INTERFERENCE PATTERN CALCULATION OF SPACE WAVE PROPAGATION FOR MICROWAVE COMMUNICATION LINKS

A Thesis

by

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The thesis titled ''**INTERFERENCE PATTERN CALCULATION OF SPACE WAVE PROPAGATION FOR MICROWAVE COMMUNICATION LINKS**'' submitted by Sunil Kumar Adhikary, Roll No.901304F, Session '88-89 to the Department of Electrical and Electronic Engineering of B.U.E.T. has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Master of Science in Engineering (Electrical and Electronic).

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Symbols	Description
f_1	Radiation field strength pattern of transmitting antenna
f_2	Radiation field strength pattern of receiving antenna
h_1	Transmitting antenna height
h_2	Receiving antenna height
k_0	Propagation constant
$\rho e^{j\phi}$	Reflection co-efficient
ρ	Mangnitude of reflection co-efficient
$\phi/\phi/\phi_h$	Phase angle of reflection co-efficient /Vertical polarization/Horozontal polarization
R_1	Direct path length
R_2	Reflected path length
ψ	Grazing angle
ψ_0	Elevation angle
F	Path gain factor
λ_0	Wave length
σ	Ground conductivity
k	Dielectric constant
f	Frequency
r_f	Free space reference range
r	Direct line-of-sight length (Chapter 2)
ϵ	Permitivity

Symbols	Description
v	Vertical direction wave length
N	Refractivity
n	Refractive index
p	Pressure
e	Partial pressure of water vapor
T	Ratio of antenna heights (Chapter 3)
T	Absolute Temperature (Chapter 4)
D	Divergence factor
ζ	Path difference phase variable
d_1	Distance from transmitter
d_2	Distance from receiver
r	Radius of curvature of earth
a	Earth radius
a_e	Effective earth radius
h	Height above earth surface (Chapter 3)
d	Total path length
h_c	Clearance height of obstraction
V(X)	Attenuation factor
U(Z)	Height gain function
F_d	Path gain factor due to diffraction
H_1	Radius of first Fresnel zone
S/N	Signal to noise ratio

Symbol	Description
h	Plank's constant (Chapter 4)
K	Boltzman constant
R	Resistance (Chapter 4)
B_n	Band width
NF	Noise figure
N_{in}	Noise input
N_{out}	Noise output
S_{in}	Signal input
S_{out}	Signal output
G	Gain of the system
dB	Decibel
T_r	Effective input noise temperature
ΔN	Noise difference between input and output
N_0	Receiver noise
C_{min}	Received carrier level
P_T	Transmitter output power
P_R	Receiver output power
G_T	Directivity gain of transmitting antenna
G_R	Directivity gain of receiving antenna
G_s	System gain
A_{eff}	Effective area of receiving antenna
P_{Di}	Radiate power per unit area of antenna

Symbols	Description
EIRP	Effective isotropic radiate power
L_{dB}	Line loss
L_{Feed}	Feeder loss
L_B	Branching network loss
G_{dB}	Antenna gain
FM	Fade margin

Abstract

Interference in microwave space-wave propagation occurs when two waves from the same source meet at a point after traveling through separate paths. In case of microwave propagation, the waves reach the receiving point not directly (line-of-sight path) but also after being reflected from the ground. If the frequency and height of antenna is such that the difference between the direct and the ground reflected wave exactly equals one wave length, the two waves completely or partially cancel depending on the constants of the earth, but if the path difference equals half wavelengths, reinforcement of received waves take place. A succession of such points lie one above the other giving an interference pattern having alternate cancellation and reinforcements. Such patterns can be plotted from the actual field strength measurements or by actual calculation. The evaluation of a proposed communication link must be carried out with due attention given to these interference effects. The goal would be to ensure that sufficient signal-to-noise margin is available so that under adverse propagation conditions outages will occur for only small intervals of time.

Interference effects are analyzed for microwaves (above 1GHz) and a computer model is developed to obtain radiation patterns (lobes and nulls) due to interference. Appropriate formulas for the interference effects due to antennas located over a flat earth and over a spherical earth, for field in the diffraction zone and for calculating midpath obstacle (hills and buildings) diffraction loss are used to develop the model. Effects of earth's curvature, earth's imperfections and roughness, shadowing effects of hills and buildings on the field strength in the interference zone are incorporated in the model.

