SOME PRELIMINARY INVESTIGATIONS ON THE PROPAGATION OF V. H. F. RADIO-WAVES AT 126 Mc/S IN MOUNTAINOUS TERRAIN

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ABSTRACT

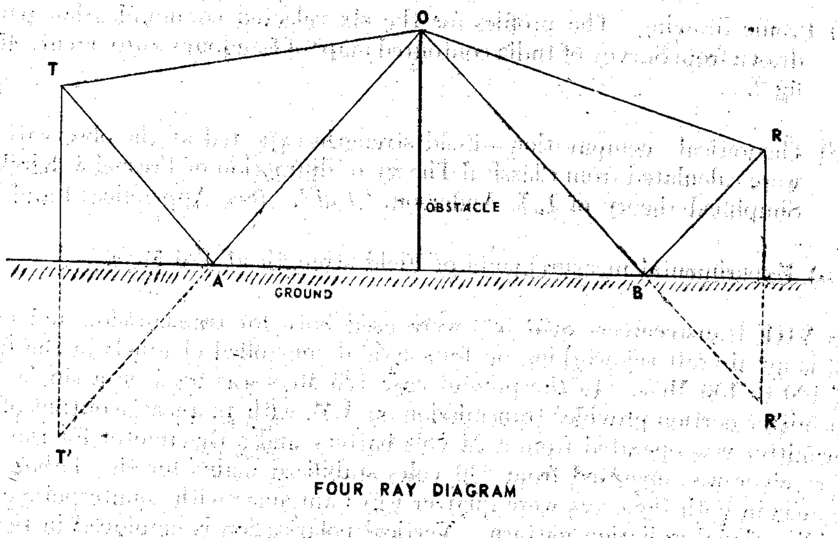
This paper deals with the propagation of VHF radio waves at 126 Mc/s within a distance of 2 km, on six different paths. Practically observed field strengths have been considered and compared with those theoretically calculated.

The observations indicate a difference of about 10—12 db on average from the predicated figures for vertically polarised waves which is expected to arise due to absorption by vegetation and the effect of hillocks close by. The differences tend to zero in simpler cases of diffraction not complicated by vegetation etc. An extreme difference of even 25 db was observed to be accounted by absorption due to surroundings of vegetation, and buildings.

INTRODUCTION

The subject of propagation of VHF Radio Waves in mountainous regions assumed importance in view of the increased communication activities in this band of frequencies in hilly terrains. VHF frequencies have the advantages of (*i*) Greater reliability; (*ii*) Freedom from interference and external static; (*iii*) Easier directional transmission and greater secrecy; (*iv*) Simpler antenna structures for portability and easy mobility. A scientific study of the propagation of VHF Radio Waves in mountainous regions is expected to provide useful knowledge in assessing the difficulties faced in VHF Communication and methods of overcoming them in mountainous areas. Diffraction can play an important part for communication between points which are not in line of sight.

The classical theory of optical diffraction of Fresnel and Kirchoff[1] is well known. The simplified theory of Knife Edge diffraction by L.J. Anderson, *et al.*[2] takes into consideration the combined effect of the four rays (see fig 1) which reach the receiver behind



FOUR RAY DIAGRAM

Fig. 1

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an obstacle. The summation expression of the total field converted into a product expression, and thereby permits graphical evaluation.

The four rays are (*i*) T–O–R: (*ii*) T–A–O–R: (*iii*) T–A–O–B–R : (*iv*) T–O–B–R.

In this paper attempts have been made to study the diffraction of VHF Radio Waves by mountain obstacles and to assess the extent of applicability of the existing theories for practical computation of field strengths in the mountainous terrain with broken country and dominated by a number of undulating hill ranges having peaks of widely varying heights.

Literature available on the subject is not much and is far from satisfactory. The diffraction theory though old is expected to be of limited scope due to treatment of idealised cases only. However, it continues to be the starting point. Propagation studies with one predominant obstacle coming between the transmitter and the receiver were made[3] which also is of limited applicability to mountainous areas. Paths with a number of obstacles, which is the general case in a hilly terrain, have not been studied in detail for communication purposes. However, such cases are treated theoretically by assuming a fictitious knife edge at the point where the lines tangential to the limiting elevations of the terrain from the antennas intersect. This procedure is followed in the present study also.

EXPERIMENTAL DETAILS

The practical work carried out can be summarised as follows—

(*i*) Profile drawing—The profiles for the six selected communication paths were drawn from Survey of India contoured map[5] of Landour Cantonment, Mussoorie fig 2.

(*ii*) Theoretical computation—Field strengths expected at the observation points were calculated from Classical Theory of diffraction of Fresnel & Kirchoff[1] and Simplified theory of L.J. Anderson, '*et al*'[2]. (See Appendices I and II)

(*iii*) Experimental measurements of Field strength at 126 Mc/s.

