

The Joint Radio Committee of the Nationalised Power Industries

A Guide to the Evaluation of
Effective Radiated Power
for Point-to-Point Radio Links
in the 450 - 470 MHz Band

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SECTION 1 - INTRODUCTION

The purpose of the paper is to provide a guide and some references to the assessment of effective radiated power required for a system such that the received input power level is in accordance with the parameters given in the Ministry Specification W6457 and W6458. (7) The paper is not intended to be complete in itself and it is strongly urged that the paper be read in conjunction with Chapter 14 of item 1 under bibliography.

1.1 Definitions of Effective Radiated Power (e.r.p)

1.1.1 British Standards Institution Definition (8)

In a given direction. The product of the power gain of the aerial in that direction and the total power radiated by the aerial divided by the power gain (maximum) of a half-wave dipole.

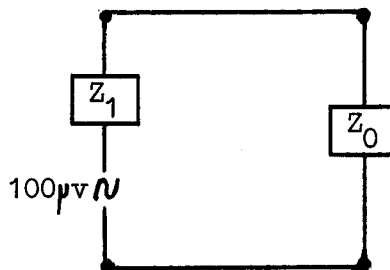
1.1.2 Ministry of Posts & Telecommunications Definition (7)

For the purposes of the Ministry Specification the e.r.p is the average power supplied to the aerial by the transmitter during one radio frequency cycle under conditions of no modulation multiplied by the gain relative to a half-wave dipole, of the aerial system in the direction of maximum radiation.

1.2 System Alignment

Reference item 3.1 page 23 of the "Provisional Specification for Single Channel Systems in the 450-470 MHz Band", W6458, the maximum permitted receiver input is 20 dB above the input required to give a signal-to-noise ratio of 40 dB. This takes into account a permitted allowance of 10 dB for fading and 10 dB for equipment deterioration.

Specification W6457 for the radio equipment specifies a minimum standard of 20 dB for the receiver input required to produce a signal-to-noise ratio of 40 dB, therefore, the maximum allowed value for the initial alignment e.m.f at the receiver input is $(20 + 20)$ dB relative to one microvolt. This is equal to 100 microvolts e.m.f or 50 microvolts p.d., if the aerial impedance matches the receiver input impedance, but the circuit may be represented in general as:



where Z_1 = aerial impedance

Z_0 = receiver impedance

Therefore potential difference (p.d) across $Z_0 = \frac{100}{Z_1 + Z_0} \cdot Z_0 = 50$

when $Z_1 = Z_0$.

If to give a 40 dB signal-to-noise ratio, the receiver actually requires X dB relative to one microvolt, then the required input will be (20 + X) dB relative to one microvolt e.m.f where X must be less than 20.

Thus the e.r.p to be quoted on the Form BR11 "Application for a Private UHF Point-to-Point Link", under item 32, shall be that which has been evaluated from consideration of the system gains and losses, to give an e.m.f (20 + X) dB relative to one microvolt and not exceeding 100 microvolts e.m.f, at the receiver input.

In all cases, in attaining these figures, the effective radiated power shall not exceed 250 watts and the transmitter output shall not exceed 15 watts.

SECTION 2 - SYSTEM LOSSES AND GAINS

If we consider a path between two sites A and B, we can represent the various losses and gains throughout the system as in Table 1.

TABLE 1

Item	Direction	
	A to B	B to A
(a) Transmitter Output Level	PdBW	UdBW
(b) Transmitter Feeder Loss	QdB	QdB
(c) Aerial (Tx) Gain	TdB	TdB
(d) Path Loss	SdB	SdB
(e) Aerial (Rx) Gain	TdB	TdB
(f) Receiver Feeder Loss	QdB	QdB
Addition of Items (a) to (f) to give Receiver input power level	RdBW	RdBW

dBW is the level of power in decibels above or below 1 watt.

For example:-

$$\text{Transmitter output level PdBW} = 10 \log_{10} \frac{G_2}{G_1}$$

where G_2 = output in watts of transmitter

$$G_1 = 1$$

Assumptions made in compiling the above table are that:

- (a) the feeder losses at both sites are the same. This may not necessarily be the case, and
- (b) aerial gains for the transmitter and receiver at both sites are the same. The specification for the aerial systems is given under item 2.2 of the Ministry specification W6458, but does not require similar transmitter/receiver aerials to be used.

The required input is calculated in terms of dBW. The data in the specification W6458 is quoted in microvolts e.m.f or half the value in p.d (see 1.2).

To convert from microvolts to dBW the equation

$$\text{dBW} = -10 \log \frac{(Z_0 \cdot 10^{12})}{(V)^2} \dots\dots\dots(1)$$

can be used.

V is the signal input voltage expressed in microvolts p.d.

Z₀ is the receiver input impedance.

Example

If a receiver of 50 ohms input impedance requires 18 dB relative to 1 microvolt e.m.f. for a 40 dB signal-to-noise ratio, then:-

$$\begin{aligned} \text{Required input} &= (20 + 18) \text{ dB} \\ &= 38 \text{ dB relative to 1 microvolt} \\ &= 80 \text{ microvolts e.m.f.} \end{aligned}$$

If aerial impedance is 50 ohms then:-

$$\begin{aligned} \text{p.d. at receiver input} &= 40 \text{ microvolts (ref 1.2)} \\ \text{Input power into 50 ohms} &= 10 \log \frac{(50 \times 10^{12})}{(40)^2} \\ &= \underline{\underline{-105 \text{ dBW}}} \end{aligned}$$

It is suggested that all calculations are dealt with in levels of power, dBW or if necessary dBm.

Level in dBm - 30 = Level in dBW.

(dBm = decibels above or below 1 milliwatt)

Table 2 gives the equivalents in e.m.f., p.d. and power levels.

