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FIELD INTENSITY ESTIMATES OF TELEVISION COVERAGE

AUSTRALIAN BROADCASTING CONTROL BOARD.

REPORT No. 26

FIELD INTENSITY ESTIMATES OF TELEVISION COVERAGE

Prepared by W.R. Baker.

1. Introduction

Methods of computing ground wave field intensities over a smooth spherical earth have been given by Burrows and Gray,[1] and by Norton[2] for various frequencies, distances, antenna heights and ground constants. For frequencies above 30 MC/S, a comprehensive series of ground wave propagation curves have been prepared by the Director of the C.C.I.R. for various distances and antenna heights over sea and land for both horizontal and vertical polarisation using metric units of length[3, 4].

Bullington[5] produced a series of nomograms, which give field intensities for a range of heights and distances using the simplifying assumptions of a plane earth or a smooth spherical earth. To allow for obstacles in the path between transmitting and receiving antennae he used the concept of shadow triangles embracing the obstacles to assess the additional losses above the losses inherent in the plane and smooth earth field intensities.

The Federal Communications Commission of the U.S.A.[6] presented field intensity graphs based on a large number of field measurements of television stations for various frequencies and transmitting antenna heights for a standard receiving antenna height of 30 feet. The median field intensities were less than the corresponding smooth earth values for short distances the deficiencies being greater at higher frequencies in the V.H.F. range with a tendency to be comparable with smooth earth for distances above 30 to 40 miles. The F.C.C. later issued amended curves[7] which showed that the median values are appreciably higher than smooth earth at considerable distances.

Epstein and Peterson[8, 9] presented methods of estimating field intensities, which relied more directly on knife edge diffraction for predicting the effect of obstacles on the path losses. The first paper resulted from measurements made at a frequency of 850 MC/S, and illustrated a useful method of computing the diffraction loss for multiple knife edge obstructions. It was found that each knife edge such as P introduces a transmission loss at the top of the succeeding knife edge Q approximately equal to that of a single knife edge in free space, and at the same time acts as a new source of signals in the direction of the knife edge Q, which in turn introduces a transmission loss equivalent approximately to a knife edge in free space with its source at the preceding knife edge P and its receiving point at the top of the next knife edge R. The degree of approximation of this rule for a double knife edge has since been put on a firm mathematical basis by Millington, Hewitt and Immirzi[10]. With the trend toward elevated transmitting sites, knife edge diffraction methods can be used as a basis for computing the losses of a surprising number of obstructed transmission paths.

Where the receiving point is an antenna at the standard height of 30 feet above ground, the knife-edge methods must usually be modified to allow for the additional loss caused by the effect of the ground on the path from the equivalent wave source, which is located approximately at the top of the last obstruction, to the receiving antenna. Epstein and Peterson, in their second paper[9] have used the "clutter loss" method, which depends on the angle of arrival of the wave with respect to the ground level at the receiving point. An alternative method is to imagine a hypothetical transmitter at the top of the last obstruction and compute the loss relative to free space of this transmission over this last leg of the propagation path by approximate methods. For a single obstruction

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these methods usually give optimistic results unless the obstruction is a fairly pronounced knife edge. To counteract this trend it is desirable to allow an additional transmission loss for the rounded nature of the obstruction.

An alternative method has been developed for dealing with obstructed paths and optical paths which are only poor approximations of a smooth earth. It is useful as a check on the above knife edge methods or where doubt exists about their application. With some types of path, however, it gives optimistic results particularly where multiple knife edges are involved. The method is based largely on Bullington's shadow triangle technique [5] and a statistical analysis of Australian field intensity measurements in Band III. It resulted from the observation that computations using a plane earth and shadow method tend to have an opposite error trend with distance to those based on smooth earth and shadow techniques. An average of the results of the two types of calculation at any distance tends to correct for the error trends of the individual calculations.