Two VHF transreceivers SCR 522 were used both for transmission and reception. SCR 522 is an aircraft set working on four crystal controlled channels in the frequency range of 100 to 156 Mc/s. In the present case 126 Mc/s was used on a single channel. The transmitter portion provides transmission on A.M. with an average output of 6 watts. The transmitter was operated from a 24 volt battery and a dynamotor for the field set and the receiver was operated from 230 volts stabilised mains for the Laboratory set. The antennas in both the cases were quarter wave antennas with counterpoise earth and had omnidirectional radiation pattern. Vertical polarisation is employed in the present case. The receiver portion has a sensitivity of 5 to 10 microvolts for 10 mW output. The receiver portion was used as a Field Intensity Meter and for this purpose it was calibrated with Ferris Microvolter Model 18-C. The effective length of the antenna for computation of field strength was assumed as $\lambda/2\pi$ for a $\lambda/4$ antenna[6].

The field strengths were computed from the measurement of AVC voltage or Cathode current of the 1st I.F. stage in the receiver portion. Calibration curves were drawn to show relation between AVC voltage and signal voltage and I.F. Cathode current and signal Voltage (fig. 4).

Field strength measurements were made at four or five scattered points at each location and the values obtained tabulated.

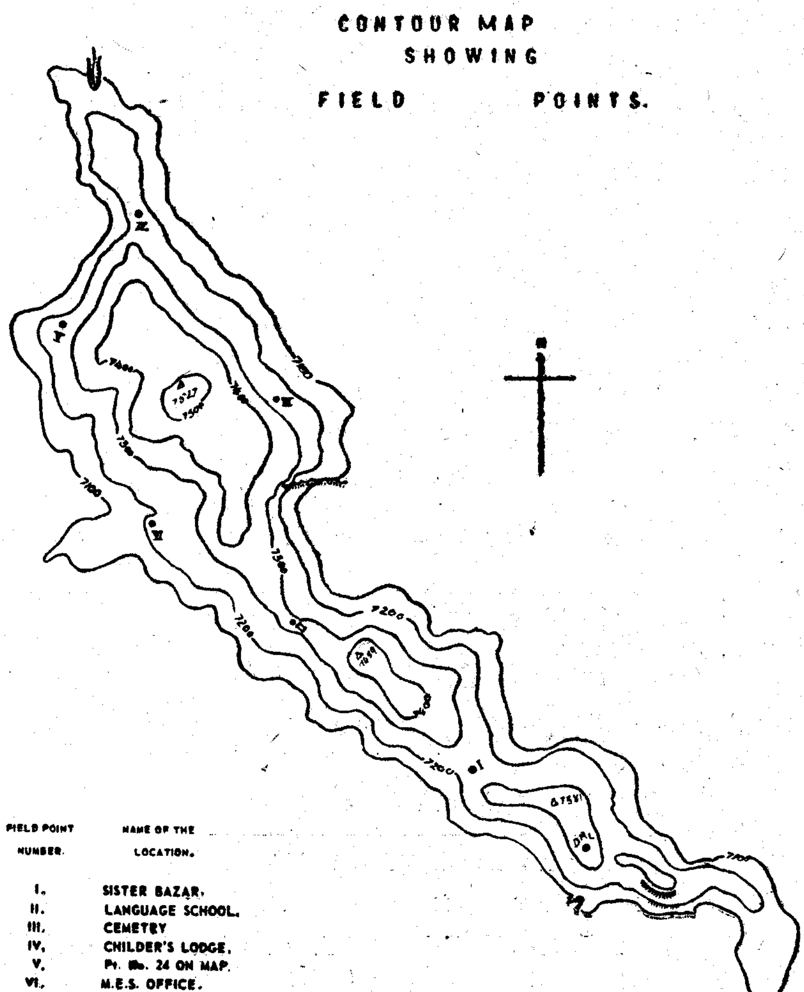


Fig. 2

Table 1

Sl. No.	Field Point Number	Distance (Meters)			Height of the Knife edge above T–R Line** (Meters)	Free space Field Strength in DBU*** (without obstacle)	Field Strength with Obstacles—in DBU (Calculated values)		Observed values of Field Strength with Obstacle in DBU.
		Transmitter To Receiver	Transmitter To Knife Edge	Knife Edge to Receiver			Classical Method	Simplified Method	
1	I (Sister Bazar) ..	280	198	82	0	99·0	93·0	99·0	98·0—100
2	II (Language School)	765	605	160	34·5	90·0	68·0	73·0	57·0—74·0
3	III (Cemetry) ..	1,205	1,145	60	10	86·0	69·0	71·0	52·0—60·0
4	IV (Children's Lodge)	1,625	1,270	355	18·5	84·0	69·0	70·0	51·0—69·0
5	V (Pt. No. 24 on Map)	1,560	1,400	160	63·0	84·0	58·0	60·0	51·0
6	VI (M.E.S. Office) ..	1,170	542	628	14·1	86·0	75·0	77·0	53·0—74·0

** T–R line is the line connecting the radiation and the receiving centres of the transmitting and the receiving antennas respectively.

