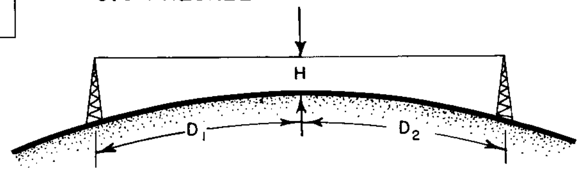
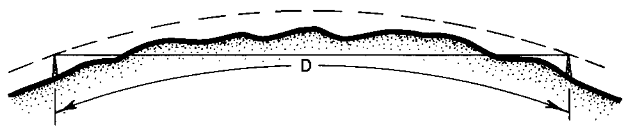
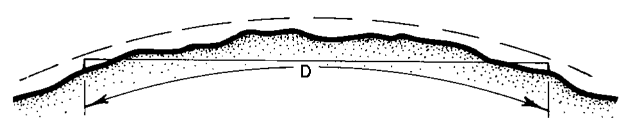
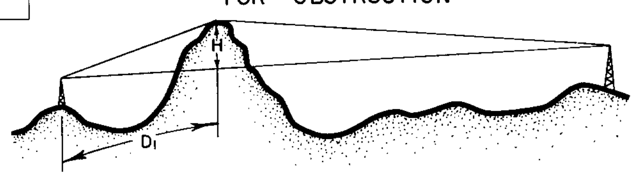
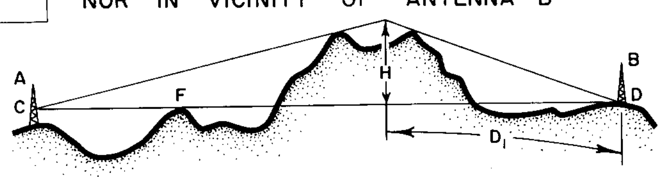
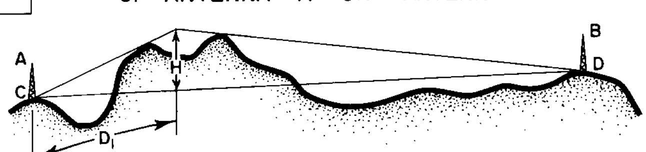
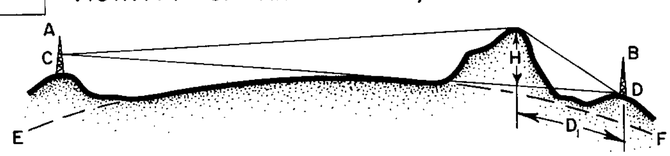
TYPE OF PATH	BOTH ANTENNAS LOWER THAN "LIMITING HEIGHT" SHOWN ON GRAPH 2A	ONE OR BOTH ANTENNAS HIGHER THAN "LIMITING HEIGHT" SHOWN ON GRAPH 2A	
		Within Line-of-Sight	Beyond Line-of-Sight
PLANE EARTH (up to approx. 10 miles)	Graph 1A or 1B or 1D	Graph 1A or 1B or 1D	
SMOOTH EARTH (from approx. 10 to 50 miles)	Graphs 1D and 2A	Graph 1A or 1B or 1D	Graphs 1A (or 1B) and 2B
IRREGULAR TERRAIN	Graphs 1D, 2A and 3B	Graphs 1D and 3B or 1A and 3B	Graphs 1A, 2B and 3B
PATHS LONGER THAN 50 MILES	Graph 1C (scatter propagation)		Graph 1C (scatter propagation)
	Graph 5B (empirical data)		Graph 5B (empirical data)

To calculate base-to-mobile or mobile-to-base signal strengths, use page 2 of Signal Strength Calculation Form 10003-3. Determine transmission losses by the same method used for base-to-base calculations, except use 20 feet for the mobile antenna height below 50 megacycles and use 6 feet above 100 megacycles. Losses due to terrain factors, determined from Graph 3A, must also be added.

Using an effective mobile antenna height of 20 feet (below 50 MC) or 6 feet (above 100 MC) will produce calculations in most situations. If the transmission path lies largely over sea water or poor soil (rocky or sandy soil), however, the accuracy can be improved by either using the actual mobile antenna height (at the feed point) or the minimum effective height (determined from Figure 4) --- whichever is higher. This is particularly true for low-band systems (25-50 MC). The effects of ground conductivity on propagation are discussed in more detail in DATAFILE Bulletin 10003-2.

When a typical quarter-wave whip antenna is mounted on the roof of an ordinary passenger car, the feed point of the antenna is about six feet above the ground. Due to the surface wave, however, the effective height of the antenna may be as high as 180 feet at 40 MC or 22 feet at 160 MC. Below this height --- called the "minimum effective height" --- the signal strength is not appreciably affected by changes in the antenna height. Above the minimum effective height, received power increases approximately 6 db every time the antenna height is doubled (until free-space transmission is reached). Below this height, the actual height of the antenna can be ignored and the minimum effective height used for calculating path losses. Notice in Figure 4 that the minimum effective height is considerably higher over

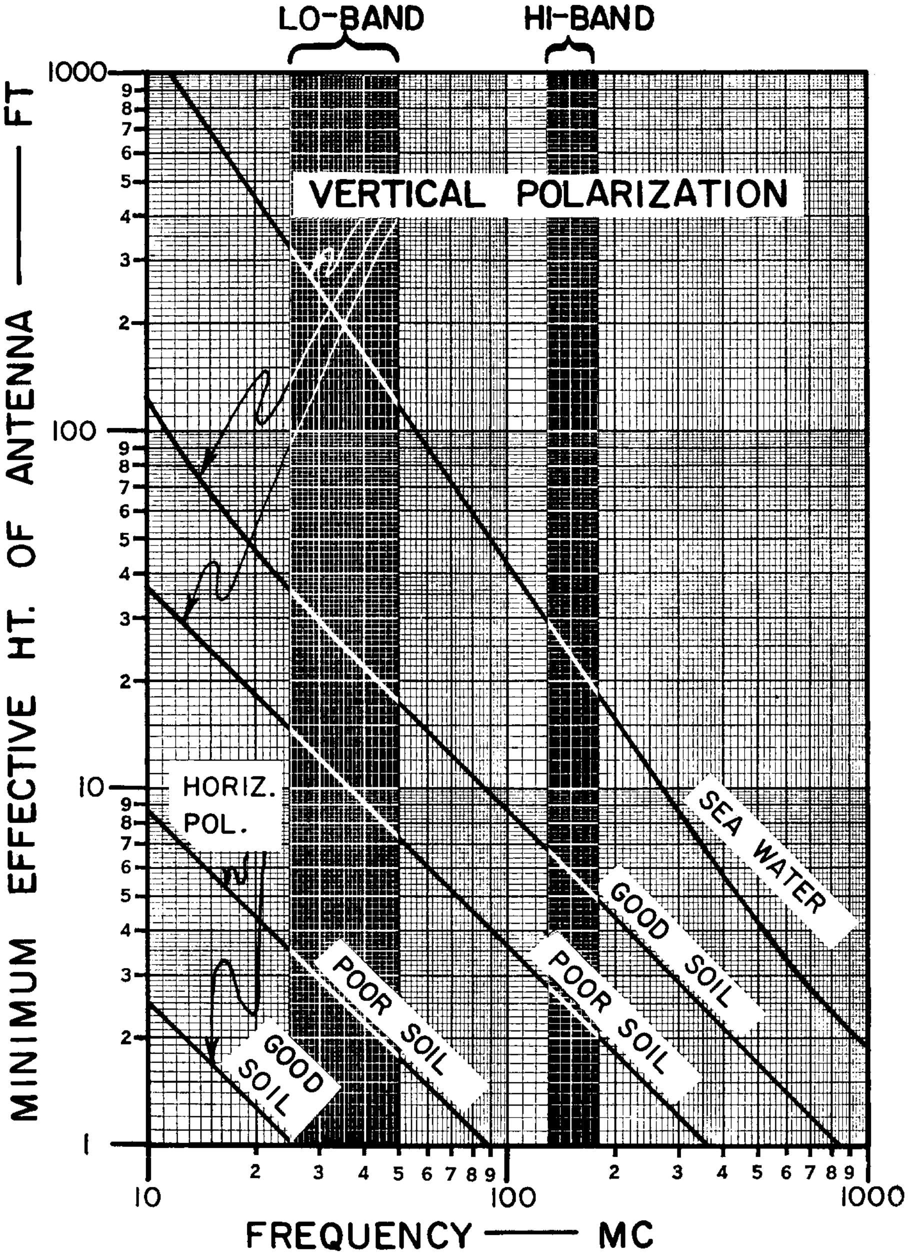
FIGURE 3 — CALCULATION OF POINT - TO - POINT PATH LOSS