TABLE 2

Microvolts e.m.f.	Microvolts p.d.	Power level for 50 Ω impedance	
		dBW	dBm
1	0.5	- 143	- 113
2	1	- 137	- 107
4	2	- 131	- 101
8	4	- 125	- 95
16	8	- 119	- 89
20	10	- 117	- 87
32	16	- 113	- 83
40	20	- 111	- 81
64	32	- 107	- 77
80	40	- 105	- 75
100	50	- 103	- 73

For 0 dB reference

Thus by working in reverse from a required receiver input power and calculating the path losses, the e.r.p and the transmitter output power can be derived. The e.r.p for both directions should be calculated, as it should not be assumed that the overall loss for each direction will be identical unless the feeder losses are the same and identical transmitter and receiver aeri-als are used.

From Table 1, e.r.p for each direction will be $(P + T - Q)$ dBW and $(U + T - Q)$ dBW. If the net system loss of items (d), (e) and (f) is AdB and BdB for A to B and B to A respectively, then for A to B

$$(P + T - Q) - A = R$$

e.r.p

therefore $(P + R - Q) = A + R$

e.r.p

and for B to A

$$(U + T - Q) - B = R$$

e.r.p

therefore $(U + T - Q) = R + B$

Obviously if the overall losses (sum of items (b), (c), (d), (e) and (f)) are the same for each direction then $P = U$.

Thus from a knowledge of A and B and the required receiver input power R, the e.r.p's can be assessed for both directions.

2.1 Path Losses

The computation of the path losses is the important factor in the accurate prediction of system performance. One of the most useful tools available at the present time is the set of nomograms prepared by Bullington (1)(2) (see Appendices). These nomograms are based on a smooth spherical earth and have been designed to take into consideration reflection, refraction and diffraction which are the fundamental properties of wave mechanics. Provided the nomograms are used with a reasonable degree of care, relatively accurate predictions of system performance can be made.

Details on how these nomograms may be applied to ascertain system performance and thus to assess e.r.p's required, for the varying types of link path profiles may be obtained from the literature (1).

It would seem that path profiles for clear line of sight and obstructed line of sight can be analysed to ascertain the path losses such that the required receiver input power can confidently be expected to exist for 90% of the time, provided that the following basic principles are observed.

- (a) All profiles to be drawn on earth's radius of $\frac{4}{3}$ times the true radius.

- (b) For paths where complete Fresnel zone clearance exists over the entire path, the path loss will be the free space loss and is obtained from the appropriate nomogram or by utilising the equation

$$L_{fs} \text{ in dB} = 36.6 + 20 \log F + 20 \log d \dots\dots\dots(2)$$

L_{fs} = free space loss

F = frequency MHz

d = distance between isotropic antennas in miles

N.B.

It is generally accepted that the path loss is the loss between the input power to a transmitting isotropic antenna and the output power available from a receiving isotropic antenna. The isotropic antenna is a hypothetical antenna and the nearest practical form is the half wave dipole which has a gain 2.2 dB above that of the isotropic antenna.

Utilising the Bullington nomogram gives the free space loss between half wave dipoles with 1 watt radiated. The above equation gives the free space loss between isotropic antennas. In order to comply with the Ministry definition of e.r.p and the aerial specifications in W6458, which both refer to the gain of the aerial relative to a half wave dipole, the free space loss between half wave dipoles should be taken. If this figure is used, then the aerial gains must be relative to a half wave dipole. In general UHF aerial gains quoted by the manufacturer are to this reference.

If the free space loss is derived between isotropic antennas then in order to correct to that between half wave dipoles, the former figure is reduced by a factor of 4.4 dB.

For example, if the free space loss between isotropic antenna, 1 watt radiated = 120 dB then the free space loss between half wave dipoles, 1 watt radiated = 115.6 dB.

- (c) For clear line of sight paths where first Fresnel zone clearance does not exist over the entire path, a plane earth is drawn through possible points of reflection (whether they are in the immediate vicinity of the antennas or well away) and the effective antenna heights so given are used to find the plane earth loss from the appropriate nomogram.
- (d) For obstructed line of sight paths, the same concept of plane earth is used as in (c), and the path loss is increased due to the loss by the obstruction as obtained from the appropriate nomogram.
- (e) The possible exception to (d) is the case of an obstructed line of sight path which would come under the free space category but for the obstruction. Such a path is analysed using the nomogram giving shadow loss relative to free space.

SECTION 3 - WORKED EXAMPLE

A radio link is to operate between points A and B, 20 miles apart. The path is line of sight, with first Fresnel zone clearance over the entire path.

3.1 System Parameters

3.1.1 Receivers require 18 dB relative to 1 microvolt e.m.f for a signal-to-noise ratio of 40 dB. Receiver input impedance 50 ohms.

3.1.2 Aerial system impedance 50 ohms, gain 12 dB relative to half-wave dipole.

3.1.3 Transmitter and receiver feeder lengths at site A, 50 feet, at site B, 100 feet. Cable attenuation 3 dB per 100 feet.

For simplicity, we will assume the transmitter frequencies in both directions are of the order of 460 MHz.

3.2 Calculation

3.2.1 The required receiver input level, permitting for fading and equipment deterioration as per specification W6458 will be:-

$$\begin{aligned} &= (20 + 18) \text{ dB relative to 1 microvolt e.m.f} \\ &= 38 \text{ dB} \\ &= \underline{80 \text{ microvolts e.m.f}} \\ &= \underline{40 \text{ microvolts p.d}} \quad (\text{from item 1.2 since aerial impedance} \\ &\quad \text{matches receiver input impedance}) \\ &= \underline{105 \text{ dBW}} \quad (\text{reference equation (1), section 2}) \end{aligned}$$

3.2.2 The feeder losses at site A will be:-

$$\begin{aligned} \text{Transmitter feeder loss} &= 1 \text{ dB} \\ \text{Receiver feeder loss} &= 1 \text{ dB} \end{aligned}$$

The feeder losses at site B will be:-

$$\begin{aligned} \text{Transmitter feeder loss} &= 3 \text{ dB} \\ \text{Receiver feeder loss} &= 3 \text{ dB} \end{aligned}$$

3.2.3 From the drawn link profile it was seen that the path was line of sight. To establish if there was first Fresnel zone clearance over the entire path, nomogram H "First Fresnel zone clearance" (see Appendix 8) was used.