The model is used to calculate the signal-to-noise margin, path gain factor, maximum link distance corresponding to a particular earth's surface, frequency and height of the antenna, the incident power per unit area at the receiving terminal, the field for a microwave link. Specific results for a number of UHF and SHF links have been obtained and compared with datas taken from Bangladesh T.& T. Board. The agreement between the two results is found to be satisfactory.

CHAPTER 1

INTRODUCTION

1.1 PROPAGATION OF ELECTROMAGNETIC WAVES AND INTERFERENCE EFFECT

There are many possible propagation paths to reach the radiated energy from the transmitting antenna to the receiving antenna. Some of them are shown in fig 1.1.

Waves scattered by the troposphere [5,11] are called tropospheric waves. Some of these arrive at the receiver after reflection or scattering in the ionosphere are named sky wave. Energy propagated over other paths near the earth surface is termed ground wave. It is divided into two parts such as the space wave and the surface wave. The space wave is again divided into two parts. The signal that travels through the direct path from transmitter to receiver is called direct wave and the signal arriving at the receiver after being reflected from the surface of earth is termed as ground reflected wave. The surface wave is called the 'Norton surface wave' and is usually guided along the earth's surface.

In communication phenomena interference occur whenever there are two or more paths through which the waves can propagate along to reach the receiving antenna. Fading [1,3,8] takes place

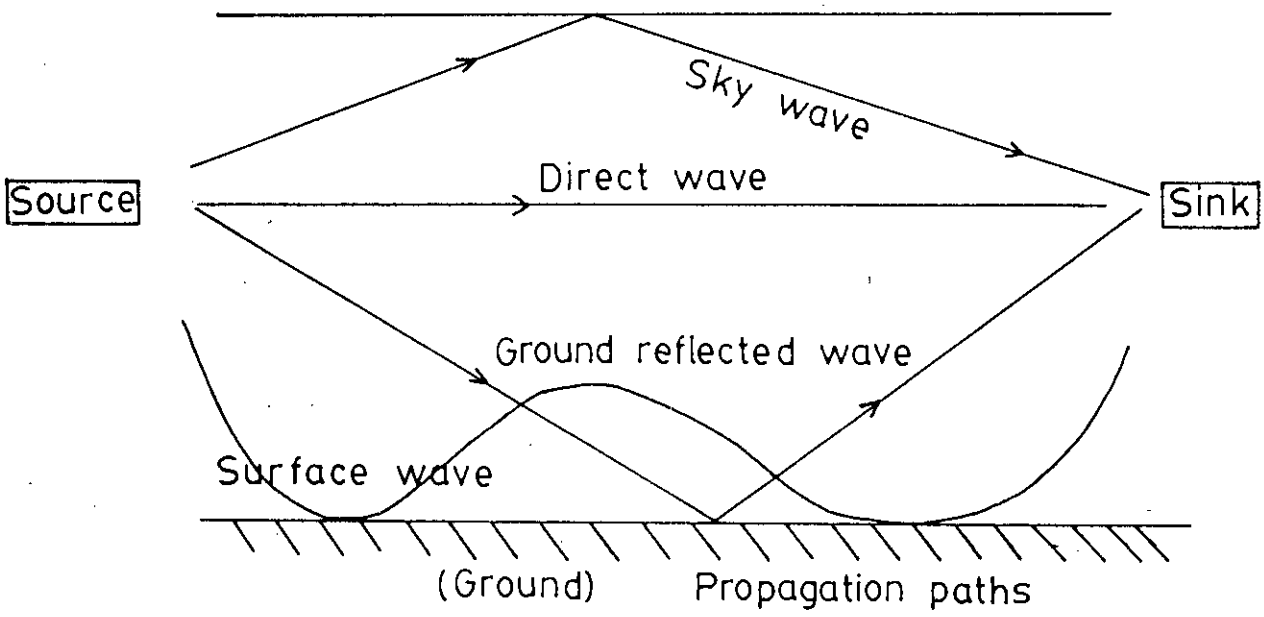


Fig.1.1 Illustration of propagation paths

if the propagation path is not stable and as a result large variation in the received signal power takes place over time intervals. The instability in the propagation path is due to the variation of index of refraction of atmosphere which is the function of temperature and humidity. Variations in the index of refraction [5,12] cause the phase angle of the signal arriving at the receiving site to vary in a random way. Thus signals arriving along different paths combine more or less with random phases. As a result of these phase differences often these signals tend to cancel one another. This may cause fading. Generally, some diversity techniques are used to overcome the above effects.