	TYPE OF PROFILE (K= 4/3)	TO DETERMINE PATH LOSS
LINE-OF-SIGHT	**A** 0.6 FRESNEL ZONE CLEARANCE 	● PLOT PATH ON 4/3 EARTH CURVATURE PROFILE PAPER. ● USING GRAPH 5C, CHECK TO SEE THAT H IS 0.6 FRESNEL ZONE CLEARANCE. ● IF H IS LARGE ENOUGH TO PROVIDE 0.6 FRESNEL ZONE CLEARANCE, COMPUTE FREE-SPACE ATTENUATION FROM GRAPH 1A OR 1B.
NON - OPTICAL	**B** IRREGULAR TERRAIN ● NO PEAKS TALLER THAN ANTENNAS ● D IS LESS THAN 50 MILES 	● DETERMINE PLANE-EARTH LOSS FROM GRAPH 1D AND ADD DIFFRACTION LOSS FROM GRAPH 2A. ● ALTERNATE METHOD: ADD LOSSES DETERMINED FROM GRAPH 2B TO FREE-SPACE LOSSES FROM GRAPH 1A.
NON - OPTICAL	**C** IRREGULAR TERRAIN ● NO TALL PEAKS D IS GREATER THAN 50 MILES 	● DETERMINE PATH LOSS FROM GRAPH 5B. GRAPH 5A IS USEFUL IN FINDING DISTANCE TO HORIZON (K=4/3). ● ALTERNATE METHOD: USE GRAPH 1C FOR SCATTER ATTENUATION. BE SURE TO USE FREQUENCY-CORRECTION FACTOR, IF NEEDED.
LINE-OF-SIGHT EXCEPT FOR OBSTRUCTION	**D** 0.6 FRESNEL ZONE CLEARANCE EXCEPT FOR OBSTRUCTION 	● USING GRAPH 5C CHECK FOR 0.6 FRESNEL ZONE CLEARANCE AT CENTER OF PATH. ● DETERMINE FREE-SPACE LOSS FROM GRAPH 1A AND ADD SHADOW LOSS FROM GRAPH 3B (USING SCALE "H FOR FREE SPACE").
LINE-OF-SIGHT EXCEPT FOR OBSTRUCTION	**E** NO 0.6 FRESNEL ZONE CLEARANCE AT F NOR IN VICINITY OF ANTENNA B 	● DRAW PLANE-EARTH LINE FROM BASE OF ANTENNA B THROUGH F TO INTERSECT ANTENNA A AT C. AC IS EFFECTIVE HEIGHT OF ANTENNA A. ● USE PRODUCT OF EFFECTIVE ANTENNA HEIGHTS (AC X BD) TO DETERMINE PLANE-EARTH LOSS FROM GRAPH 1D. ● INCREASE ATTENUATION BY SHADOW LOSS DETERMINED FROM GRAPH 3B (USING SCALE "H FOR SMOOTH EARTH").
LINE-OF-SIGHT EXCEPT FOR OBSTRUCTION	**F** NO 0.6 FRESNEL ZONE CLEARANCE IN VICINITY OF ANTENNA A OR ANTENNA B 	● DRAW PLANE-EARTH LINE CD FROM BASE OF ANTENNA A TO BASE OF ANTENNA B. ● USE PRODUCT OF EFFECTIVE ANTENNA HEIGHTS (AC X BD) TO DETERMINE PLANE-EARTH LOSS FROM GRAPH 1D. ● INCREASE ATTENUATION BY SHADOW LOSS DETERMINED FROM GRAPH 3B (USING SCALE "H FOR SMOOTH EARTH").
LINE-OF-SIGHT EXCEPT FOR OBSTRUCTION	**G** 0.6 FRESNEL ZONE CLEARANCE IN VICINITY OF ANTENNA A, BUT NOT B 	● DRAW ARC EF, RUNNING THROUGH LOWEST ELEVATION ALONG PATH. ● DRAW PLANE-EARTH LINE FROM BASE OF ANTENNA B, TANGENT TO ARC EF, TO INTERSECT ANTENNA A AT C. AC IS EFFECTIVE HEIGHT OF ANTENNA A. ● USE PRODUCT OF EFFECTIVE ANTENNA HEIGHTS (AC X BD) TO DETERMINE PLANE-EARTH LOSS FROM GRAPH 1D. ● INCREASE ATTENUATION BY SHADOW LOSS DETERMINED FROM GRAPH 3B (USING SCALE "H FOR SMOOTH EARTH").

RC-782

sea water or good soil than over poor soil in low band. In high band, the actual antenna height will normally approximate or exceed minimum effective height, unless the path lies over sea water.

Figure 4 - Minimum Effective Antenna Heights



GRAPH 1A

Free-Space attenuation in db at a given frequency and distance can be determined by following the appropriate point on the distance scale up to the curve for the appropriate frequency, and then across to a reading on the "DB" scale.

GRAPH 1B

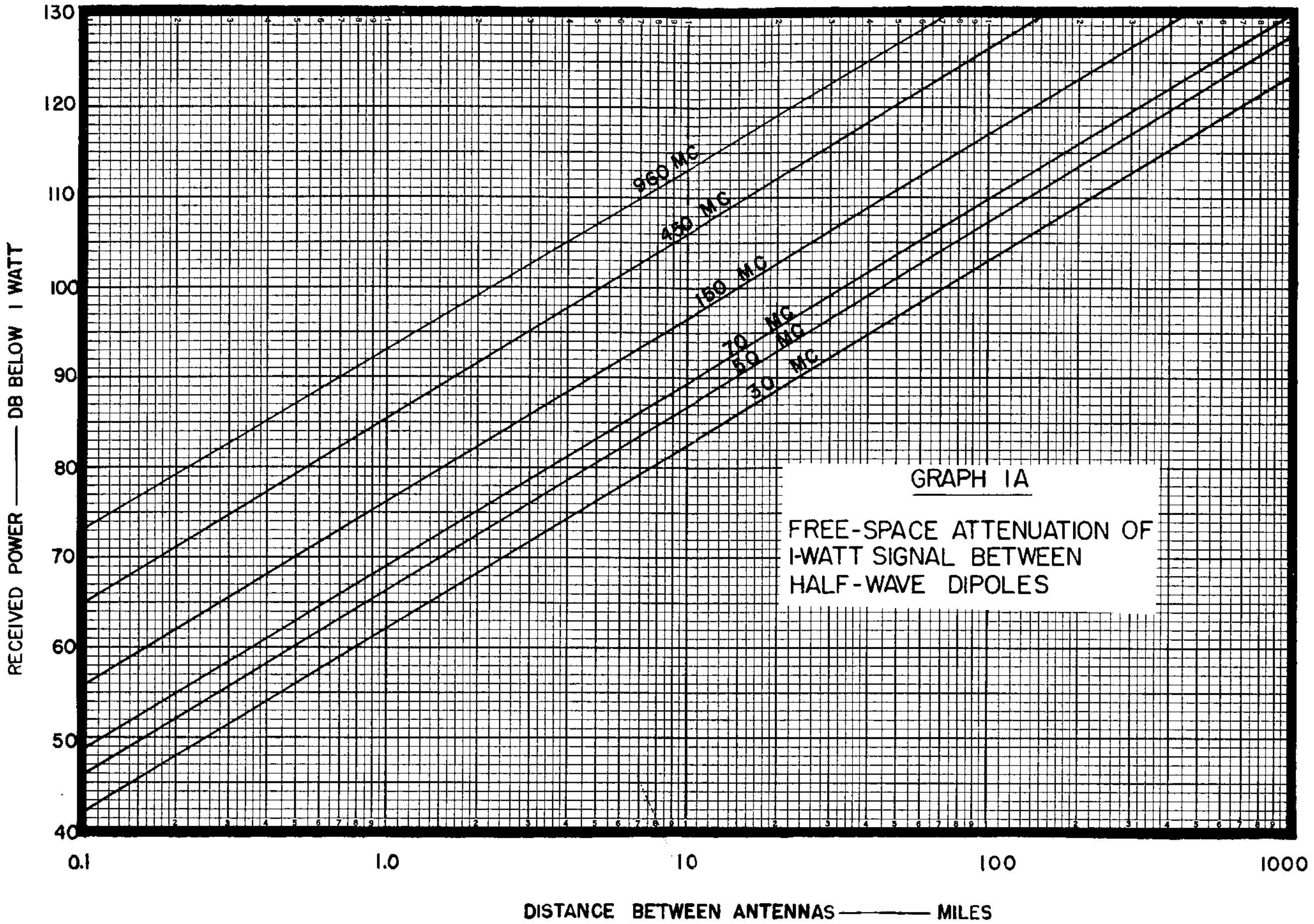
Same as Graph 1A, except that the distance and frequency scales have been reversed. Most useful for short paths (up to two miles).