*** DBU—in DB with one microvolt per metre as ODB

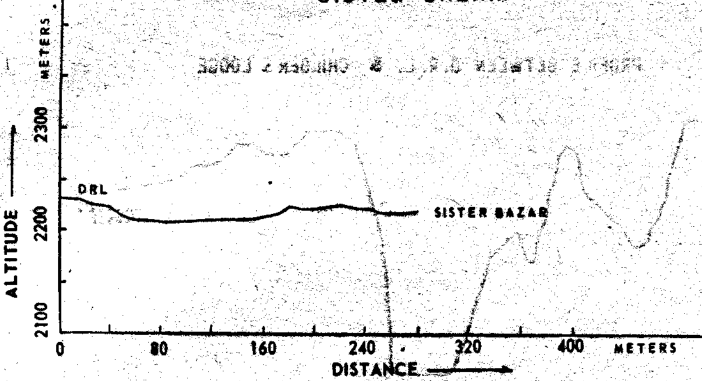
The relation between signal voltage, field strength and the effective length of the antenna is given by[6],

$$\text{Field Strength} = \frac{\text{Signal Voltage}}{\text{Effective length of the Antenna}}$$

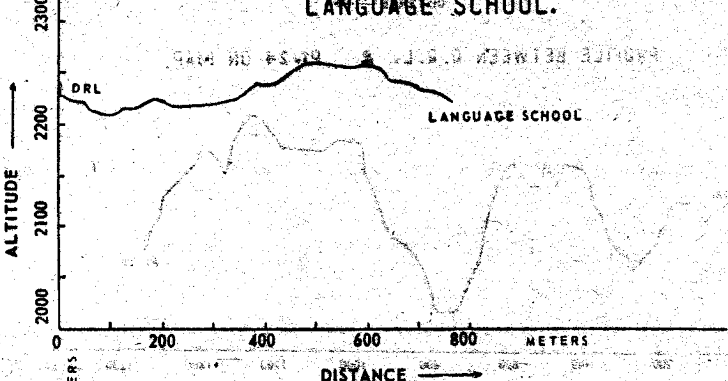
RESULTS AND DISCUSSIONS.

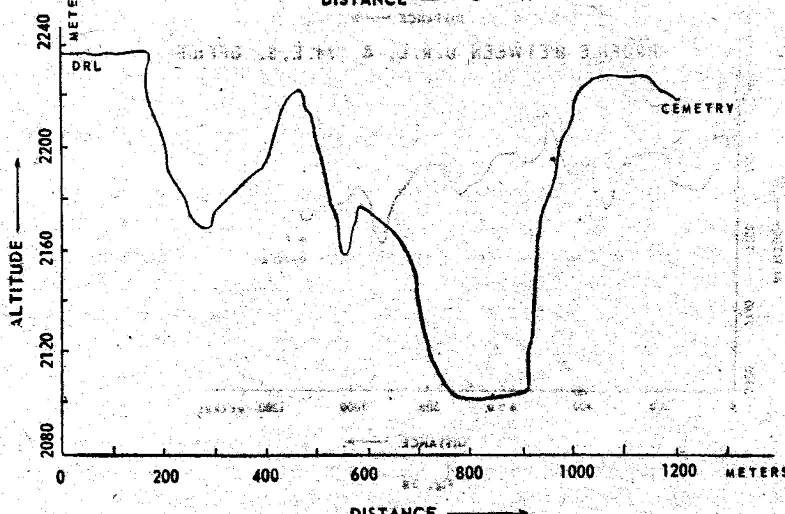
The results have been tabulated in Table 1. Attenuation of cables is taken as 2·5 db for RG 8U cables of 50 ft. length at each end[7]. The observed values show a variation of 10—20 db at different points in the same location indicating considerable effect of surroundings and importance of proper siting. Part of the difference can arise due to variation in the obstacle heights due to changes in the profile map for each point of a location.

PROFILE BETWEEN D. R. L. & SISTER BAZAR.



PROFILE BETWEEN D. R. L. & LANGUAGE SCHOOL.





PROFILE BETWEEN D. R. L. & CEMETRY.