Alternatively the expression:

$$H = 13.15 \sqrt{\lambda \cdot \frac{D1 \cdot D2}{D3}} \quad \text{can be used}$$

where H is the vertical distance required between the point of reflection and the ray representing the radio path to give "First Fresnel zone clearance".

D1 is the distance from the transmitter to the possible point of reflection in miles.

D2 is the distance from the receiver to the possible point of reflection in miles.

D₃ is the distance between the two sites in miles.

λ is wavelength in centimetres.

It was ascertained from the above that the path had Fresnel zone clearance over the whole length.

Free space loss between antennas is controlling as long as 0.6 Fresnel zone clearance from obstructions is maintained around the line of sight path.

Therefore for direction A to B, the path loss will be the free space loss. The latter was obtained from the appropriate nomogram and was found to be 111 dB.

For direction B to A, the path loss will be the same.

Equation 2 can also be used, and in this instance with F = 460 MHz
d = 20 miles.

$$\begin{aligned} \text{The free space loss} &= 36.6 + 20 \log 460 + 20 \log 20 \\ &= \underline{115.87 \text{ dB}} \text{ between isotropic antennas} \\ &= \underline{111.47 \text{ dB}} \text{ between half wave dipoles} \end{aligned}$$

3.2.4 The system gains and losses can be tabulated as in the form shown in Table 1 or in graphical form of a level diagram as shown in Fig. (1). The diagram shows the levels for the direction A to B.

TABLE 3

Item	Direction	
	A - B	B - A
(a) Transmitter output	?	?
(b) Transmitter Feeder	1dB	3dB
(c) Aerial (Tx) Gain	12dB	12dB
(d) Path Loss	111dB	111dB
(e) Aerial (Rx) Gain	12dB	12dB
(f) Receiver Feeder Loss	3dB	1dB
Receiver input level	-105dBW	-105dBW

The sum of the items (a), (b) and (c) is the e.r.p of system.

Therefore for direction A to B we have:

$$\text{e.r.p} = -105 - (\text{sum of items (d), (e) and (f)})$$

Since addition of items (a) to (f) gives receiver input level.

$$\begin{aligned} \text{Therefore e.r.p} &= -105 - (-111 + 12 - 3) \\ &= -105 - (-102) \\ &= -105 + 102 \\ &= \underline{-3\text{dBW}} \end{aligned}$$

Therefore the e.r.p required from site A to give a receiver input level of -105 dBW at site B will be -3 dBW. This is equivalent to 500 milliwatts e.r.p.

For direction B to A

$$\begin{aligned} \text{e.r.p required} &= -105 - (-111 + 12 - 1) \\ &= -105 - (-100) \\ &= \underline{-5\text{dBW}} \end{aligned}$$

For direction A to B the transmitter output required will be:

$$\begin{aligned} &= \text{e.r.p} - (\text{sum of items a, b}) \\ &= -3 - (-1 + 12) \\ &= \underline{-14\text{dBW}} \end{aligned}$$

For direction B to A the transmitter output required will be the same, since the overall losses for both directions are the same.

$$\begin{aligned} &= \text{e.r.p} - (-3 + 12) \\ &= -5 - 9 \\ &= \underline{-14\text{dBW}} \end{aligned}$$

SECTION 4 - CONCLUSION

It can be seen that knowing the losses and gains on the system, and working to a required receiver input power level, an assessment of the effective radiated powers and thus the transmitter output powers required can be made simply, in accordance with the specifications laid down by the Ministry of Posts and Telecommunications.

BIBLIOGRAPHY

1. RCA Electronic Training Series Manual "Point-to-Point Radio Relay Systems, 44MHz to 13MHz"

Obtainable from:

RCA (Great Britain) Ltd.
Lincoln Way
Windmill Road
Sunbury-on-Thames
Middlesex

Price £4.50.

2. PIRE October 1947 - Bullington: Radio Propagation at Frequencies above 30MHz.
 3. Helmut Carl., 1966 "Radio Relay Systems" Macdonald, London.
 4. Donald H. Hamsher 1967 "Communication System Engineering Handbook" McGraw-Hill Book Company.
 5. P.A. Matthews 1965 "Radio Wave Propagation VHF and Above". Chapman and Hall.
 6. J.J. Egli "UHF Radio Relay System Engineering" PIRE January 1953.
 7. Ministry of Posts and Telecommunications 1963. Performance Specifications No. W6457 and W6458, for Private Point-to-Point Systems in the 450-470MHz Band. HMSO.
 8. British Standards Institution 1960 BS 204. Glossary of terms used in Telecommunication and Electronics.
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D24/1/2/THC