Line of sight transmission paths can also be treated in a number of ways. Where the terrain conforms approximately to a smooth earth, the F.C.C. curves [6, 7] are convenient for use, particularly as they assume the use of a receiving antenna 30 feet above ground. The median figures so obtained are reduced by 6 db. when applied to the built up area of a town. As mentioned earlier these curves allow for degradations below smooth earth values, particularly at short distances. Where high ground or hills are sufficient to impair the degree of clearance at any part of the path, the calculations can be made by one of the methods used for obstructed paths.

Many cases arise in Australia where it is desired to compute the median field intensity at considerable distances beyond the line of sight. For rolling terrain and 30 ft. receiving antennae the F.C.C. curves [7] can be used. For mountainous terrain, or with heights appreciably greater than 30 feet it is desirable to use an angular distance method such as reference 11 which takes account of the terrain for a specific path.

2. Field Intensity Calculations For Line of Sight Paths

2.1 Paths with First Fresnel and "Free Space" Clearance

If the ground has first Fresnel clearance below the line drawn from transmitting to receiving antennae (assuming standard refraction) then a median grade of signal equal to free space is assured. For the so-called criterion of "free space" clearance (path to any obstacle at least $\frac{\lambda}{2}$ greater than the direct path) the median received signal will also be of substantially free space grade.

2.2 Paths approximating to smooth earth - 30 ft. receiving antennae

The F.C.C. curves [6, 7] can be used. The effective height of the transmitting antenna can be taken as the height of the transmitting antenna above the average height of the terrain from two to 10 miles from the transmitter in accordance with the instructions for using these curves. Fig 1 shows a height distance graph of a typical path plotted according to the usual parabolic representation of the curved earth. The earth's equivalent radius is taken as 5280 miles (standard refraction). Another method is to take the effective transmitting antenna height as the difference between the transmitting antenna height and the point P at which the ground contour crosses a curve of first Fresnel clearance with respect to the straight line between transmitting and receiving antennae. For this purpose too much emphasis need not be placed on the accuracy of estimating first Fresnel clearances. When a lot of paths must be dealt with the work is greatly speeded by the use of a family of curves showing first Fresnel clearance against distance from the transmitter with total distance between transmitter and receiver as the parameter. Such a set of curves is shown in figure 2 for Band III. A slightly less conservative answer for the received field intensity is obtained by using "free space" clearance as the criterion. A family of "free space" clearance curves is also shown on figure 2 for Band III. It is usually found with experience that the path clearances need not be checked at more than one or two points. For receiving points in built up areas 6 db should be deducted from the median field intensities so computed.

2.3 Paths Approximating Smooth Earth With Elevated Receiving Antennae

In this case the elevated nature of the receiving antenna may result from the placement of a 30 ft. antenna on a local hill or from the use of a high mast. In such cases a C.C.I.R. Atlas 3, 4 may be used in the same manner as the F.C.C. curves in section 2.2 above. The receiving antenna effective height is estimated in the same manner as the transmitting antenna effective height by the use of first Fresnel or "free space" clearances. These are theoretical curves to which no corrections have been made so that it is desirable to deduct from 6 to zero db for land paths in Band III, depending on the ratio of the antenna heights product to the wavelength.

2.4 Paths Not Approximating to Smooth Earth

Where obstructions significantly reduce the clearances of the path while still providing line of sight transmission it is often possible to apply smooth earth and plane earth methods with simple corrections to allow for the effect of obstacles. Later in section 3.4 examples of this technique are described together with another method of treating the problem.

3. Obstructed Paths

3.1 Single Dominant Obstruction with Transmitting and Receiving Antennae Visible from the Top of the Obstruction.

A typical path is illustrated in figure 3. The triangle TOR is drawn through the transmitting and receiving antennae and the top of the obstacle. The losses on this path relative to free space propagation between transmitting and receiving antennae can be approximated as follows:-

(A) The loss along the path from T to O due to

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ground effects. If "free space" clearance above the ground exists at all points below the line TO, zero loss on this section of the path can be assumed. If a point such as P has significantly less than "free space" clearance, a knife edge loss can be assessed from figure 8, reference 5, the distance used being the smaller of TP or PO (in miles), and height H (negative) being the distance in feet of P below the line TO. This loss is usually well under 6 db.