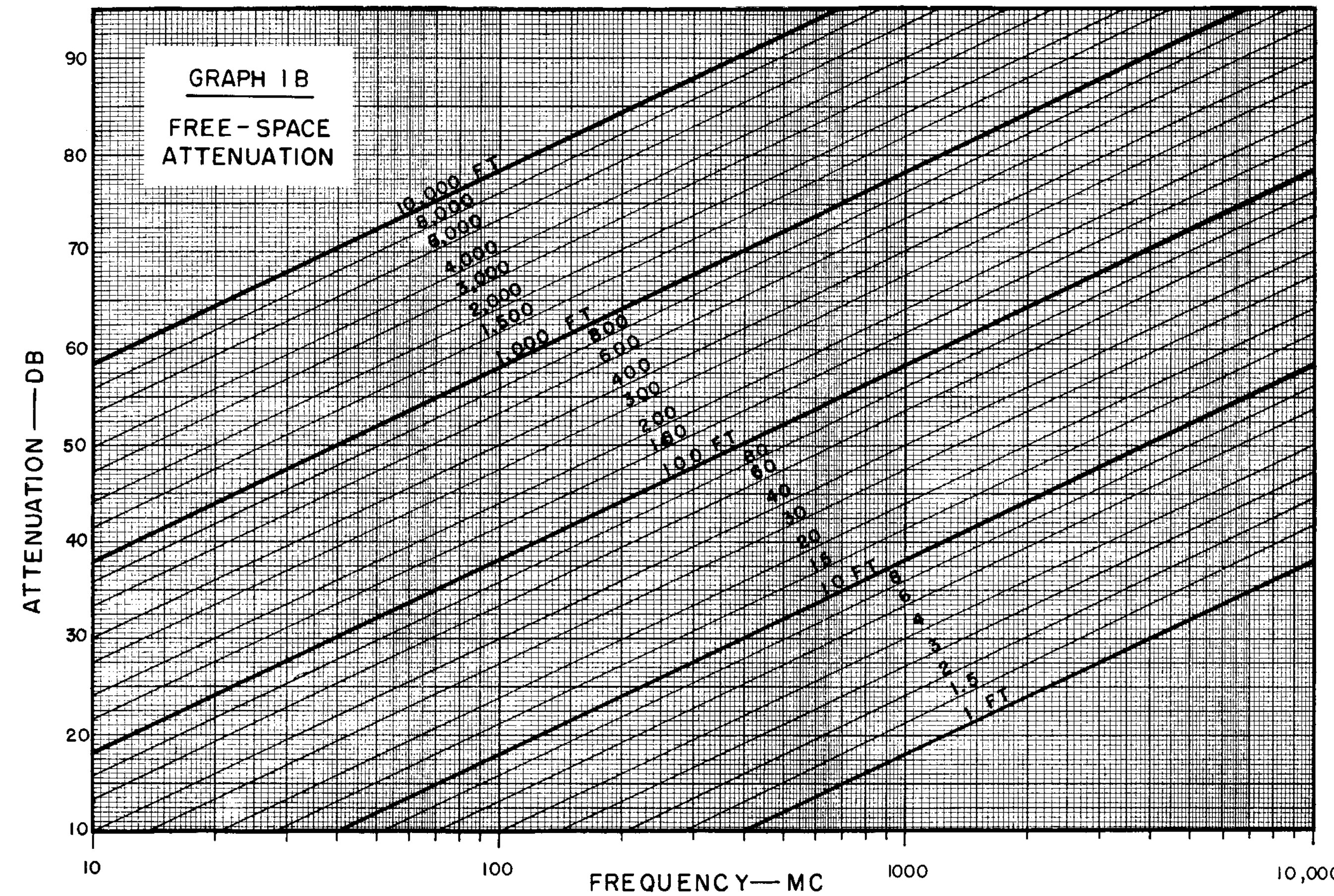
GRAPH 1C

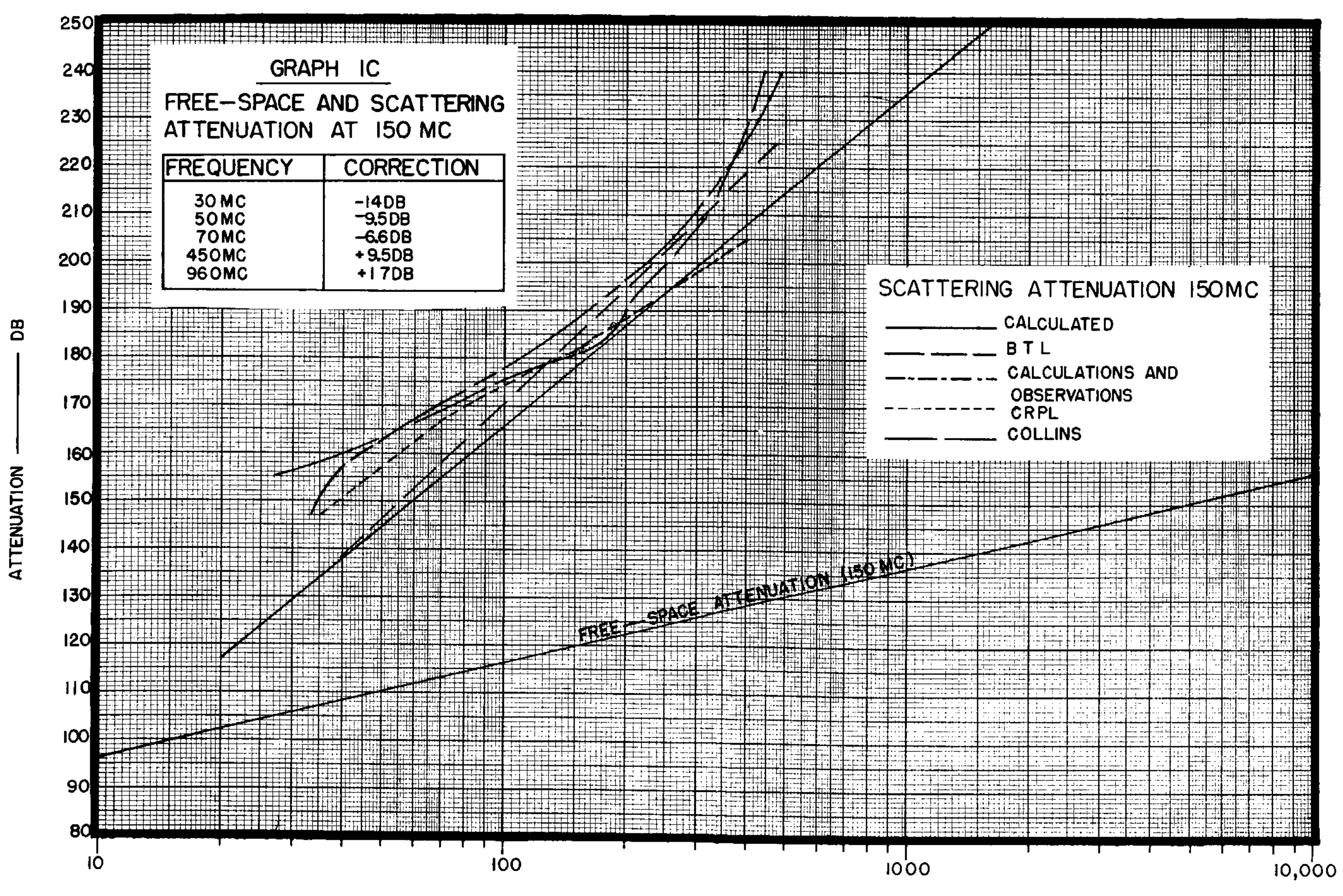
Scatter attenuation curves at 150 MC are shown, which are taken from various calculated and observed data. To determine scatter attenuation at other frequencies, it is necessary to add or subtract the correction values.

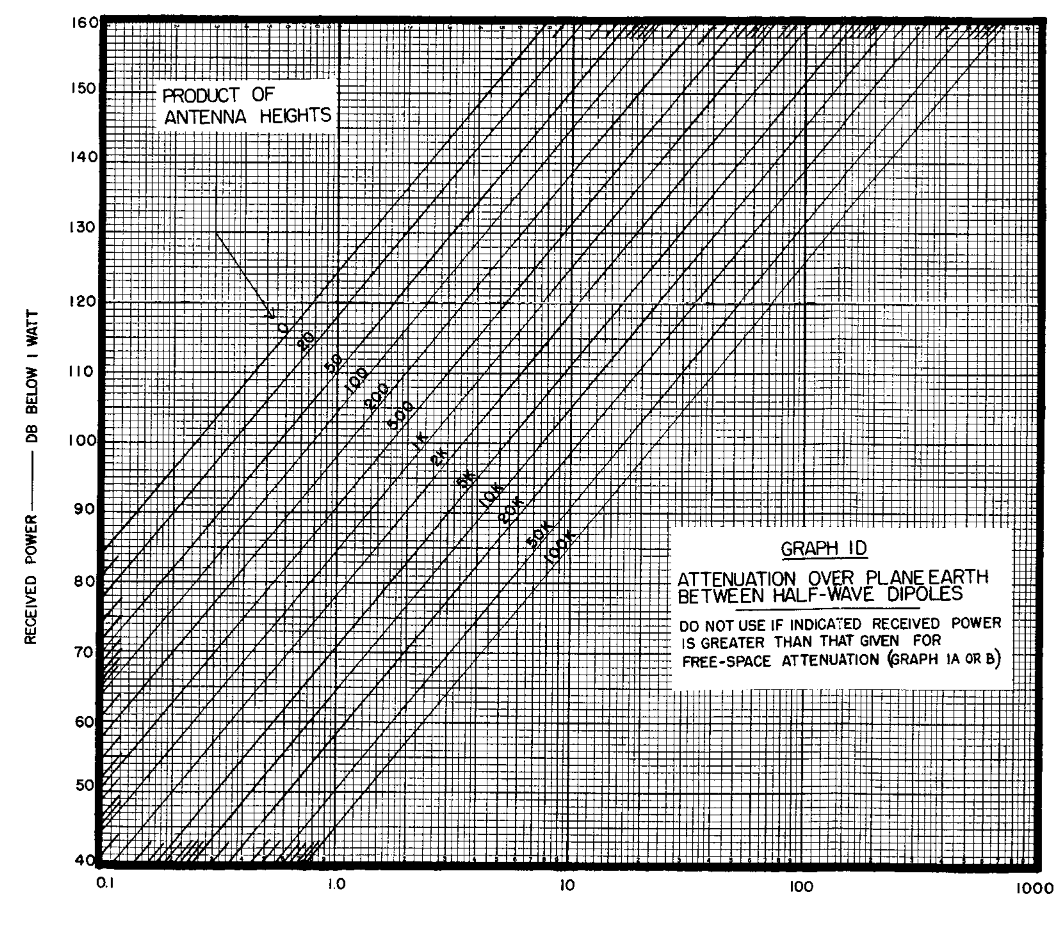
GRAPH 1D

The attenuation over plane earth (no earth curvature) between two half-wave dipoles may be determined by reading the line corresponding to the product of the effective heights of the two dipoles. Do not use this graph if the attenuation is less than the value obtained from Graph 1A (or Graph 1B) for free-space loss at the same distance and frequency.