30 September 1971

LEVEL DIAGRAM OF THE RADIO LINK

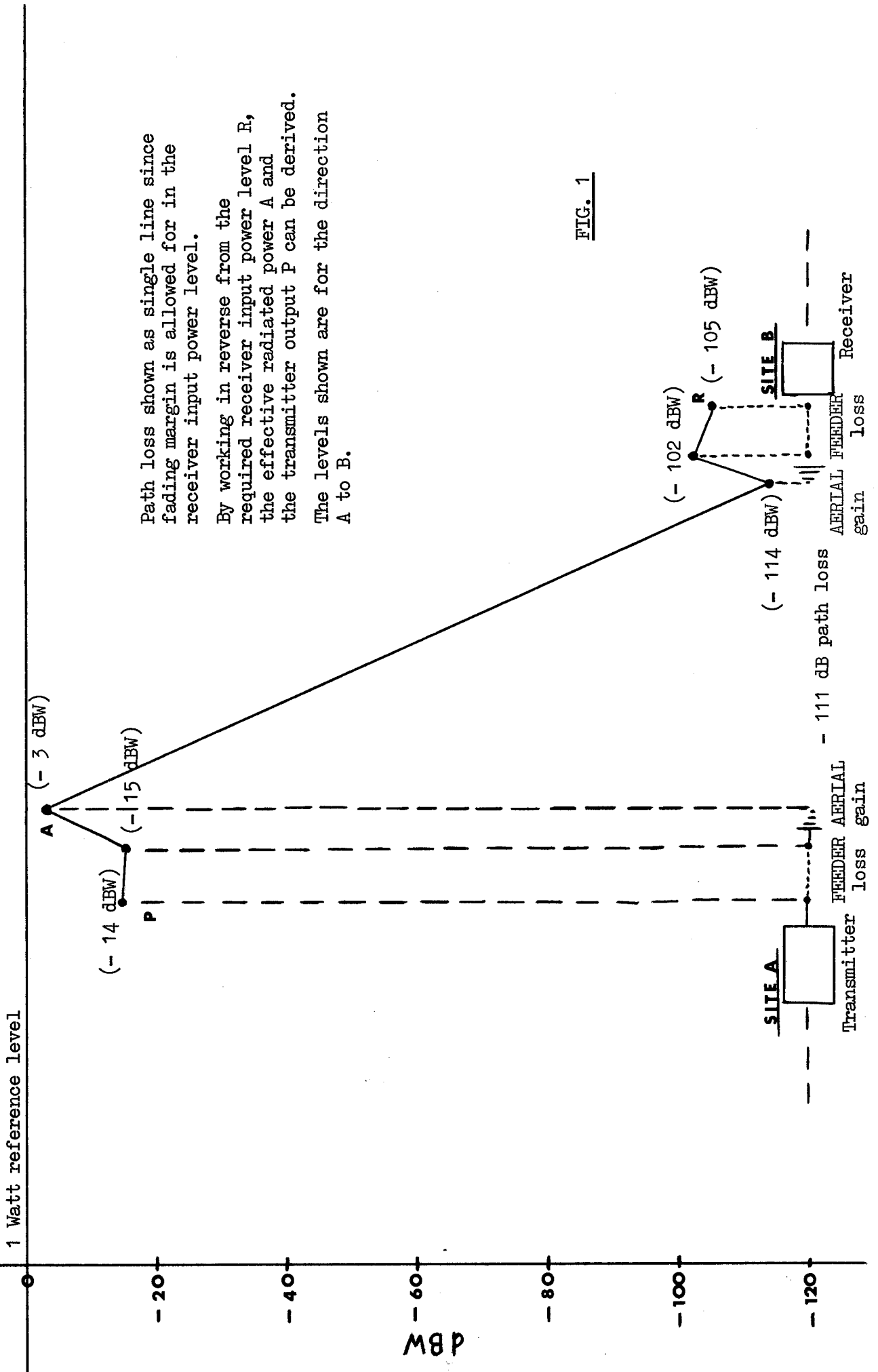
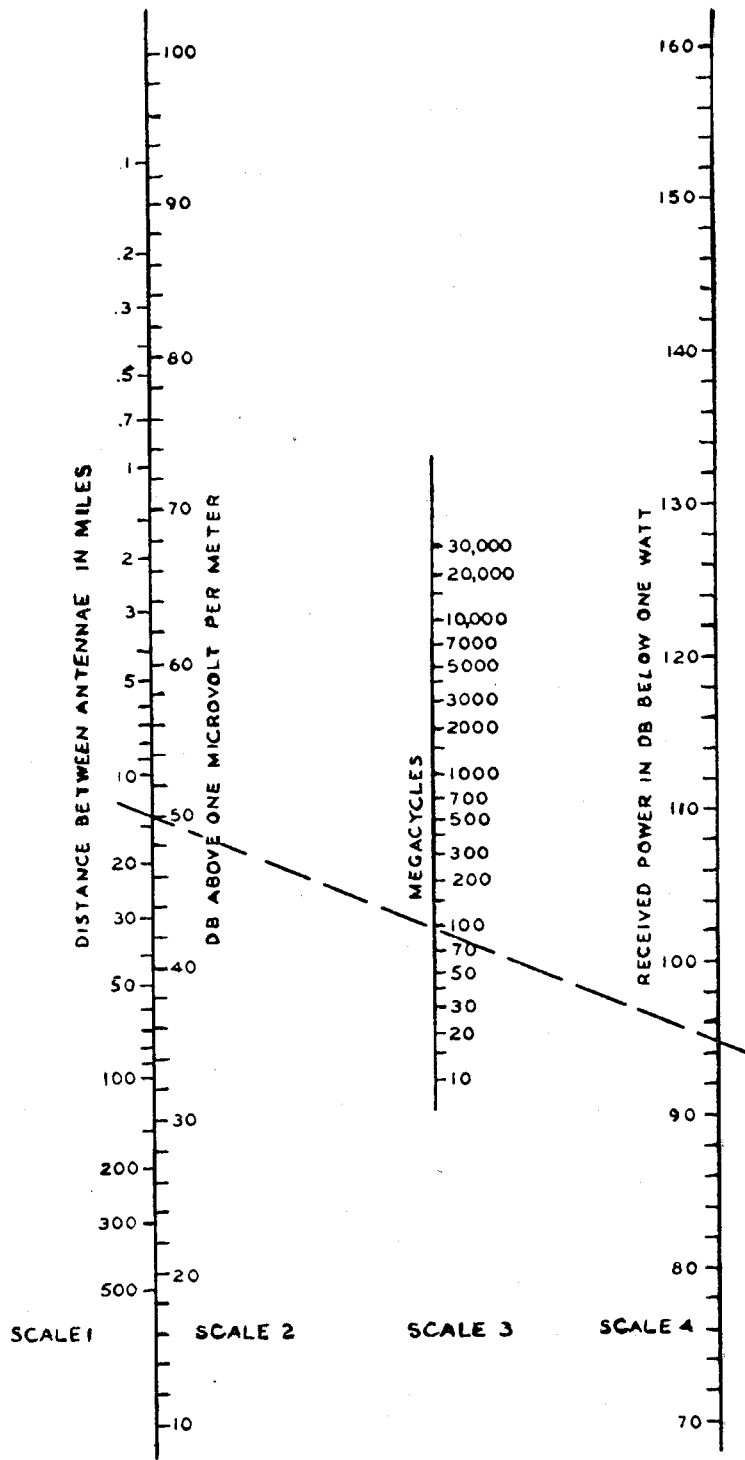


FIG. 1

Path loss shown as single line since fading margin is allowed for in the receiver input power level.