The propagation of the electromagnetic energy between the transmitting and receiving antennas takes place under free-space condition . Free space propagation essentially occurs for some communication links under ideal conditions. However, for most communication links the signal propagation is modified by the presence of the earth, the atmosphere, the ionosphere and atmospheric hydrometeors such as rain fall, snow, hail etc. The influence of the natural enviornment on propagation of radio wave is highly dependent on the frequency and the proximity of the antennas to the ground.

1.2 PROPAGATION DUE TO FREQUENCY RANGE

The propagation mode of a radio wave is closely dependent upon its frequency. Here some broad freqency intervals that influence the radio-wave propagation are described.

In case of extremely low frequencies the wavelength is greater than 100 km. The antennas used are very large and are of necessity close to the ground. Transmission in this range is primarily due to surface wave because of relatively low ground attenuation. The sky wave is reflected [1,6] from the ionosphere and a form of earth-ionosphere waveguide exists that may be thought of as providing a guiding path for the waves as they propagate around the earth.

As the frequency is increased above 30 kHz the propagation is strongly influenced by the presence of the ground. The sky wave attenuation is less in the lower range of this band of frequences but increases in the higher range such as 30 kHz or above. In general, the day time sky wave absorption is relatively high in the ionosphere and long distance communication is uncertain due to varying conditions of ionosphere. But long-range night communication via sky wave is reliable. At the higher range of medium frequencies (around 2-3 MHz) the sky waves are highly attenuated and the only reliable communication during day is by

surface wave propagation.

Frequency range from few MHz up to 30 MHz to 40 MHz include the international shortwave broadcasting and radio wave reflected from the ionosphere to provide communication over long skip distances. Over the propagation path, free-space propagation conditions are approached, but the variability of the electron concentration with of day, yearly variations etc., produces a considerable amount of fading as well as periods of time when only certain frequencies are usable.

A sky wave above 50 MHz [1,6] does not return to earth and pass out into space. The surface wave are rapidly attenuated due to heavy ground losses. Hence transmission in this range is effected by space wave. The antennas are relatively small and the main propagation effects are those associated with interference between the signals which propagate along the direct line-of-sight path and those reflected from ground. At SHF range and above, attenuation and scattering occur due to rain and atmospheric gases. The diffraction [1] of the waves due to hill, buildings, trees etc. are also much more pronounced in this range. Our proposed thesis work is based on this band of frequencies.

In the region of millimeter wavelength atmospheric attenuation as well as attenuation due to rain becomes a serious

factor in the distance between transmitting and receiving antennas. This attenuation is exponential in character and it can severely limit the propagation distance.

1.3 FREQUENCY BAND DESIGNATION

The different bands of frequencies and standard band designation [1,3,11] are shown in the table-1. The microwave and millimeter frequency bands are broken down into several bands designated by letters. These are discussed in appendix A.

Table-1

Desingnation	Frequency Band		Typical service
Very Low Frequencies (VLF)	3-30	kHz	Navigation, sonar
Low Frequencies (LF)	30-300	kHz	Radio beacons
Medium Frequencies (MF)	300-3000	kHz	AM broadcasting, maritime radio
High Frequencies (HF)	3-30	MHz	Telephone, telegraph, facsimile
Very High Frequencies (VHF)	30-300	MHz	Television, FM broadcast, police
Ultra High Frequencies(UHF)	300-3000	MHz	Television, satellite communication
Super High Frequencies (SHF)	3-30	GHz	Airborne radar, MW links, satellite
Extra High Frequencies (EHF)	30-300	GHz	Radar
Microwave Frequencies	MWF	Generally Above 1 GHz	

CHAPTER 2

RADIOWAVE INTERFERENCE PHENOMENA OVER FLAT EARTH

2.1 INTRODUCTION

When a plane radio wave strikes the surface of earth it is reflected with an angle of reflection equal to the angle of incidence. Reflected wave changes in magnitude as well as in phase. Vector ratio of reflected to incident wave is called reflection co-efficient. The reflection co-efficient depends in a complex way upon frequency, dielectric constant, conductivity of earth, plane of polarization and angle of incidence of the wave on the earth.