Fig. 3 A

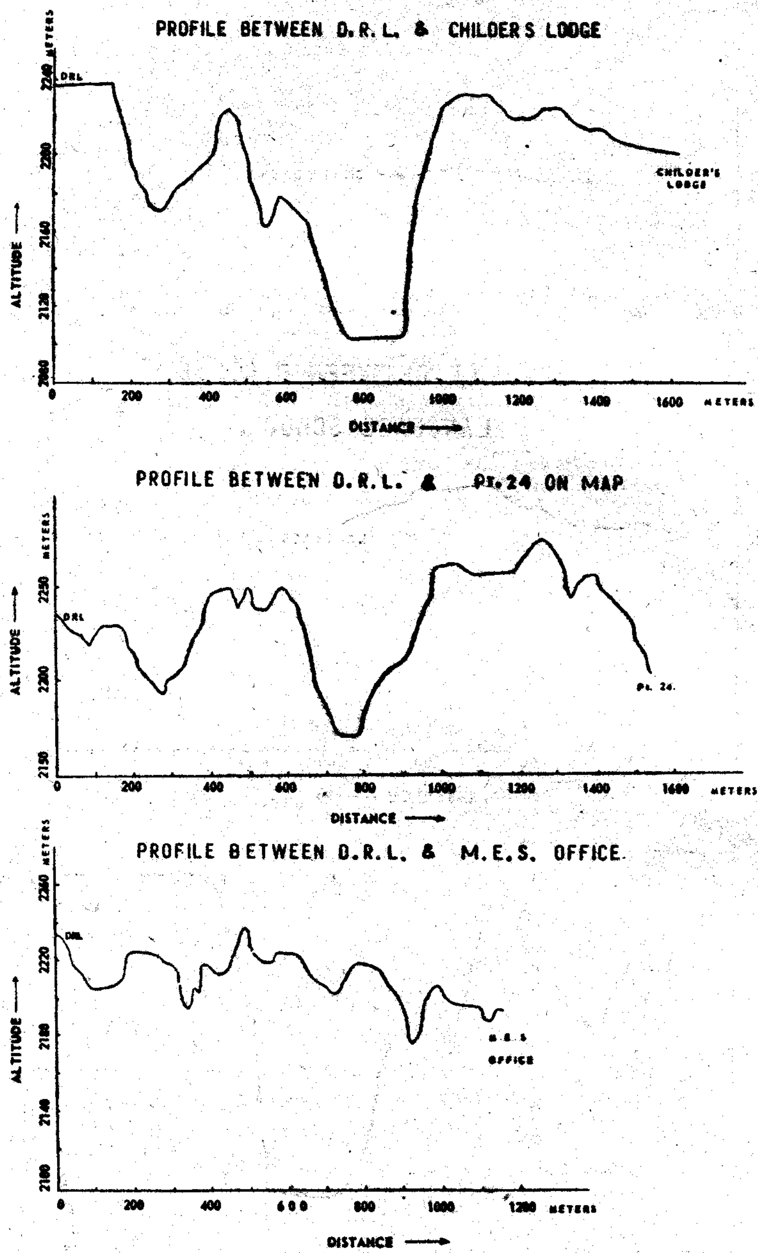
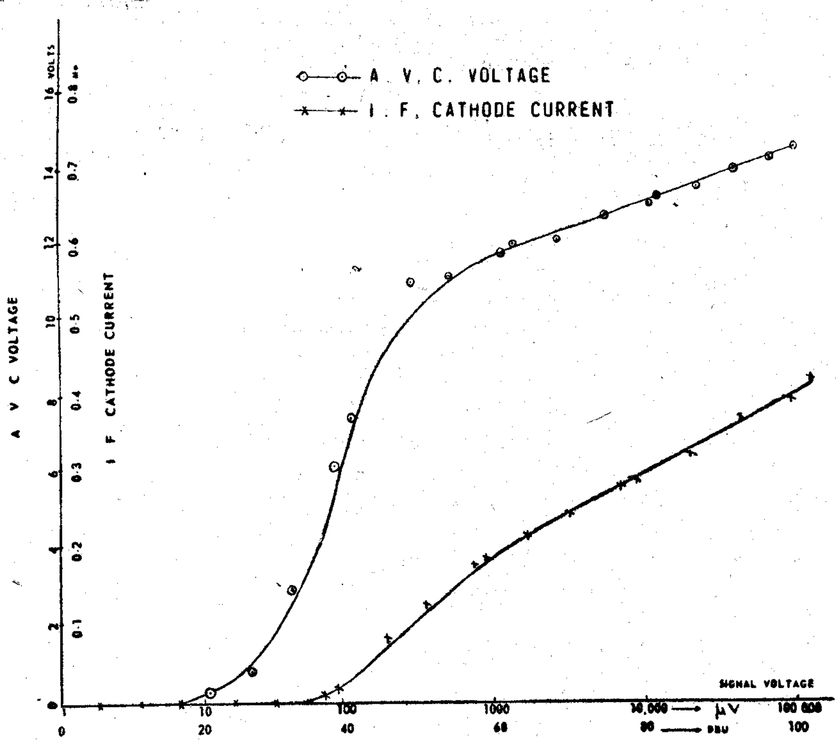