(B) A knife edge diffraction loss due to the bending of the direct rays TO and OR by the knife edge. This is also assessed from figure 8 reference 5 using the positive height OM and the smaller of the distances TO and OR.

(C) If the obstruction O is a rounded hill extending for several miles rather than a pronounced knife edge, an additional diffraction loss of approximately 6 db. for Band III should be added.

(D) A space wave loss due to the effect of ground reflections on the path from O to R. This can be assessed by the empirical "clutter loss" method (figure 2 reference 9), which gives increasing losses with increasing frequency and decreasing losses with increasing angle of arrival of signals at the receiving antenna. An alternative method for assessing this loss is to imagine a hypothetical transmitting antenna at O, the effective height of which is obtained by drawing a tangent at the ground below the receiving antenna to cut the vertical line through O at a point N, giving ON as the effective height of the hypothetical transmitter. The median field intensity for height ON and distance OR is then computed by the F.C.C. curves (reference 6) and deducted from the free space field for distance ON to give the approximate space wave loss for path OR. This method is too pessimistic for small values of ON, and in such cases the "clutter loss" is the only simple method available. The ratio of height ON to distance OR is also the most convenient method for computing the angle of arrival for use in the "clutter loss" estimation so that little extra work is involved in computing the loss by both methods, thereby permitting an average of the results by the two methods to be used in most cases.

(E) The received field intensity is obtained by adding the losses of (A), (B), (C) and (D) and subtracting the total from the free space field for the full distance TR, decibel units being used in all cases.

3.2 Multiple Obstructions

A typical path with two dominating obstructions is shown in figure 4.

The procedure for computing the median field intensity at R follows similar lines to the previous example (3.1)

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with an additional knife edge loss to be added and a valley between the knife edges to be cehcked for possible losses.

(a) The loss from T to O_1 is estimated in identical manner as for section 3.1 (a).

(b) The knife edge loss for obstruction O_1 is estimated by drawing the straight line TMO2 and applying the positive height O1 M (feet) and distance O1 O2 (or TO1 if less than O1 O2) to figure 8 reference 5.

(c) The path from O1 to O2 is checked for "free space" clearances of the ground below O1 O2 and zero loss is allowed unless there is a ground obstruction having a clearance appreciably less than "free space". In such an eventuality a loss (usually quite small) would be assessed in the same manner as for section 3.1 (a).

(d) The knife edge diffraction loss for obstruction O2 is found by joining O1 to R and applying the positive height O2 Q and distance O1 O2 (or O2 R if it were less than O1 O2) to figure 8 reference 5.

(e) The space wave loss from O2 to R is computed in the same manner as in section 3.1 (d).

(f) If O1 or O2 is considerably rounded an additional 3 db. loss is added for each rounded obstruction.

(g) The losses found in (a), (b), (c), (d), (e) and (f) above are added and the total subtracted from the free space field intensity (decibel units) for the full distance TR.

The procedure for a path with three dominant obstructions is similar to that for two dominant obstructions with an extra knife edge loss to be added and an extra valley between the knife edges to be checked for possible small losses.

3.3 Alternative Method for Obstructed Paths

For cases where a path is not readily classified as one of those treated above, another method has been developed from a statistical analysis of a number of Australian measurements of Band III television stations using 30 ft. receiving antennae. It is based broadly on Bullington's method[5] of drawing "shadow loss triangles" embracing the significant obstacles along the propagation path. It was found empirically that when this shadow loss is added to an equivalent plane earth loss the resulting field intensity Fp is increasingly optimistic with increasing length of the path. On the other hand if a shadow loss is added to an equivalent smooth earth loss the field intensity Fs is increasingly pessimistic with increasing distance. An average of Fp and Fs in decibel units results in a field intensity more in agreement with measured values. A typical path is illustrated in figure 5.