Graphs 1A, 1B, 1C & 1D

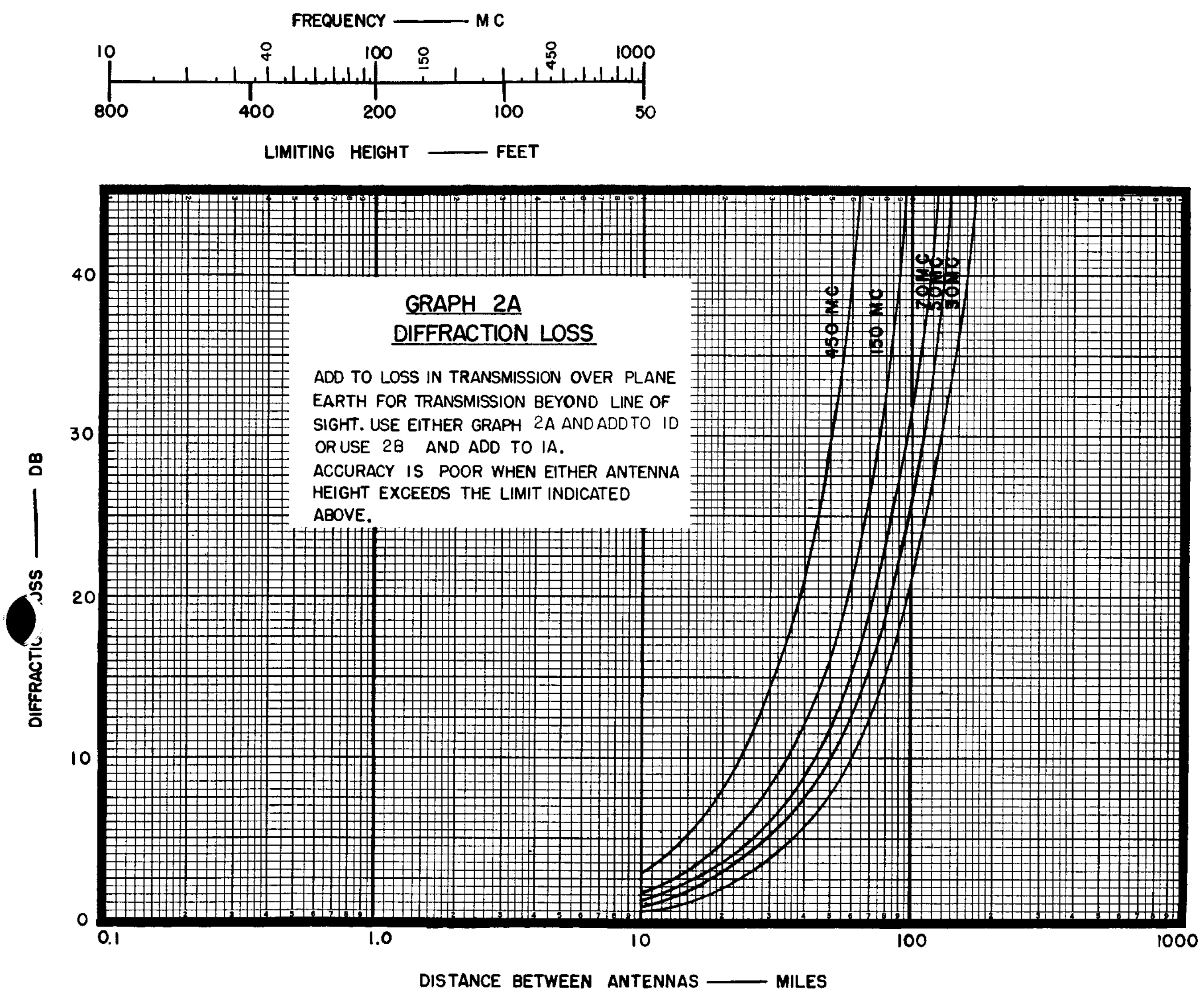
FREE-SPACE ATTENUATION,
PLANE-EARTH ATTENUATION,
SCATTERING ATTENUATION

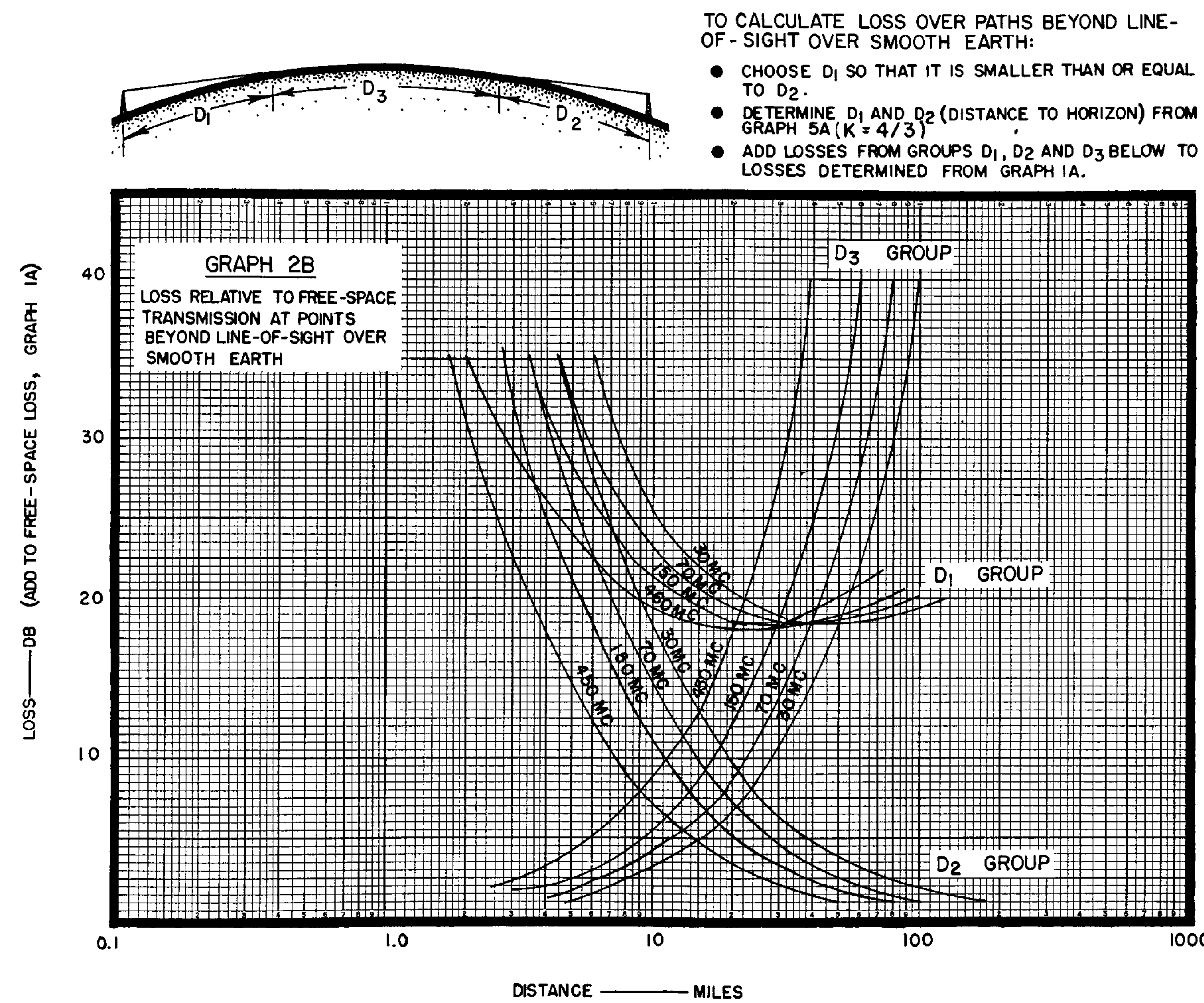
GRAPH 2A

The total transmission loss for paths beyond line-of-sight over smooth earth can be determined by adding the diffraction loss, due to the curvature of the earth, to the plane-earth loss found from Graph 1D. Diffraction loss becomes significant between 10 and 20 miles and produces loss greater than scatter loss beyond 50 miles. Figure 1 illustrates this rapid attenuation of the signal beyond 50 miles (over smooth earth). The accuracy of this graph is poor when either antenna height exceeds the "LIMITING HEIGHT" indicated in the scale above the graph.

GRAPH 2B - ALTERNATE METHOD

This graph presents an alternate method of determing the transmission loss due to the earth's curvature. Use Graph 5A for K=4/3 to find D_1 and D_2. Add the losses determined from the "D_1 GROUP", the "D GROUP" and the "D_3 GROUP" to the losses determined from Graph 1A. Losses determined by this method should agree within approximately 3 db with losses determined by the method described above. For ranges beyond 50 miles, Graph 1C or 5B should be used, when the indicated loss is due to scatter.