PROFILE BETWEEN D. R. L. & CHILDERS LODGE
ALTITUDE
METERS
DRL
CHILDER'S LODGE
0
200
400
600
800
1000
1200
1400
1600
METERS
DISTANCE
PROFILE BETWEEN D. R. L. & Pt. 24 ON MAP
ALTITUDE
METERS
2250
2200
2150
DRL
Pt. 24.
0
200
400
600
800
1000
1200
1400
1600
METERS
DISTANCE
PROFILE BETWEEN D. R. L. & M. E. S. OFFICE
ALTITUDE
METERS
2260
2220
2180
2140
2100
DRL
M. E. S
OFFICE
0
200
400
600
800
1000
1200
METERS
DISTANCE

Fig. 3B



CALIBRATION CURVES

Fig. 4

The observed and calculated values of the field strengths for any one location show a difference of approximately 10—12 db on average reaching extremes of even 25 db. The difference is expected to bring about the considerable effect of absorption due to vegetation and the effect of the close by hillocks, which are difficult to be quantitatively accounted. The side of the hillocks towards field points III, IV, V is considerably more vegetated than the side of points I, II, VI. Also diffraction calculations were idealised for knife edge cases and fictitious knife edges. The simplified theory was involving certain ambiguity in selection of the datum line and average terrain level was taken as basis. The agreement in the case of field point I is quite good as the path is not much complicated by vegetation as in the case of other paths. The observations indicate that the single ray diffraction calculations may possibly be taken as reasonably good rough guide over which differences to the extent of even 25 db loss could be expected as absorption loss due to vegetation and surroundings. The difference is reduced by proper siting. The considerable effect of absorption by trees, the losses amounting to 21 db at 200 Mc/s for vertically polarised waves, is also pointed out by Burrows[4].

CONCLUSIONS

It is concluded from the present study made within a distance of 2½ km, that the calculated field strengths from single ray diffraction cases can be taken as rough guide over which variation up to 25 db even can be expected on account of absorption due to vegetation and the effect of neighbouring hillocks. Importance of proper siting also is indicated.

More detailed studies extending to longer distances with different types of typical terrain, greater range of frequencies, horizontal and vertical polarisations are considered worthwhile.

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APPENDIX I

Computation of Knife edge diffraction Field using Fresnel and Kirchoff's Method

The method of computation of diffraction field strength using the Fresnel Kirchoff's method depends upon computing the contribution of the exposed wave front at the receiving point. In estimating of this the contribution of the exposed wavefront, the contribution of the secondary wavelets arising from each point of the exposed wave front, is considered elementally and the integration between the necessary limits performed to get the total effect of the exposed wavefront and the equation for the field strength is

$$E = E_{\circ} \frac{e^{i\pi/4}}{\sqrt{2}} \int_{-\infty}^{v} e^{-i\pi v^2/2} \, dv \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where

(1) E_0 is the free space field at the receiver in the absence of the knife edge calculated as

$$E_{\circ} = \frac{300 \sqrt{P}}{D}$$

where D is the distance in Kilometers and P is the power in Kilowatts.

(2) v is a parameter given by the expression

$$v = \pm h_{\circ} \sqrt{\frac{2D}{\lambda \, d_1 \, d_2}} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where

(a) $h_{\circ}$ is the height of the obstacle above T—R line in meters

(b) $D = d_1 + d_2$

(c) λ = Wave length in metres

and (d) d_1 and d_2 are the relative distances of the obstacle from the receiver and the transmitter respectively. All the distances are being expressed in metres.

The evaluation of the field strength relative to free space value is conveniently done by the use of the Cornu Spiral. For this evaluation the procedure given by August Hund was followed, in which the depth of the receiving centre from the line of sight the transmitter is considered. The expression for s which is numerically same as v in equation (2), is given by

$$s = z \sqrt{\frac{2d}{(d + r_{\circ}) \, r_{\circ} \lambda}}$$

where

z is the depth of the receiving centre from the line of sight plane.

d is the distance between the transmitter and the obstacle.

r_0 is the distance of the receiver from the obstacle as measured on the line of sight plane.

λ is the wave length.

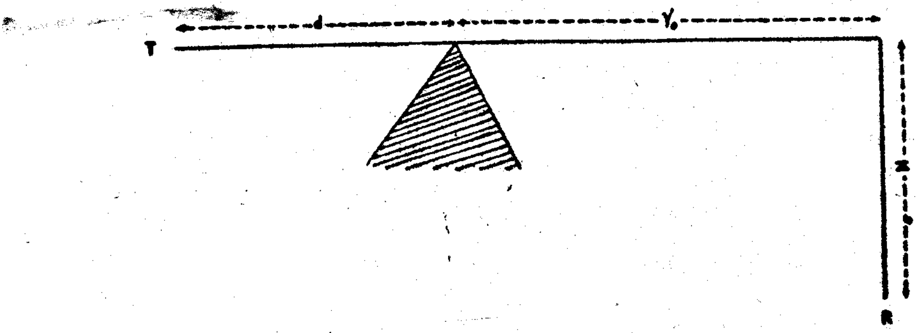


Fig. 3

The expression $\sqrt{x^2 + y^2}$ is a measure of the total amplitude contributed by the number of Fresnel Zones corresponding to the particular s value.