(a) Figure 5A shews the geometry associated with the computation of the smooth earth version Fs. The effective height Ht is the height of the transmitting antenna above the average terrain height from two to 10 miles from the transmitter. The shadow triangle RBC is drawn from the base of the effective antennae R and B through the first significant obstructions W and Z nearest to each antenna. To decide whether a point such as X near the transmitter can be discarded in drawing the shadow triangle, the line TY can be drawn. If X has "free space" clearance below this line it can be discarded. Hs (feet) and ds (miles) can be used to get the shadow loss from figure 10, reference 5, or if it is desired to restrict the number of charts in use figure 8 of this same reference can be used and 6 db. subtracted. Antenna heights Ht and 30 feet and the transmitter to receiver distance can be used to get the smooth earth field intensity in decibels units from the C.C.I.R. Atlas, reference 3 or 4 or from other appropriate sources such as the F.C.C. median curves (reference 6) with suitable corrections. The shadow loss is subtracted from the smooth earth field intensity to get the field intensity Fs.

(b) Figure 5B shews the geometry applied to the same path profile to get the plane earth version Fp. A straight line TR is drawn between transmitting and receiving antennae and a point P determined at which the curve of first Fresnel clearance below this line cuts the ground profile. The first Fresnel clearance at this point P is taken as the effective height, ht., and is marked off as TD below the transmitting antenna. If the point P falls beyond the half distance from transmitter to receiver first Fresnel clearance at the half distance is the required effective height ht. The shadow triangle DFR is then drawn and the shadow loss determined by applying Hp and Dp to figure 10 reference 5. Using Ht and 30 feet as the antenna heights together with the full distance from transmitter to receiver, the equivalent plane earth field intensity can be obtained from figure 6. The field intensity Fp is obtained by subtracting the shadow loss.

(c) An average of Fs and Fp in decibel units is taken and 3 db. subtracted to give the median field intensity. The method is based on measurements taken in built up areas of country towns. A site of average height is selected in the town for the purpose of drawing a transmitter to receiver ground profile. The results tend to be optimistic for paths having multiple dominant obstructions and also with paths for which the angle of arrival at the receiving antenna relative to ground level is small compared with the angle CRB. In the latter cases an approximate remedy is to add a loss equivalent to half the clutter loss as calculated in section 3.1 (d).

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(d) With regard to Band I sufficient field measurements have not been available for statistical analysis. As an interim measure the Band III calculations have been used without finally subtracting the 3 db.

3.4 Optical Paths not Approximating to Smooth Earth

It was noted in section 2.4 that this type of path could be treated by an obstructed path method. The method of section 3.3 has been found effective in most cases. The smooth earth and plane earth effective heights are determined in the same way and the choice triangles drawn in the same way. In some cases the point corresponding to point Y of figure 5A which determines the side BC of the triangle will be the first point on the curved earth away from the transmitter which fails to have "free space" clearance below the line from transmitting to receiving antennae.

Consider the case of a knife edge extending up to a point such as X in figure I. The height (negative) of X below the line TR and the distance of X from the transmitting antenna can be applied to figure 8, reference 5, and the resulting loss subtracted from the smooth earth calculation described in section 2.2. A single knife edge such as Y at the receiving end of figure 1, having as little as 60% of free space clearance below TR, can also be treated approximately by adding a similar single knife edge loss to the smooth earth calculations.

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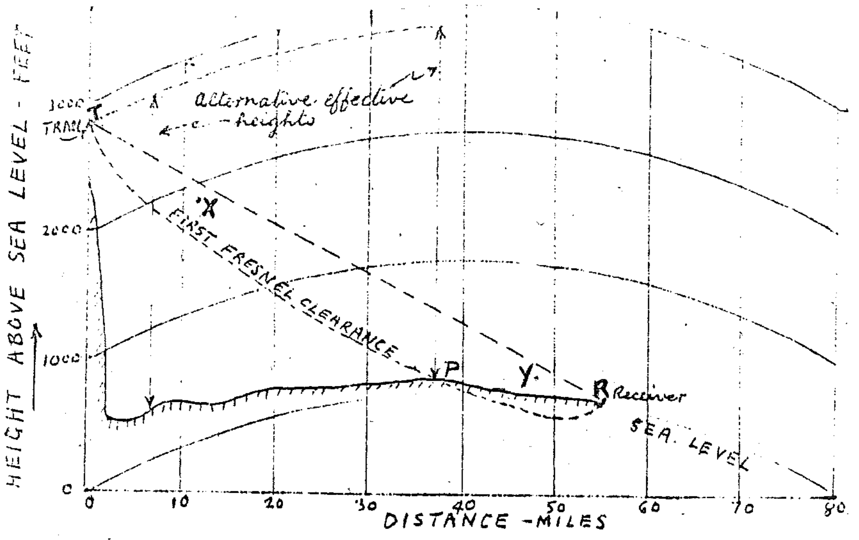