Graphs 2A and 2B

DIFFRACTION LOSS CURVES

GRAPH 3A

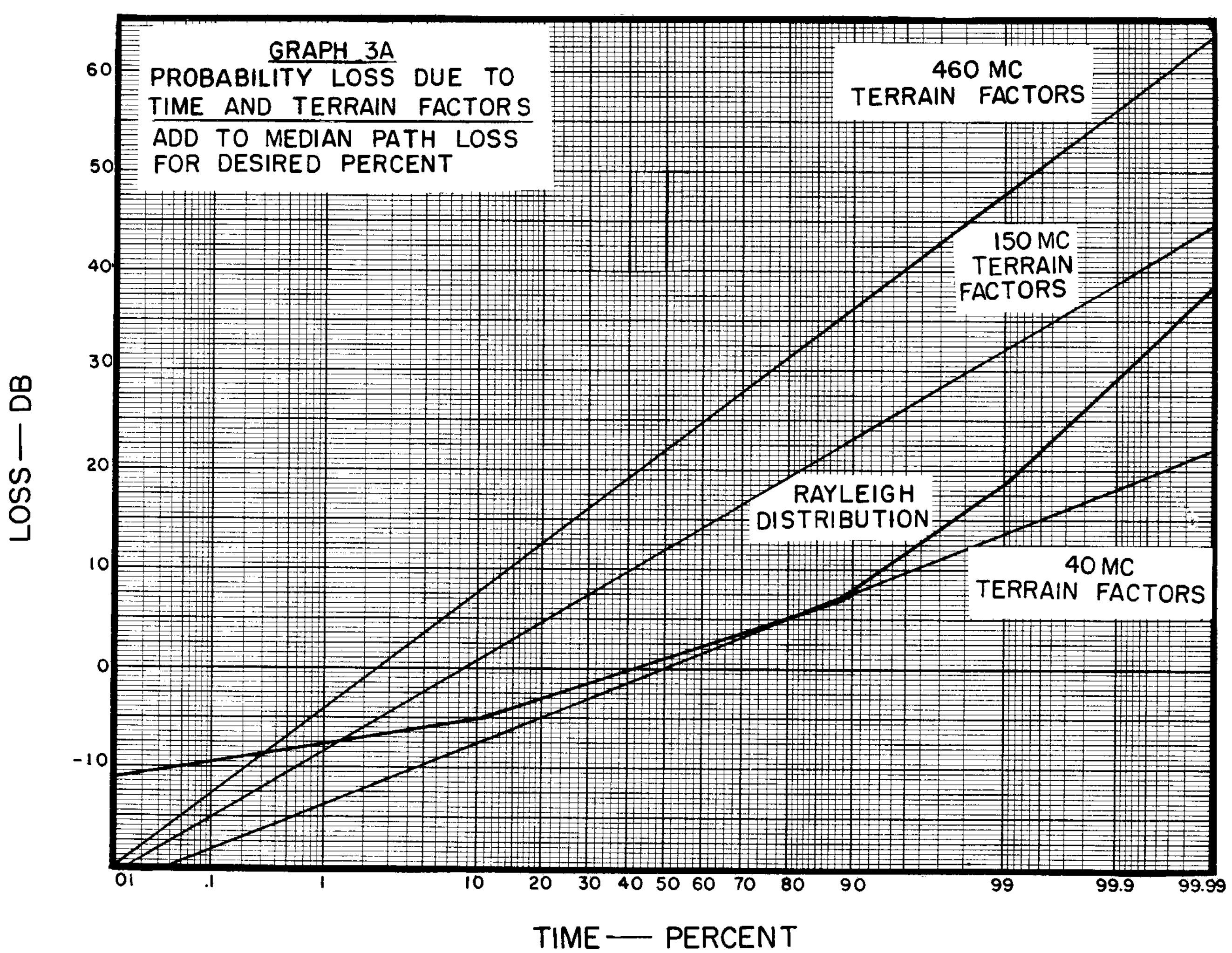
Two types of probability loss vs, percent of coverage time are shown on this graph. The Rayleigh distribution curve should be used for base-to-base paths, where the terrain contour between the two base stations is well known. The three "TERRAIN FACTOR" curves should be used for calculating base-to-mobile or mobile-to-base coverage for the desired frequency.

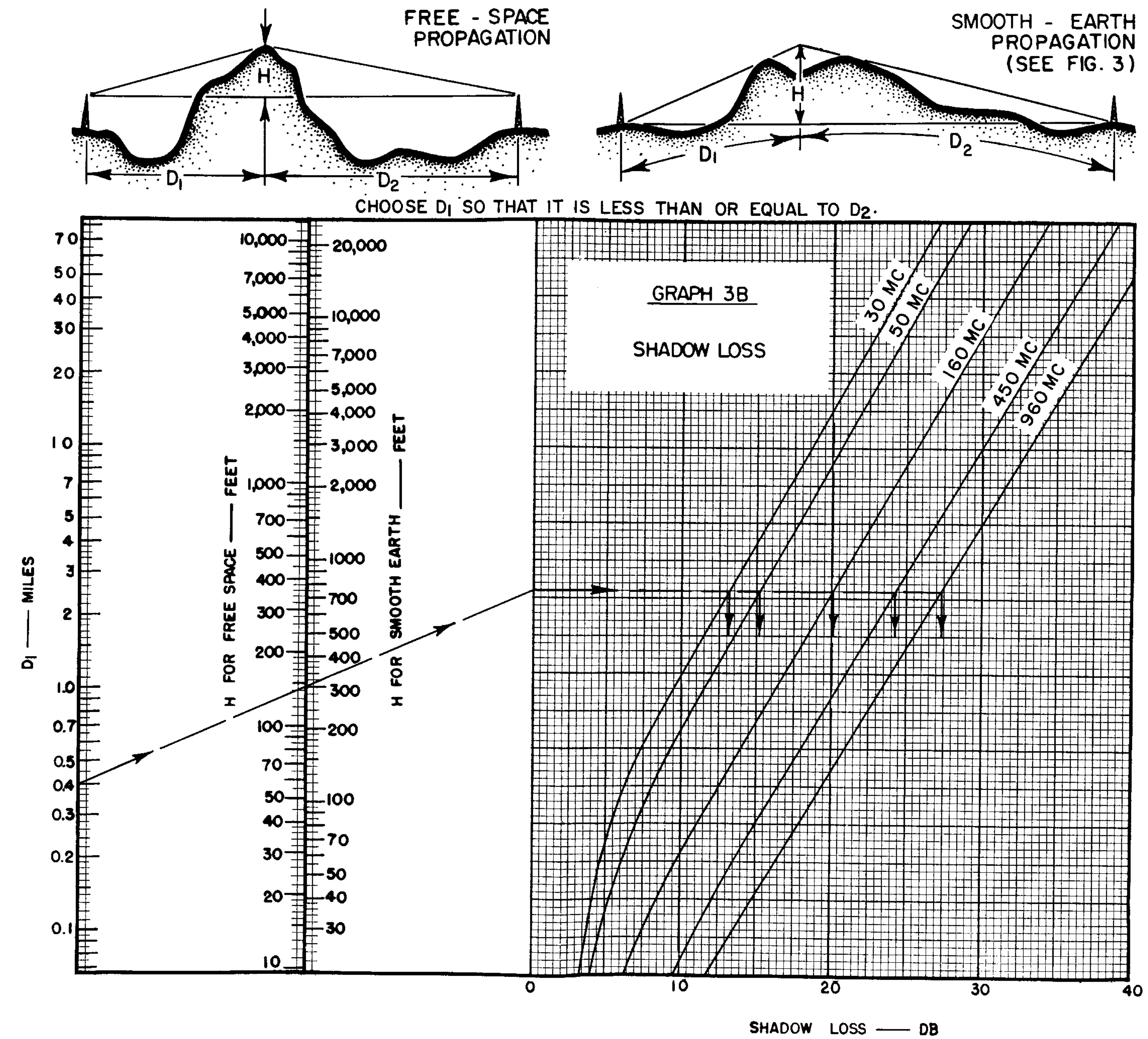
GRAPH 3B

This graph is used to determine the shadow loss, due to an obstruction in what is otherwise a line-of-sight path. Where both antennas have 0-6 Fresnel zone clearance, the "H FOR FREE SPACE" scale is used. Otherwise, the "H FOR SMOOTH EARTH" scale is used. D_1 is the distance from the obstruction to the nearer antenna.

To determine the shadow loss, draw a straight line from the D_1 scale through the appropriate H scale to intersect the zero shadow loss line. From the zero line, proceed horizontally to the curve for the appropriate frequency and read the loss below.