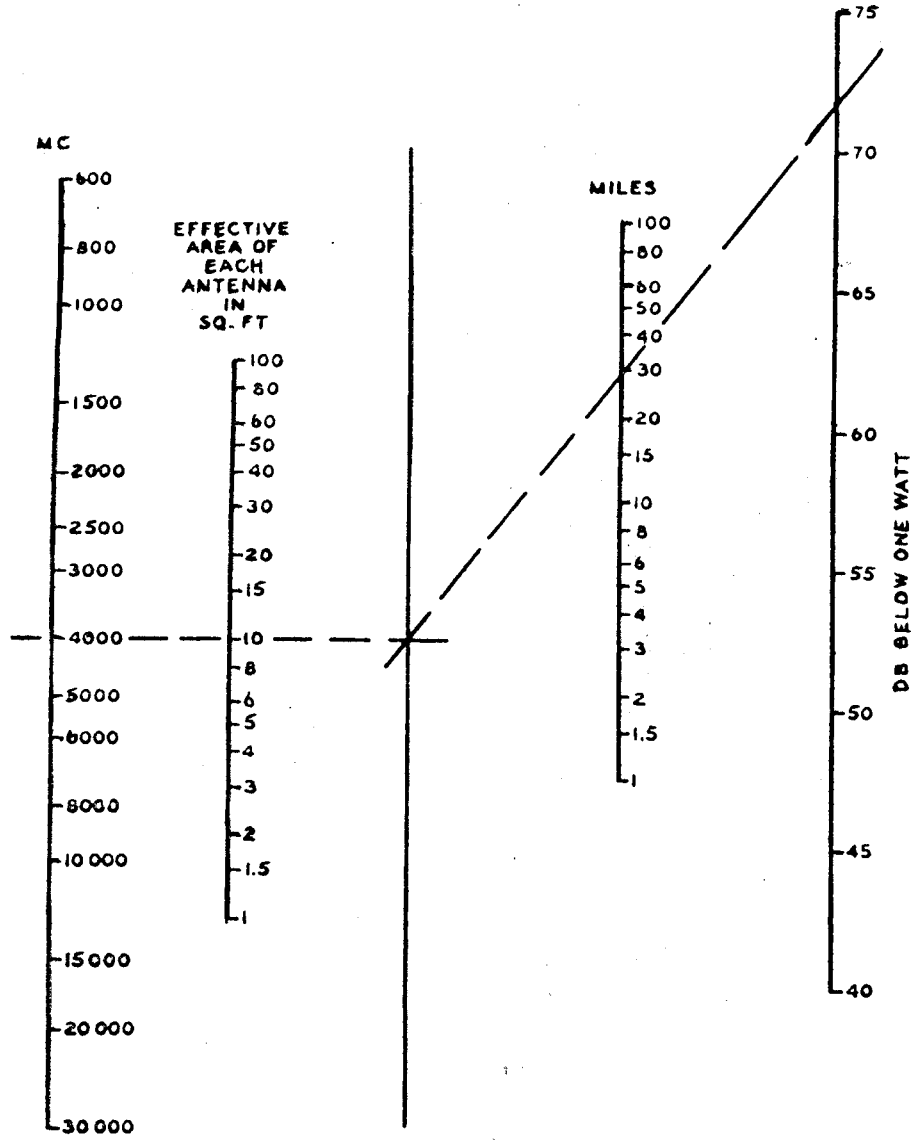
By working in reverse from the required receiver input power R, the effective radiated power A and the transmitter output P can be derived.

The levels shown are for the direction A to B.