FIG. 1

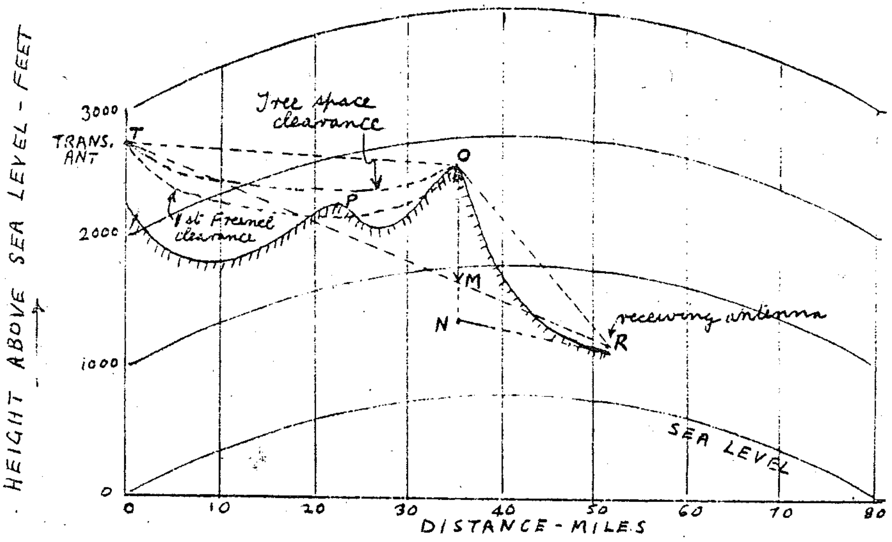


FIG.3

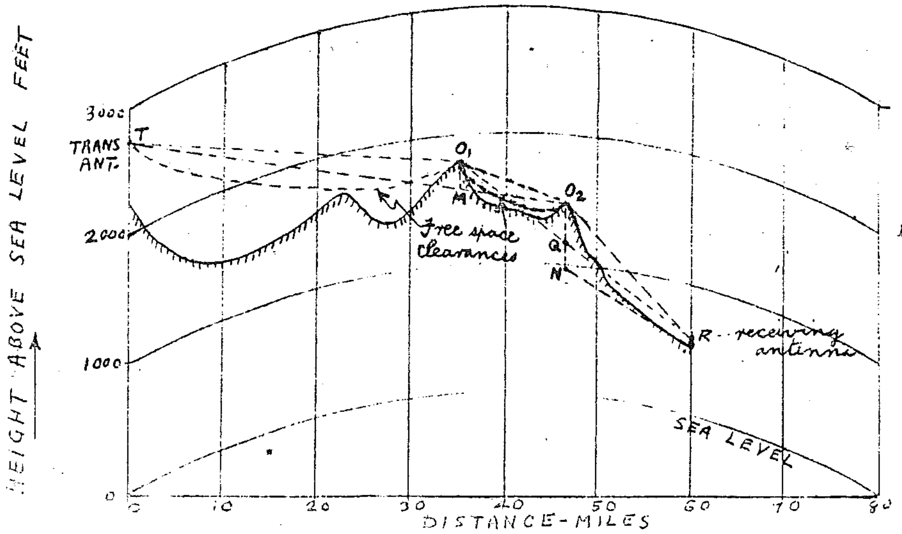


FIG.4

FIRST FRESNEL & FREE SPACE CLEARANCES FOR BAND III 197 MC/s.