PROBABILITY LOSS DUE TO TIME & TERRAIN FACTORS



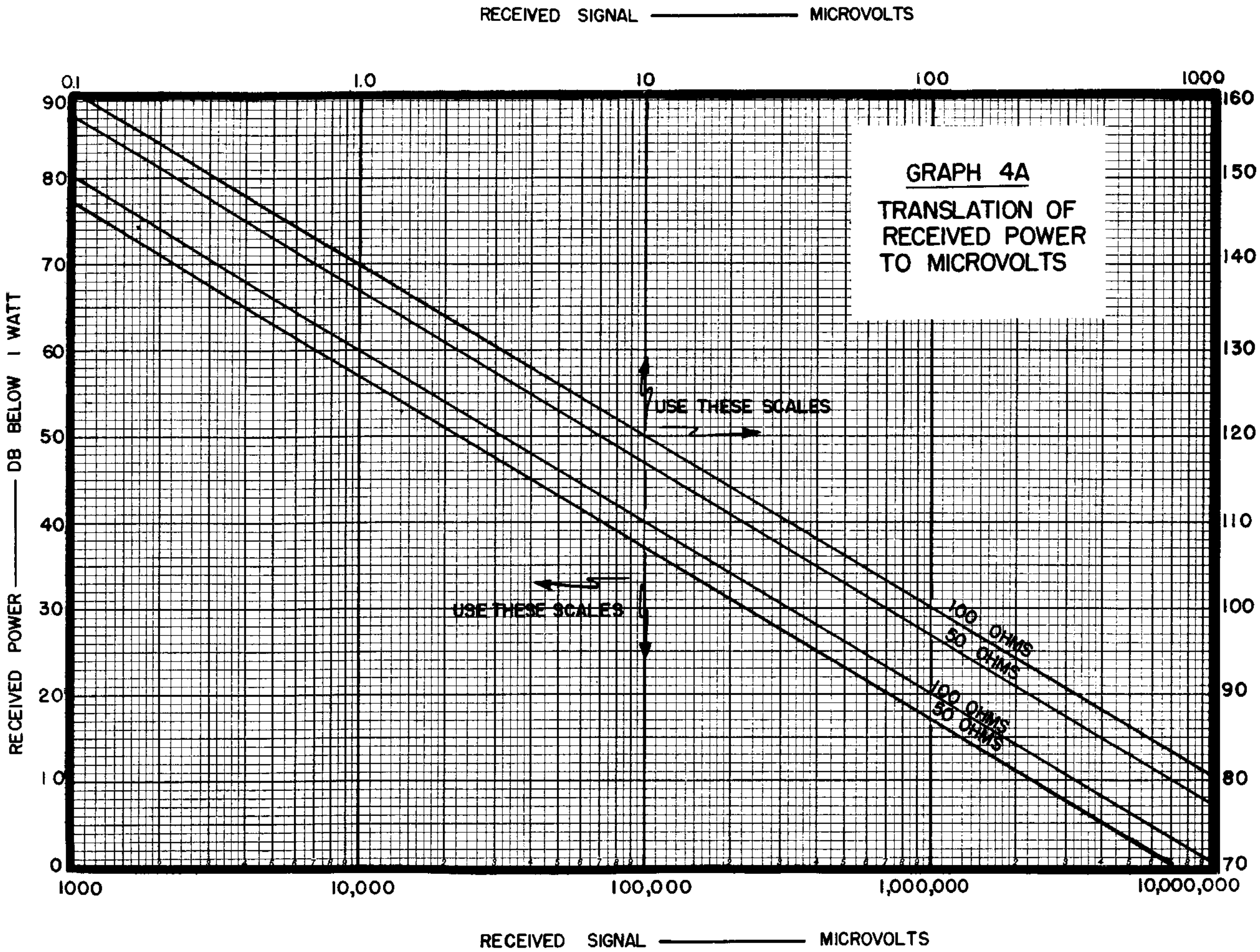


Graphs 3A and 3B

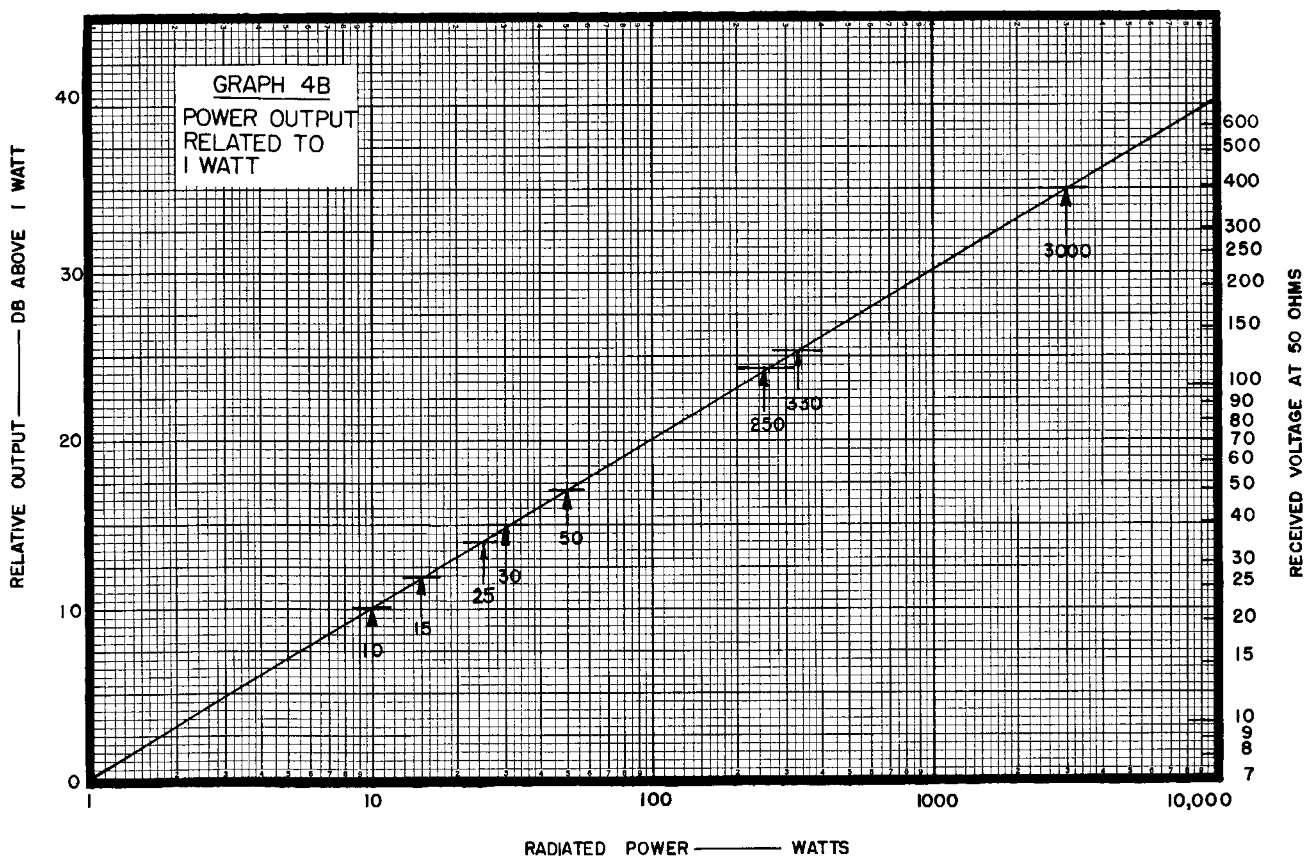
PROBABILITY LOSS CURVE & SHADOW LOSS CURVE

GRAPHS 4A, 4B AND 4C

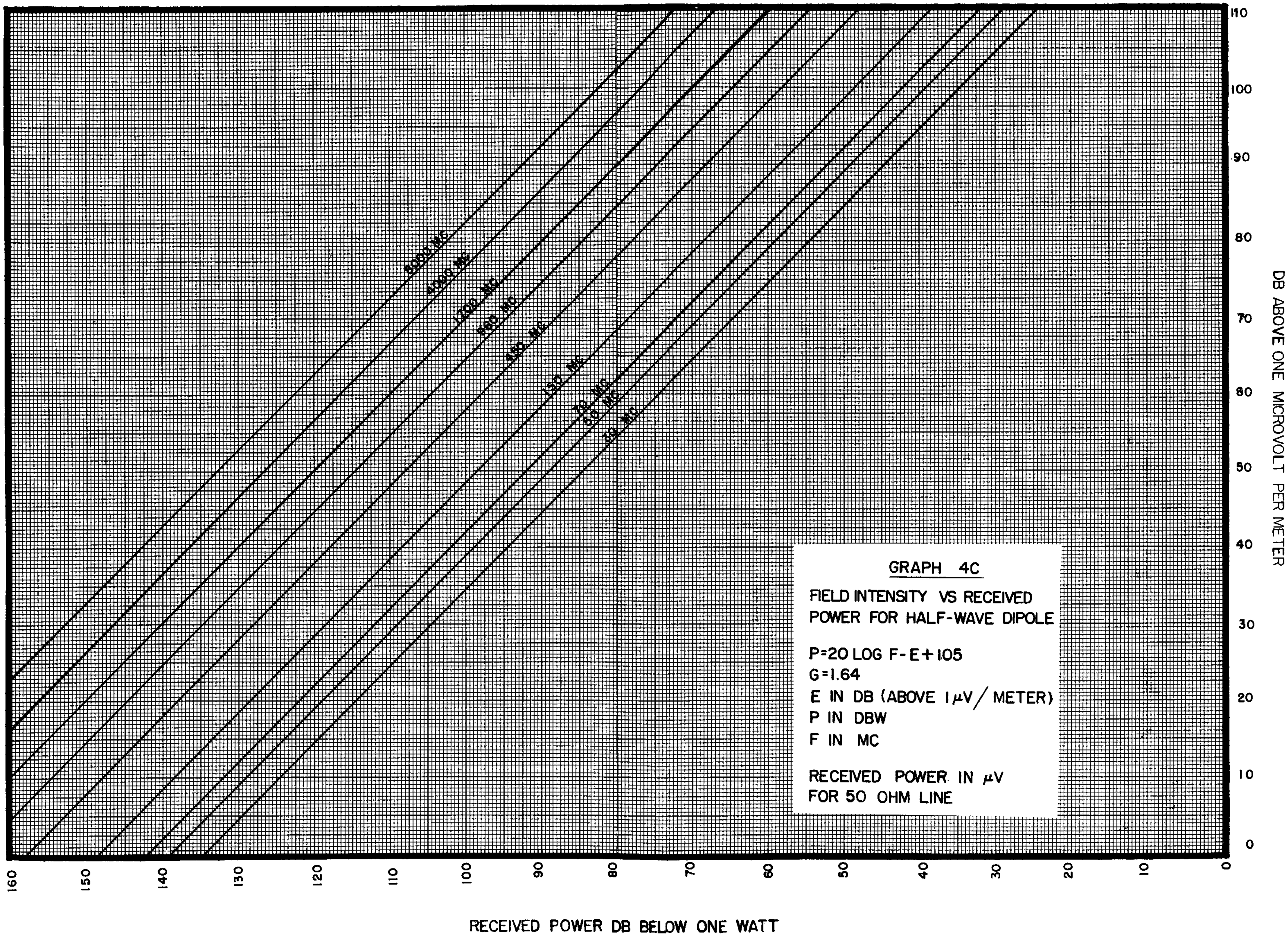
These three graphs provide conversion data necessary for calculating signal strengths from known data.