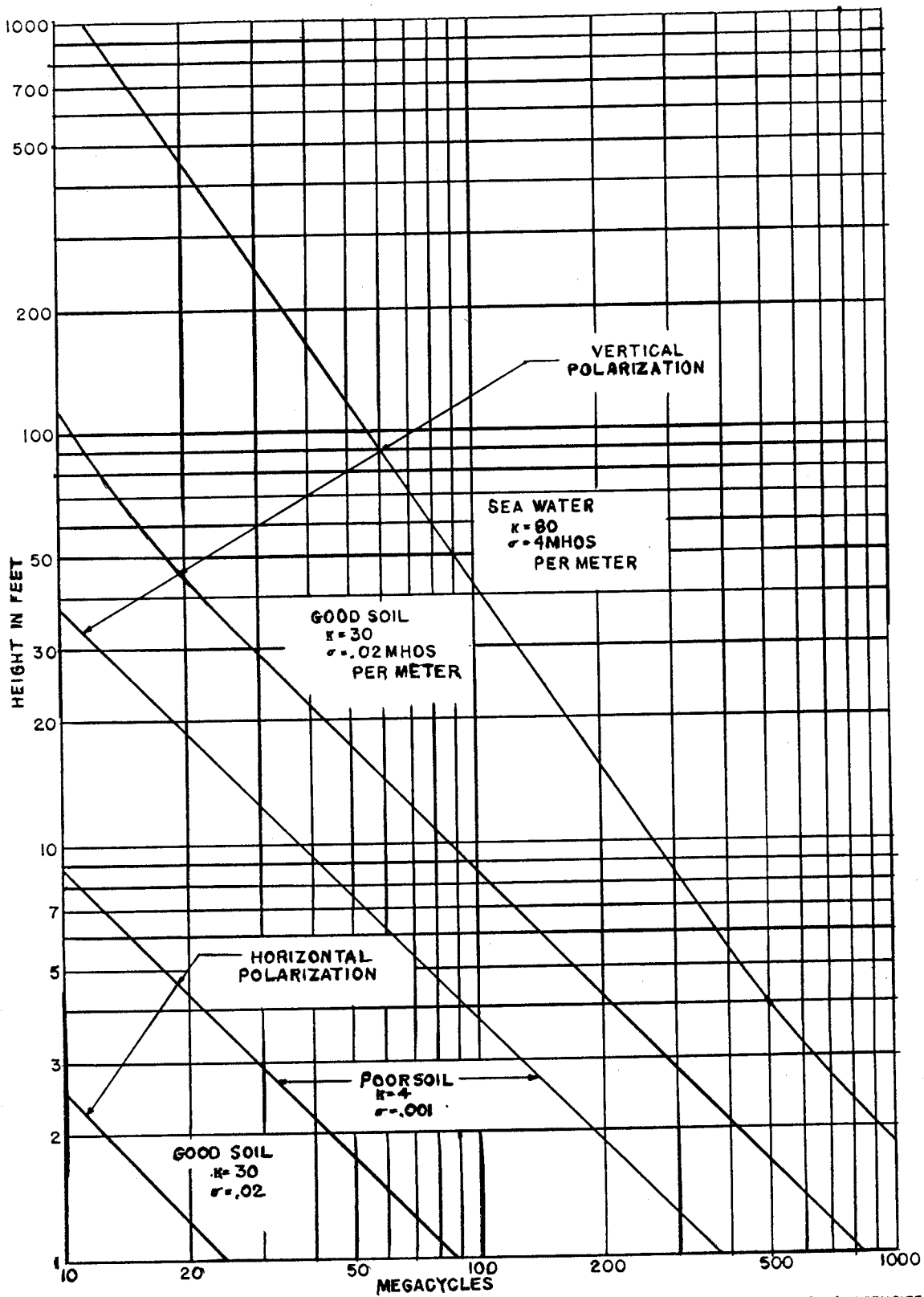
AFTER BULLINGTON

Free Space Field Intensity and Received Power between Half Wave Dipoles,
1 Watt Radiated



AFTER BULLINGTON

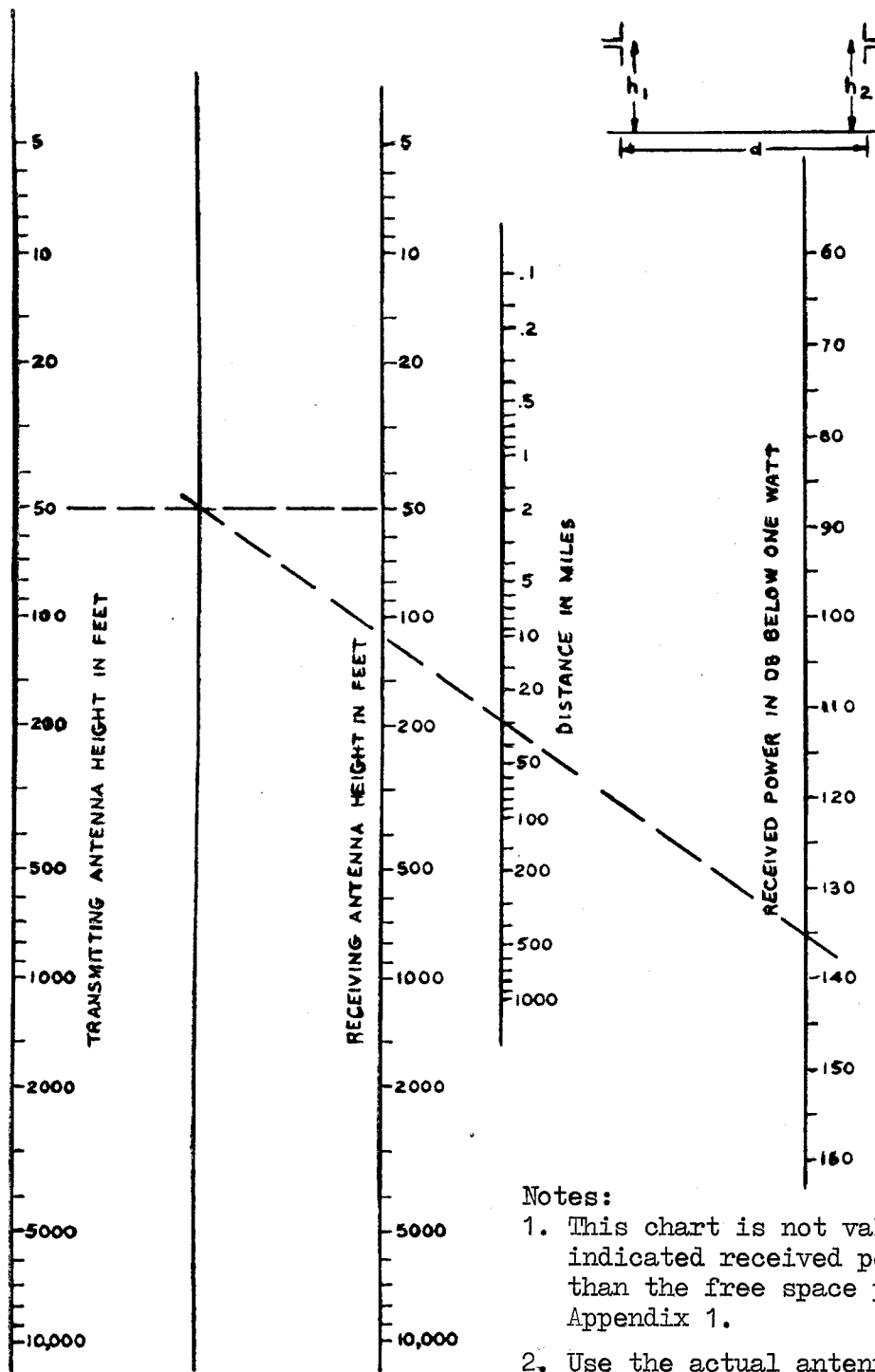
Received Power in Free Space between Two Antennas of Equal Effective Areas, 1 Watt Radiated



NOTE: FOR FREQUENCIES ABOVE 1000 MC, USE ACTUAL ANTENNA HEIGHTS.