2.2 GENERAL FEATURES OF INTERFERENCE PHENOMENA WITH ANTENNAS LOCATED OVER A FLAT-EARTH

The general features of interference phenomena associated with antennas placed over earth can be determined by studying the effects associated with antennas located over a flat-earth. The radiation field strength patterns [1,5,13] of transmitting antenna and receiving antenna are f_1 and f_2 respectively and h_1 and h_2 are the respective heights for the two antennas shown in the figure 2.1 [1,5,13].

With reference the figure 2.1 the field that reaches the receiving antenna directly produces voltage which is proportional

to

$$f_1(\theta_1)f_2(\theta_1')e^{(-jk_0R_1)}/(4\pi R_1)$$

and voltage produced by the indirect or reflected wave is proportional to

$$f_1(\theta_2)f_2(\theta_2')\rho e^{(j\phi)}e^{-jk_0R_2}/(4\pi R_2)$$

where $\rho e^{j\phi}$ is the reflection coefficient at the ground and k_0 is the propagation constant.

In the usual situation h_1 and h_2 are very small compared with the span distance d; hence the angles θ_1, θ_2, θ_1' and θ_2' are very small and the antenna patterns can be assumed constant over the range of angle involved. Therefore total received voltage will be proportional to

$$f_1(\theta_1)f_2(\theta_1')e^{(-jk_0R_1)}/(4\pi R_1)+f_1(\theta_2)f_2(\theta_2')\ e^{(-jk_0R_2)}\rho e^{(j\phi)}/4\pi R_2 \quad \ldots\ldots\ldots(2.01)$$

As the span distance d is very large we can simplifyed the above equation taking $R_1=R_2$ for the denominator as

$$f_1(\theta_1)f_2(\theta_1')\frac{e^{-jk_0R_1}}{4\pi R_1}\left|1+\rho e^{j\phi}f_1(\theta_2)f_2(\theta_2')e^{-jk_0(R_2-R_1)}/f_1(\theta_1)f_2(\theta_1')\right|$$

$$= f_1(\theta_1)f_2(\theta_1')e^{-jk_0R_1}/4\pi R_1 \ .F$$

where $F=\left|1+\rho e^{j\phi}f_1(\theta_2)f_2(\theta_2')e^{-jk_0(R_2-R_1)}/f_1(\theta_1)f_2(\theta_1')\right|$.....(2.02)

is called the path-gain factor [1,5,6,11], shows how the field at the receiving antenna differs from the value it would have under free-space propagation condition.