RECEIVED SIGNAL — MICROVOLTS
0.1
1.0
10
100
1000
GRAPH 4A
TRANSLATION OF RECEIVED POWER TO MICROVOLTS
USE THESE SCALES
USE THESE SCALES
100 OHMS
50 OHMS
100 OHMS
50 OHMS
RECEIVED POWER — DB BELOW 1 WATT
90
80
70
60
50
40
30
20
10
0
160
150
140
130
120
110
100
90
80
70
1000
10,000
100,000
1,000,000
10,000,000
RECEIVED SIGNAL — MICROVOLTS



GRAPH 4B
POWER OUTPUT RELATED TO I WATT
RELATIVE OUTPUT — DB ABOVE I WATT
40
30
20
10
0
RECEIVED VOLTAGE AT 50 OHMS
600
500
400
300
250
200
150
100
90
80
70
60
50
40
30
25
20
15
10
9
8
7
10
15
25
30
50
250
330
3000
1
10
100
1000
10,000
RADIATED POWER — WATTS



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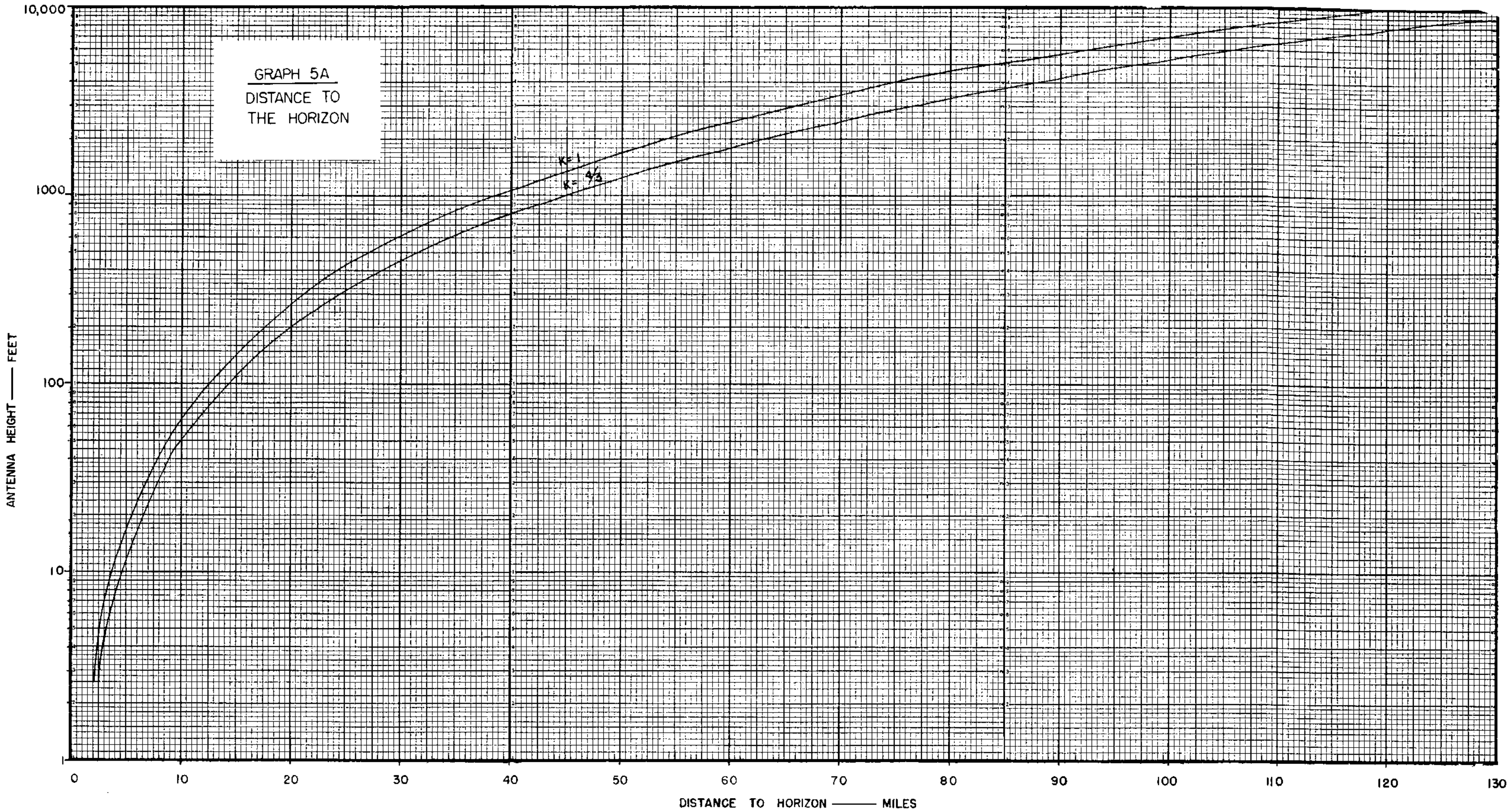
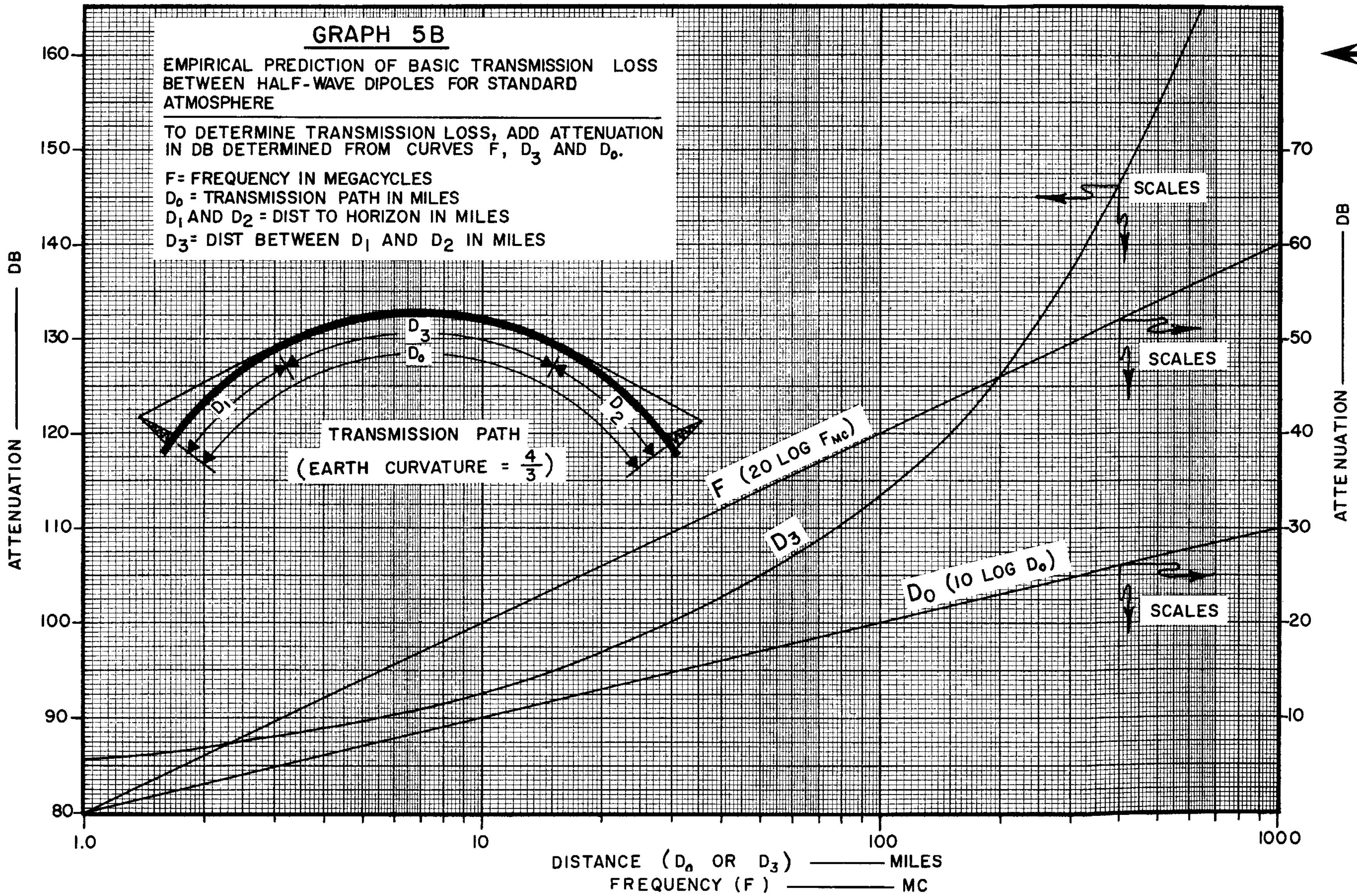




GRAPH 5A

The two curves show the distance to the horizon over smooth terrain for both physical and radio transmission purposes. Use K = 1 for the physical distance and K = 4/3 for the radio transmission distance to the horizon. All graphs in this Bulletin referring to distance to the horizon are based on K = 4/3.