The expressions for x and y are given by

$$x = \int_0^s \cos \frac{\pi s^2}{2} \, ds$$

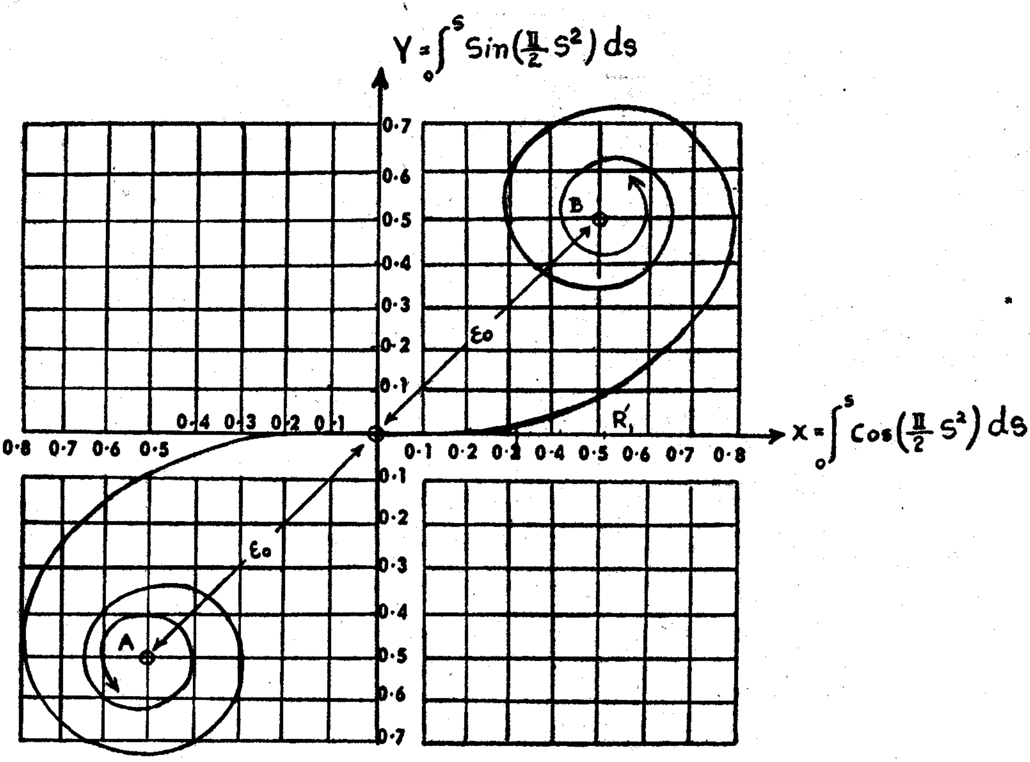
$$y = \int_0^s \sin \frac{\pi s^2}{2} \, ds$$

The method of evaluation of the amplitude from the Cornu Spiral is well known and it is briefly repeated here.

In the case of diffraction into the shadow region of an obstacle the s value which is dependent on the geometrical configuration determines the shadowing effect. If the receiving centre is just on the line of sight plane, the field contribution is known to be that contributed by half the Primary Wave front as the lower half is shadowed. This corresponds to the vector amplitude $\overrightarrow{BR_o}$ with B as one asymptotic point on the Cornu Spiral with the coordinates (1/2, 1/2), and R_o being the origin.

On the Cornu Spiral the amount of shadowing is determined by $\overrightarrow{R_0R_1'}$. Hence the contribution of the wave front exposed is determined by the amplitude of the vector $\overrightarrow{BR'_1}$. For algebraic calculations of this, the coordinates (x, y) of the point R'_1 are determined by the s value measured along the spiral from the origin. The amplitude BR'_1 is calculated as the coordinates of both B and R'_1 are known and is given by

$$\overrightarrow{BR'_1} = \sqrt{(\tfrac{1}{2} - x)^2 + (\tfrac{1}{2} - y)^2}$$



CORNU SPIRAL

Fig. 6

In the case of receiving centre being above the line of sight plane, the field contribution is due to half the primary wave front plus the additional Fresnel Zones uncovered. The amplitude in this case is evaluated as the vector $\overrightarrow{AR'_1}$ algebraically by the expression

$$\overrightarrow{AR'_1} = \sqrt{(\tfrac{1}{2} + x)^2 + (\tfrac{1}{2} + y)^2}$$

A sample calculation for *DRL*—M.E.S. Office path is given below.