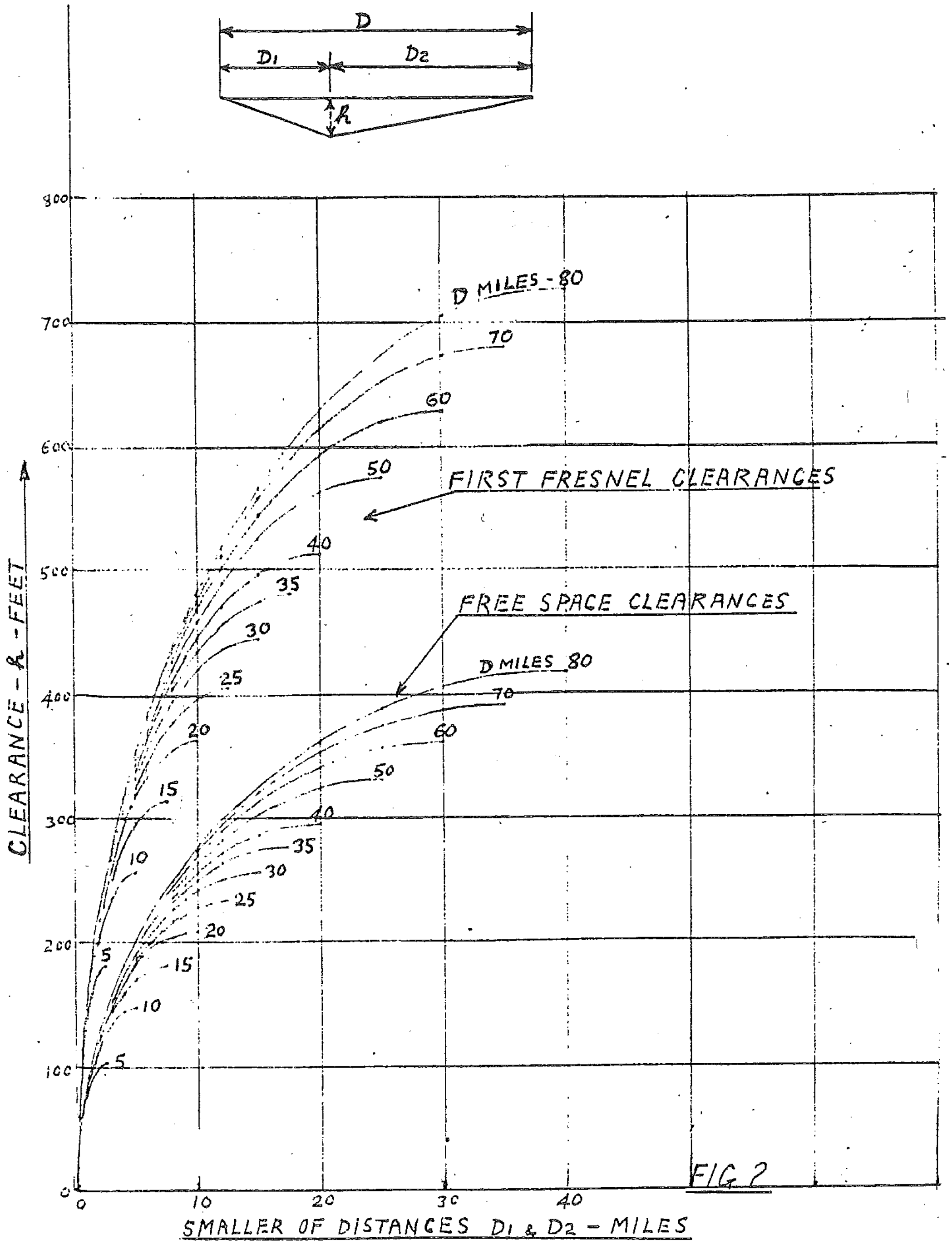


FIG 2

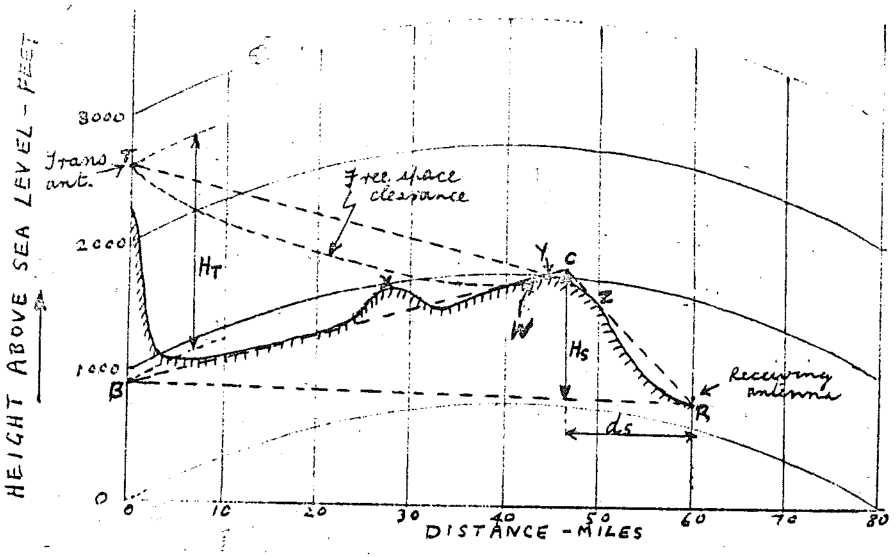

HEIGHT ABOVE SEA LEVEL - FEET
3000
2000
1000
0
Trans ant.
T
Free space clearance
H_T
Y
C
Z
W
H_S
B
L
Receiving antenna
R
ds
0
10
20
30
40
50
60
70
80
DISTANCE - MILES