AFTER BULLINGTON

Minimum Effective Antenna Height

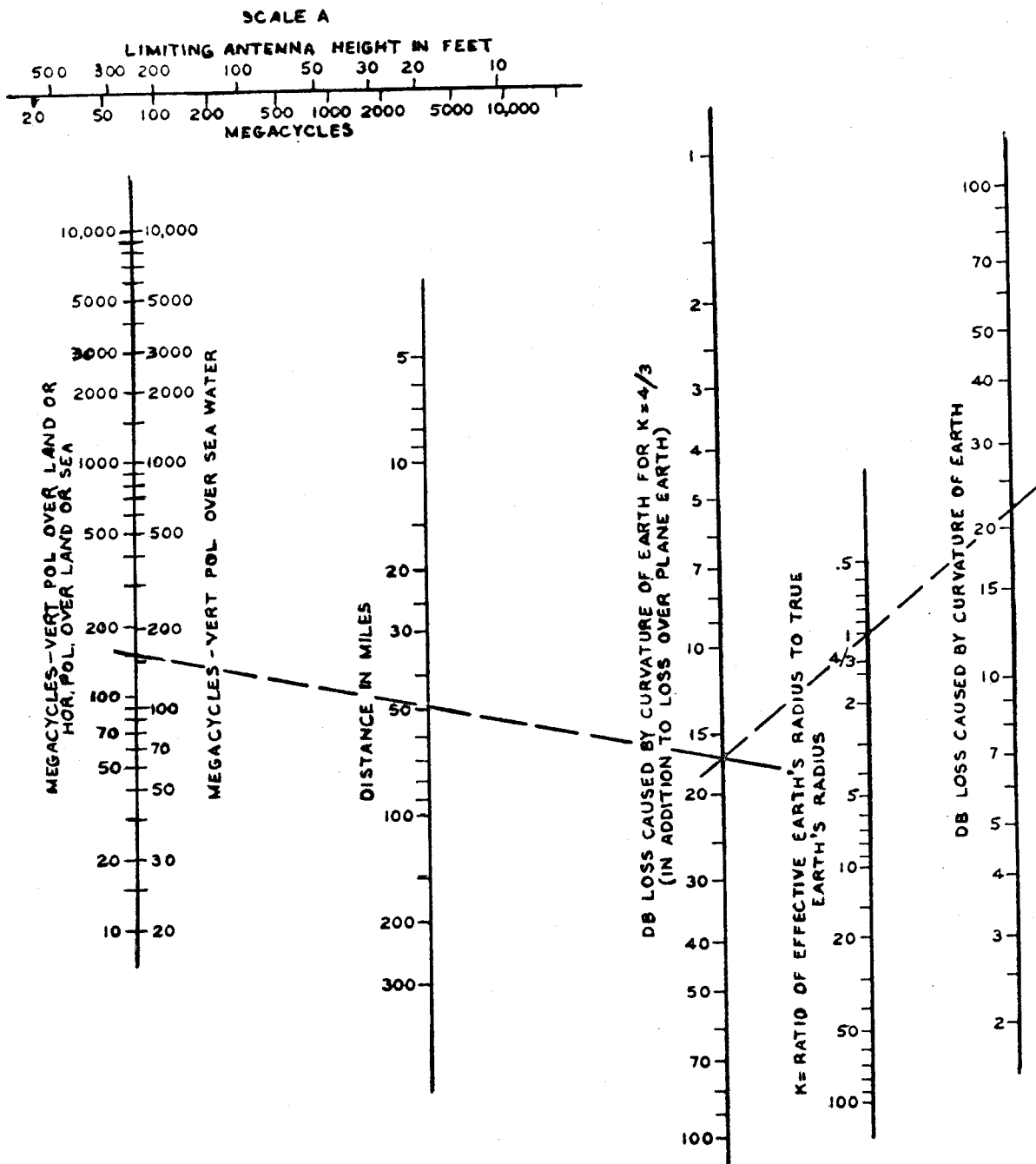


Notes:

1. This chart is not valid when the indicated received power is greater than the free space power shown on Appendix 1.
2. Use the actual antenna height or the minimum effective height shown on Appendix 3, whichever is the larger.