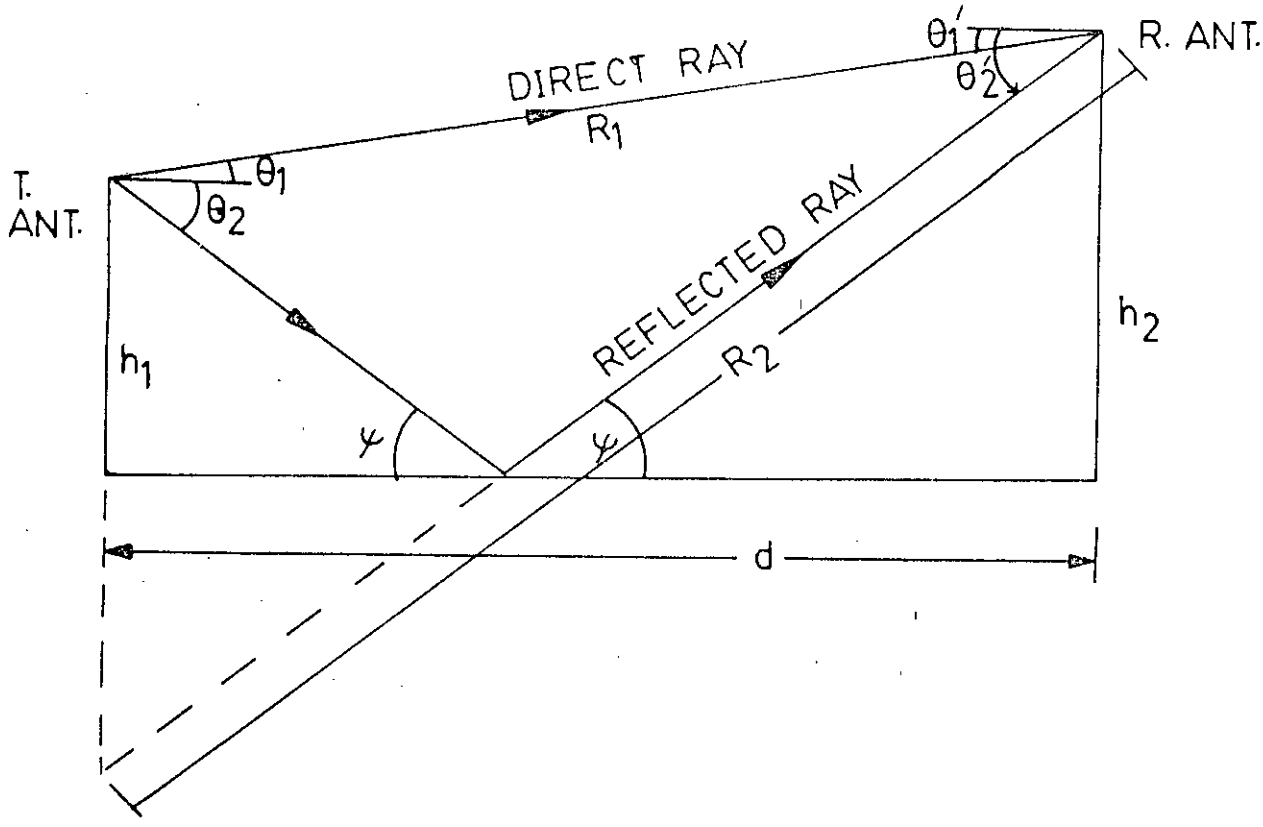


Fig.2.1 Illustration of direct and reflected rays.

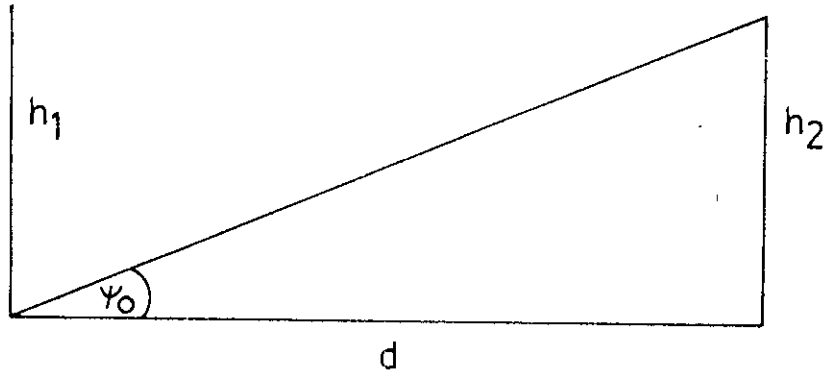


Fig.2.2 Illustration of elevation angle.

If $f_1(\theta_1) \cong f_1(\theta_2)$ and $f_2(\theta_1') \cong f_2(\theta_2')$ we can express F as

$$F = |1+\rho e^{j\phi - jk_0(R_2-R_1)}| \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.03)$$

With the reference to the figure 2.01 we have,

$$R_1 = \{d^2+(h_2-h_1)^2\}^{0.5}$$

$$= d+(h_2-h_1)^2/(2d)$$

$$R_2 = \{d^2+(h_1+h_2)^2\}^{0.5}$$

$$= d+(h_2+h_1)^2/(2d)$$

and $$R_2-R_1 = 2h_1h_2/d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.04)$$

If we consider $\rho e^{j\phi} = -1$ which is good for many of the practical cases then the above calculated value we have

$$F = |1-e^{-j2k_0h_1h_2/d}| \quad \ldots\ldots\ldots\ldots\ldots\ldots(2.05a)$$

$$= |1-\cos(2k_0h_1h_2/d)+j\sin(2k_0h_1h_2/d)|$$

$$= 2|\sin(k_0h_1h_2/d)| \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.05b)$$