In this case, we have

λ = 2·381 meters

d = 490 meters

r_o = 680 meters

z = 27 meters

Hence

$$s = 27\sqrt{\frac{2 \times 490}{2\cdot381 \times 680\ (490 + 680)}}$$
$$= 0\cdot6142$$

Now from table of Fresnel Integrals we have the values for x and y corresponding to the value of s

$$x = 0\cdot5891$$
$$y = 0\cdot1167$$

Hence the geometrical factor A is given by

$$A = \sqrt{(0\cdot5 - 0\cdot5891)^2 + (0\cdot5 - 0\cdot1167)^2}$$
$$= \sqrt{0\cdot1548}$$
$$= 0\cdot3934$$

Now we calculate $E_\circ$

$$E_\circ = \frac{300\sqrt{\cdot006}}{1\cdot17}\ mv$$
$$= 19\cdot86\ mv \text{ per meter}$$

Hence Field E at the receiving point is

$$E = 19\cdot86 \times 0\cdot3934 \times \frac{1}{\sqrt{2}};$$ $\frac{1}{\sqrt{2}}$ being proportionately factor with respect to free space field.

$$= 5\cdot524\ mv \text{ per meter.}$$

and E in $DBU = 20 \log_{10} (5\cdot524 \times 10^3)$
$$= 20 \times 3\cdot7428$$
$$= 74\cdot84$$

Thus Field E at the receiving point is 75 DBU nearly.

APPENDIX II

The simplified Method for computing the Knife-Edge Diffraction in the Shadow Region

The method consists in the evaluation of the received field strength conveniently from the graphs, which are obtained when the summation of the four field components with differing amplitude and phase, is replaced by a product of three terms. This method is applied to the four ray model. The four rays being, direct ray from transmitter to receiver via knife-edge, the ray with reflection on the receiver side only, the ray with reflection on the transmitter side only, and the ray with reflection on both sides of the knife-edge. The method was simply extended to the two ray model, with reflection on one side only and single ray model with no reflection by substitution of appropriate values of reflection coefficients.

The simplification of the computation method is obtained by the use of asymptotic approximation to the equations for the amplitude F, and phase β, due to knife-edge diffraction. The final formula when expressed as a three term product is given by,

$$\left|\frac{E}{E_{\circ}}\right|^2 = \left[\frac{1}{2\pi^2 v_{\circ}^2}\right] \times \left[\frac{4\rho_1 \cos^2 \frac{1}{2}(k\delta_1 + \phi_1)}{(1 + 2k\delta_1/\pi v'^2_{\circ 1})^{\frac{1}{2}}} + \frac{[(1 + 2k\delta_1/\pi v'^2_{\circ 1})^{\frac{1}{2}} - \rho_1]^2}{1 + 2k\delta_1/\pi v'^2_{\circ 1}}\right]$$

$$\times \left[\frac{4\rho_2 \cos^2 \frac{1}{2}(k\delta_2 + \phi_2)}{(1 + 2k\delta_2/\pi v'^2_{\circ 2})^{\frac{1}{2}}} + \frac{[(1 + 2k\delta_2/\pi v'^2_{\circ 2})^{\frac{1}{2}} - \rho_2]^2}{1 + 2k\delta_2/\pi v'^2_{\circ 2}}\right] \quad \ldots \quad \ldots \quad (1)$$

where, E = received field strength.

$E_{\circ}$ = free space (no obstacle) field $= \dfrac{300\sqrt{P}}{D}$ mv/m,

where, P = power in kW.

D = distance in Km.

$$v_{\circ} = h_{\circ}\left[\frac{2D}{\lambda\, d_1 d_2}\right]^{\frac{1}{2}},$$

where, $h_{\circ}$ = height of the knife-edge above the direct T—R line.

D = distance between the transmitter and the receiver.

d_1 & d_2 = the distances of the receiver and the transmitter, from the knife-edge on the direct $T—R$ line, respectively.

λ = wave-length. All the quantities are in same units.

ρ_1 & ρ_2 = ground reflection co-efficients on the receiver and the transmitter side respectively.

ϕ_1 & ϕ_2 = are the phase changes due to reflections at the ground on the receiver and the transmitter sides respectively.

$k = 2\pi/\lambda$

δ_1 & δ_2 = diffraction path length differences at the receiver and the transmitter sides respectively.

$$\delta_1 = \frac{H_R}{d_1}(h_\circ + h_3) \quad , \quad \delta_2 = \frac{H_T}{d_2}(h_\circ + h_3)$$

where, H_R = height of the receiving antenna above the ground level.