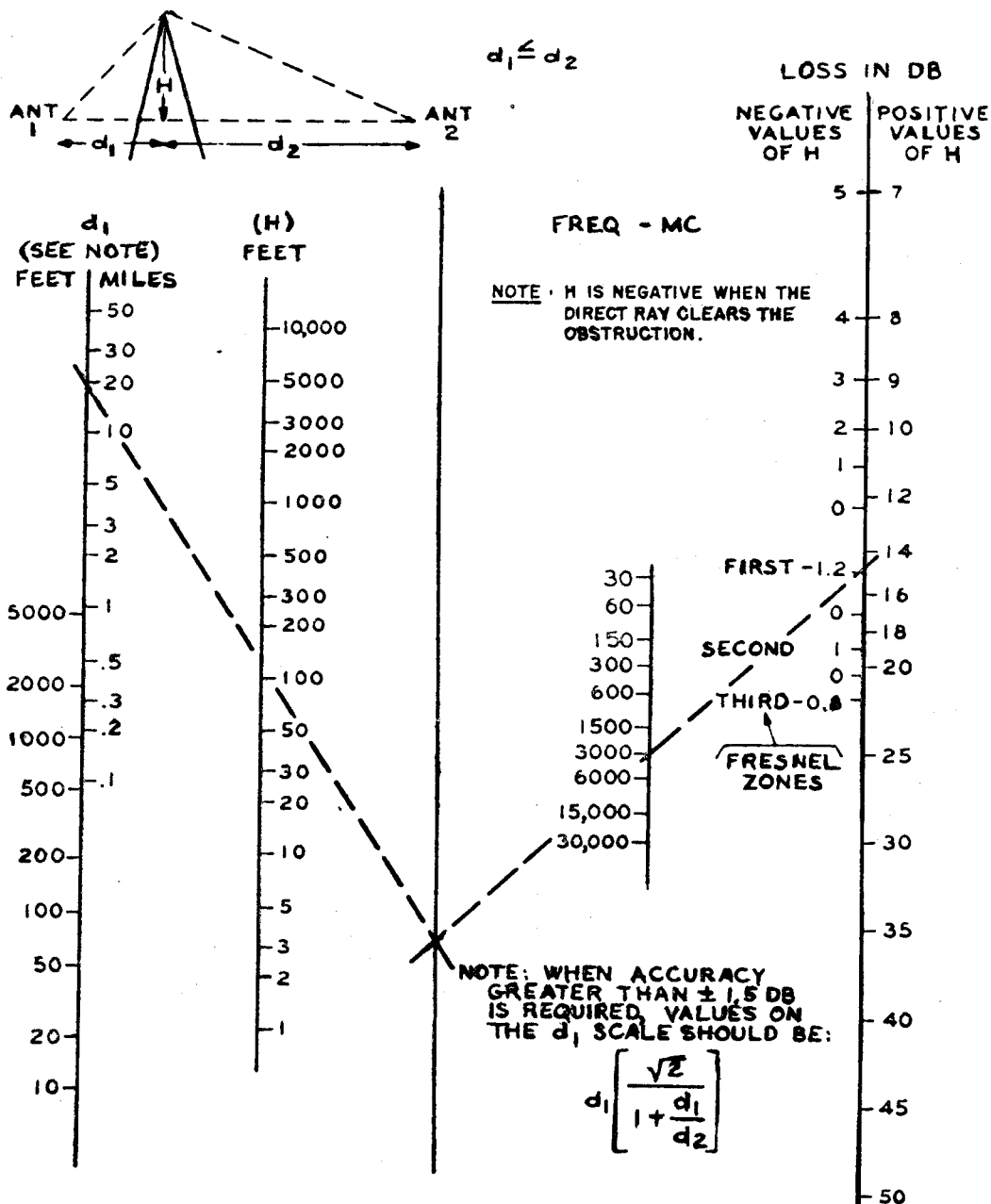
AFTER GULLINGTON

Received Power over Plane Earth Between Half Wave Dipoles, 1 Watt Radiated



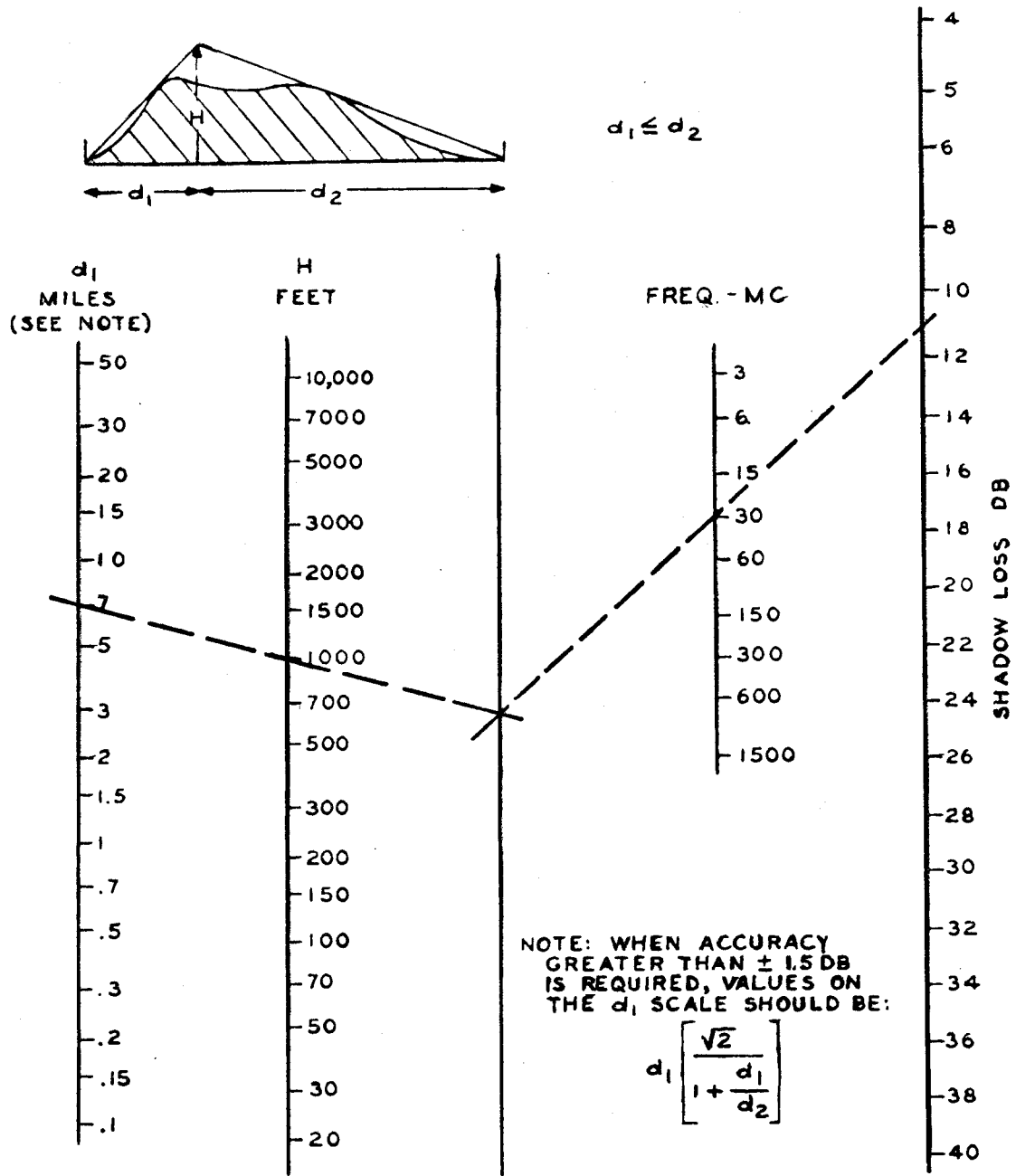
AFTER BULLINGTON

Diffraction Loss Caused by Curvature of the Earth
 Assuming Neither Antenna Height is Higher than Shown on Scale A



AFTER BULLINGTON

Shadow Loss Relative to Free Space



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Shadow Loss Relative to Smooth Earth