It is clear from the above equation that interference effects can lead to a doubling of the field strength relative to the value under free space condition. Hence the path-gain factor can be expressed in term of elevation angle refering to the figure 2.02 as

$$F = 2\sin(k_0h_1\tan\psi_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.06)$$

Therefore F is maximum when

$$\tan = (\pi/2+n\pi)/k_0h_1$$

$$= (1/4+n/2)\lambda_0/h_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.07a)$$

where n=0,1,2,....

and F is minimum when

$$\tan\varphi_o = \pi/(k_0 h_1)$$

$$\Rightarrow \tan\varphi_o = n\lambda/(2h_1) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.07b)$$

The phase change between the direct and the reflected component due to the path difference $(R_2-R_1) = \delta$ radians and the total phase shift between the direct component E_d and the reflected component E_r (E_r lagging E_d) is $180^0+\delta$, where δ is expressed in degree (shown in Fig 2.3). Since the path difference ΔR is necligible the two component are almost equal in magnitude. Therefore from the diagram 2.3

$$E^2 = E_r^2 + E_d^2 + 2E_r E_d \cos(\pi-\delta)$$

$$= 2E_d^2(1-\cos\delta)$$

$$\text{Hence } E = 2E_d\sin(\delta/2) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.08a)$$

If δ is very small, $\sin(\delta/2) \cong \delta/2$, the field strength is then

$$E = E_d\delta$$

$$= 4\pi E_d h_1 h_2/(d\lambda_0) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.08b)$$

The above discussion is based on $\rho = 1$ and $\phi = 180^0$.

2.3 REFLECTION CO-EFFICIENT FOR PROPAGATION

The reflection co-efficient $\rho e^{j\phi}$ is given by the Fresnel expressions for the reflection co-efficient for a plane wave polarized with the electric field in the plane of incidence (vertical polarization) and for a wave polarized with the

electric field perpendicular to the plane of incidence (horizontal polarization). The Fresnel reflection co-efficients depend on the ground conductivity, permitivity, frequency and angle of incidence.

The reflection co-efficient for vertical and horizontal polarization [1,2,5] are calculated using the following equations.

$$R_v = \rho e^{j\phi} = \frac{(k-jx)\sin(\psi)-[(k-jx)-\cos^2(\psi)]^{0.5}}{(k-jx)\sin(\psi)+[(k-jx)-\cos^2(\psi)]^{0.5}} \quad \ldots\ldots\ldots\ldots (2.09)$$

$$R_h = \rho e^{j\phi} = \frac{\sin(\psi)-[(k-jx)-\cos^2(\psi)]^{0.5}}{\sin(\psi)+[(k-jx)-\cos^2(\psi)]^{0.5}} \quad \ldots\ldots\ldots\ldots\ldots (2.10)$$

where $x = \sigma/w\epsilon_0$

σ = Ground conductivity,

ϵ_0 = Permitivity

ψ = The grazing angle of incidence

Some typical values of the above parameters are given below

Dielectric constant(k) = 15 (approx.)

(It may smaller for poor conductivity of soil and will increse upto about 30 for soil with high conductivity)

Ground Conductivity(σ) = from 10^{-3} to 3 x 10^{-2} S/m

When the incident wave is normal to the reflecting surface ($\psi = 90^0$) there is no difference between the horizontal and vertical polarization (Fig. 2.4). In both cases the electric

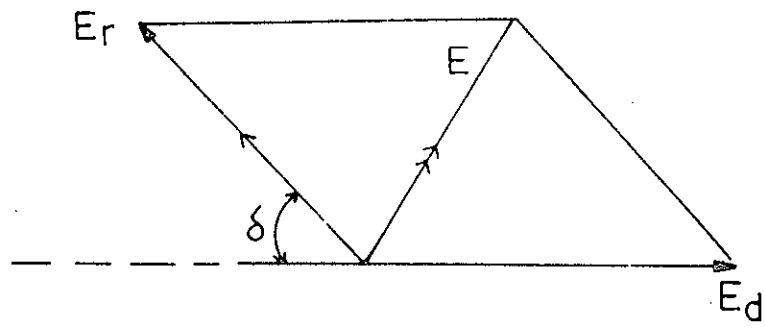


Fig.2.3 Phasor diagram of resulted field strength and phase.