H_T = height of the transmitting antenna above the ground level.

h_3 = height of the knife-edge above the image of the direct $T—R$ line.

$$v'_{01,2} = \frac{v_\circ}{1 + \dfrac{\Delta D_{1,2}}{\delta_{1,2}}}$$

$\Delta D_{1,2}$ = free space (no obstacle) path differences $= \dfrac{2H_R H_T}{D}$.

$$\Delta D_1 = (T - R') - (T - R) = \frac{2H_R H_T}{D}.$$

$$\Delta D_2 = (T' - R) - (T - R) = \frac{2H_R H_T}{D}.$$

The equation is expressed as follows for graphical evaluation in computing the field strength.

$$10 \log \left|\frac{E}{E_\circ}\right|^2 = 10 \log A + 10 \log B_1 + 10 \log B_2.$$

where the three terms in the brackets of eqn. (1) are designated as A, B_1, B_2.

10 log A is evaluated from the graph drawn between 10 log A versus v_0. 10 logB_1, and 10 logB_2, are evaluated from the common graph of 10 log B versus $2\delta/\lambda$, with v'_0 as a parameter, and for the special case of ρ=1 and $\phi=\pi$. When there is no reflection, terms 10 logB_1 and 10 logB_2 will vanish.

In this method of computation the factors $v_\circ$, $\dfrac{2\delta_1}{\lambda}$, $\dfrac{2\delta_2}{\lambda}$, v', $v_{\circ 1}'$ $v_\circ{}'_2$, are first evaluated For the evaluation of these, the quantities to be known first are $h_\circ$, D, λ, d_1, d_2, H_R, H_T, and h_3, which are already defined.

The details of calculations applying the above method for a propagation path is shown below.

PATH BETWEEN D.R.L. AND M.E.S.

$D = 1170m$, $d_1 = 628m$, $d_2 = 542m$, $Power\ (P) = \cdot 006\ Kw$, $\lambda = 2\cdot 38$ in

$H_R = 8\cdot 5m$, $H_T = 57\cdot 2m$, $h_o = 14\cdot 1m$, $h_3 = 84\cdot 3m$.

$$E_o = \frac{300\sqrt{P}}{D} = \frac{300\sqrt{\cdot 006}}{1\cdot 170} = 19\cdot 86\ mv/m.$$

$$v_o = h_o\left(\frac{2D}{\lambda d_1 d_2}\right)^{\frac{1}{2}} = 14\cdot 1\left(\frac{2 \times 1170}{2\cdot 38 \times 628 \times 542}\right)^{\frac{1}{2}} = \cdot 7685.$$

$$\Delta D = \frac{2\,H_R\ H_T}{D} = \frac{2 \times 8\cdot 5 \times 57\cdot 2}{1170} = \cdot 8310.$$

$$\delta_1 = \frac{H_R}{d_1}\left(h_o + h_3\right) = \frac{8\cdot 5}{628}\left(14\cdot 1 + 84\cdot 3\right. = \frac{8\cdot 5 \times 98\cdot 4}{628} = 1\cdot 3310.$$

$$2\delta_1/\lambda = \frac{2 \times 1\cdot 3310}{2\cdot 38} = 1\cdot 1190$$

$$\delta_2 = \frac{H_T}{d_2}\left(h_o + h_3\right) = \frac{57\cdot 2}{542}\left(14\cdot 1 + 84\cdot 3\right) = \frac{57\cdot 2 \times 98\cdot 4}{542} = 10\cdot 3900$$

$$2\delta_2/\lambda = \frac{2 \times 10\cdot 3900}{2\cdot 38} = 8\cdot 724.$$

$$v'_{o1} = \frac{v_o}{1 + \Delta D/\delta_1} = \frac{\cdot 7685}{1+\frac{\cdot 8310}{1\cdot 3310}} = \frac{\cdot 7685 \times 1\cdot 3310}{2\cdot 1620} = \cdot 4733.$$

$$v'_{o2} = \frac{v_o}{1 + \Delta D/\delta_2} = \frac{\cdot 7685}{1+\frac{\cdot 8310}{10\cdot 3900}} = \frac{\cdot 7685 \times 10\cdot 3900}{11\cdot 2210} = \cdot 7112.$$

$10 \log A = -10\cdot 5$ from graph.

$10 \log B_1 = +\ 1\cdot 5$ from gr ph.

$10 \log B_2 = +\ 0$ from graph.

$$\therefore\ 10 \log \left|\frac{E}{E_o}\right|^2 = 10 \log A + 10 \log B_1 + 10 \log B_2.$$

$$= -10\cdot 5 + 1\cdot 5 + 0. = -9\cdot 0000.$$

Or $\log \left|\dfrac{E}{E_\circ}\right| = -\ \cdot 4500 = \bar{1}\ 5500.$

$$\log E = \bar{1}\cdot 5500 + \log E_\circ = \bar{1}\cdot 5500 + \log 19\cdot 86$$

$$= \bar{1}\cdot 5500 + 1\cdot 2980 = 0\cdot 8480$$

$$E = 7\cdot 05\ mv/m = 7\cdot 05 \times 10^3\ \mu v/m$$

$$\therefore\ E \text{ in } DBU = 20 \log 7\cdot 05 \times 10^3 = 77\ DBU.$$