GRAPH 5B

For base-to-base transmissions beyond 50 miles, empirical predictions determined from this graph will be within 10 db of the basic transmission loss for the actual path. D_1 and D_2 can be determined from Graph 5A for K = 4/3.

GRAPH 5C

The distance required for 0.6 Fresnel zone clearance (H) at the center of a path (D_1 - D_2) can be read directly from this graph. For other points along the path, H must be multiplied by the correction factor determined from the small graph. The maximum correction factor is $\sqrt{2}$, when D_1 is less than 1% of D_2. Notice that D_1 must be chosen so that it is equal to or less than D_2.

GRAPH 5A

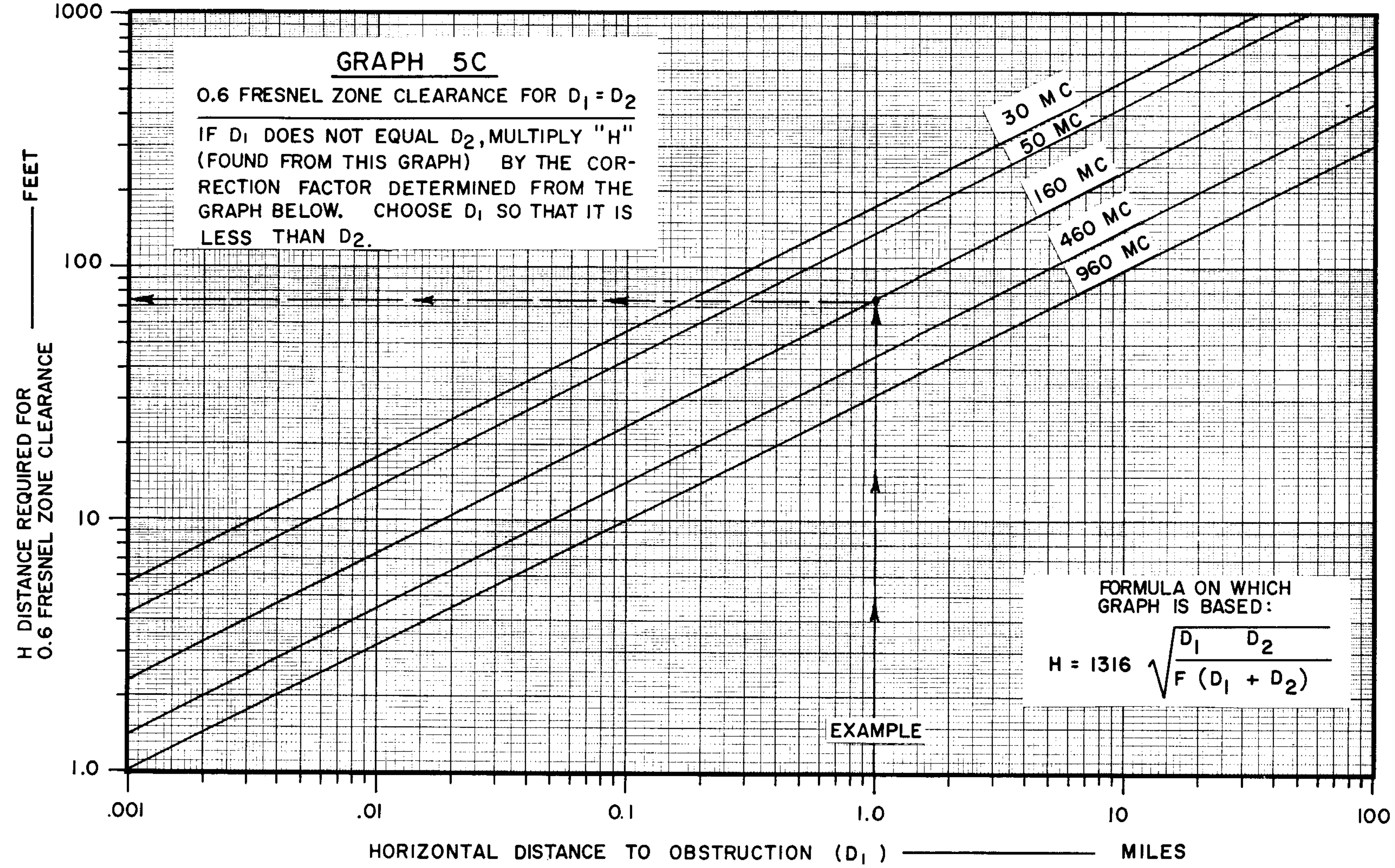
The two curves show the distance to the horizon over smooth terrain for both physical and radio transmission purposes. Use K = 1 for the physical distance and K = 4/3 for the radio transmission distance to the horizon. All graphs in this Bulletin referring to distance to the horizon are based on K = 4/3.

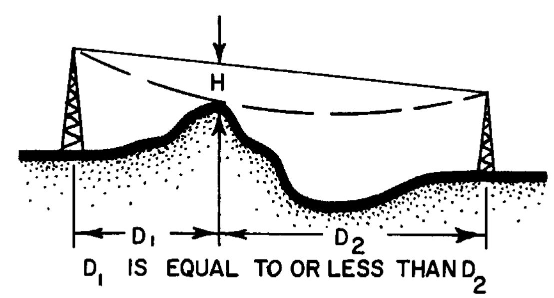
GRAPH 5B

For base-to-base transmissions beyond 50 miles, empirical predictions determined from this graph will be within 10 db of the basic transmission loss for the actual path. D_1 and D_2 can be determined from Graph 5A for K = 4/3.

GRAPH 5C

The distance required for 0.6 Fresnel zone clearance (H) at the center of a path (D_1 - D_2) can be read directly from this graph. For other points along the path, H must be multiplied by the correction factor determined from the small graph. The maximum correction factor is $\sqrt{2}$, when D_1 is less than 1% of D_2. Notice that D_1 must be chosen so that it is equal to or less than D_2.

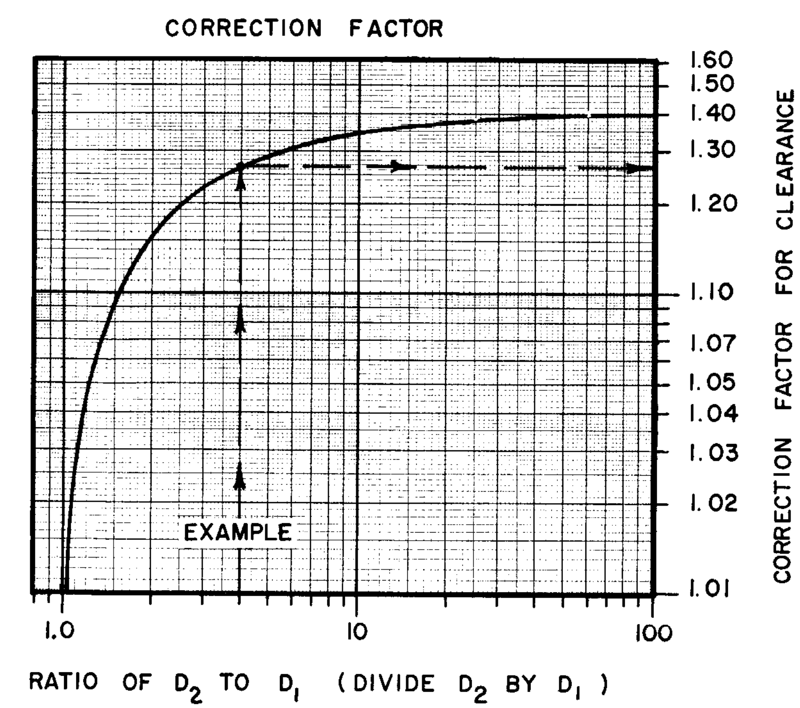




EXAMPLE

IF D_1 = 1 MILE, D_2 = 4 MILES AND FREQ. = 160 MC, CORRECTION FACTOR = 1.265 (SEE GRAPH AT RIGHT).

0.6 FRESNEL ZONE CLEARANCE = H (SEE GRAPH ABOVE) X CORRECTION FACTOR = 74 X 1.265 = 93.6 FEET.



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