FIG. 5A

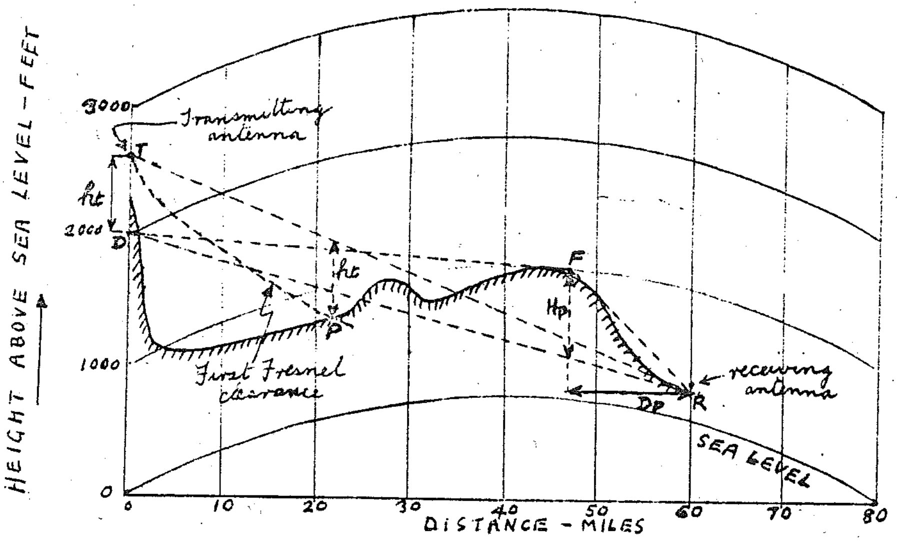
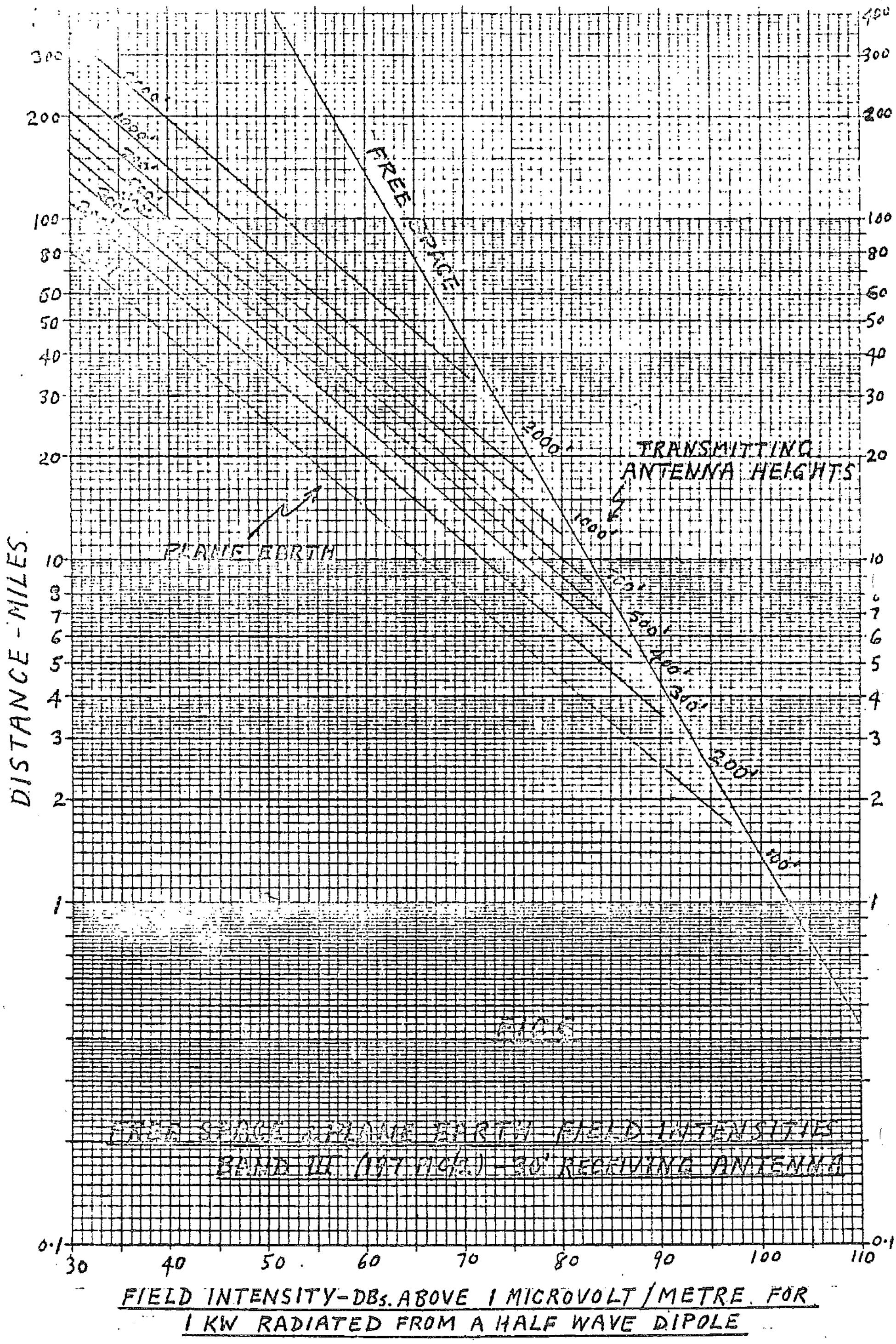

HEIGHT ABOVE SEA LEVEL - FEET
3000
Transmitting antenna
T
ht
2000
D
A
ht
P
F
Hp
First Fresnel clearance
1000
receiving antenna
R
Dp
SEA LEVEL
0
0
10
20
30
40
50
60
70
80
DISTANCE - MILES

FIG. 5B


DISTANCE - MILES
300
200
100
80
60
50
40
30
20
10
8
7
6
5
4
3
2
1
0·1
400
FREE SPACE
2000'
1000'
700'
500'
400'
300'
200'
100'
TRANSMITTING ANTENNA HEIGHTS
PLANE EARTH
FIG. 5
FREE SPACE & PLANE EARTH FIELD INTENSITIES
BAND III (197 Mc/s) - 30' RECEIVING ANTENNA
30
40
50
60
70
80
90
100
110
FIELD INTENSITY - DBs. ABOVE 1 MICROVOLT/METRE FOR
1 KW RADIATED FROM A HALF WAVE DIPOLE