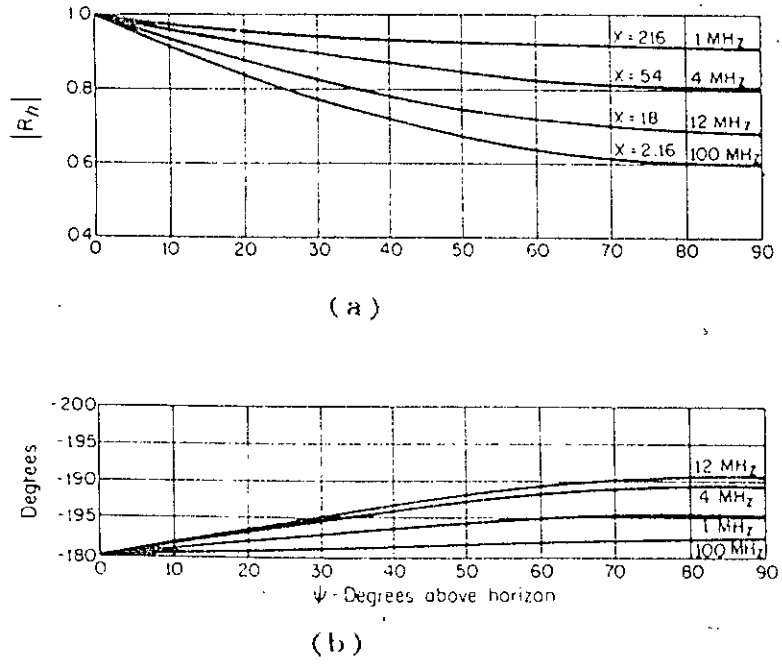
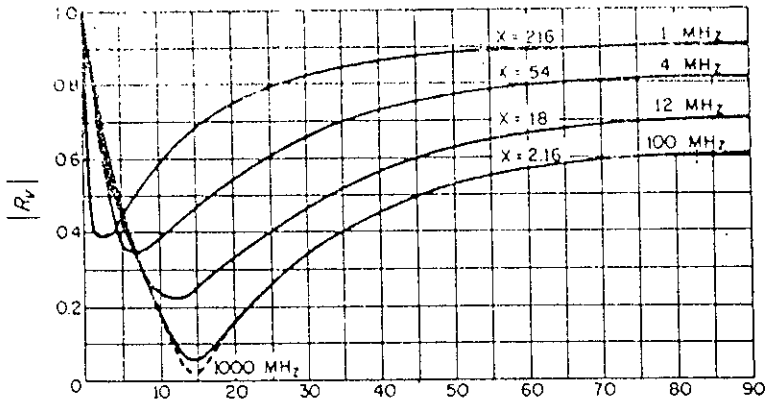
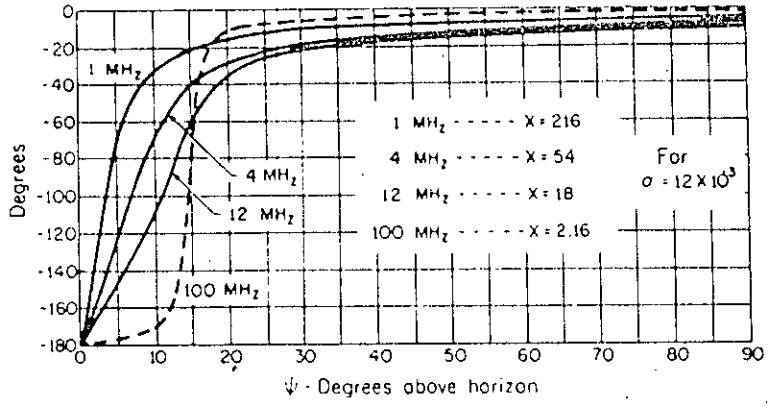


Fig.2.4 Reflection co-efficient for horizontal polarization with $\sigma = 12 \times 10^{-3}$ and $\epsilon = 15$.
(a) Magnitude of reflection co-efficient
(b) phase of reflection co-efficient

(These figures are taken from reference 5)



(a)



(b)

Fig.2.5 Reflection co-efficient for vertical polarization with $\sigma = 12 \times 10^{-3}$ and $\epsilon = 15$.

(a) magnitude of reflection co-efficient

(b) Phase of reflection co-efficient

(These figures are taken from reference 5)

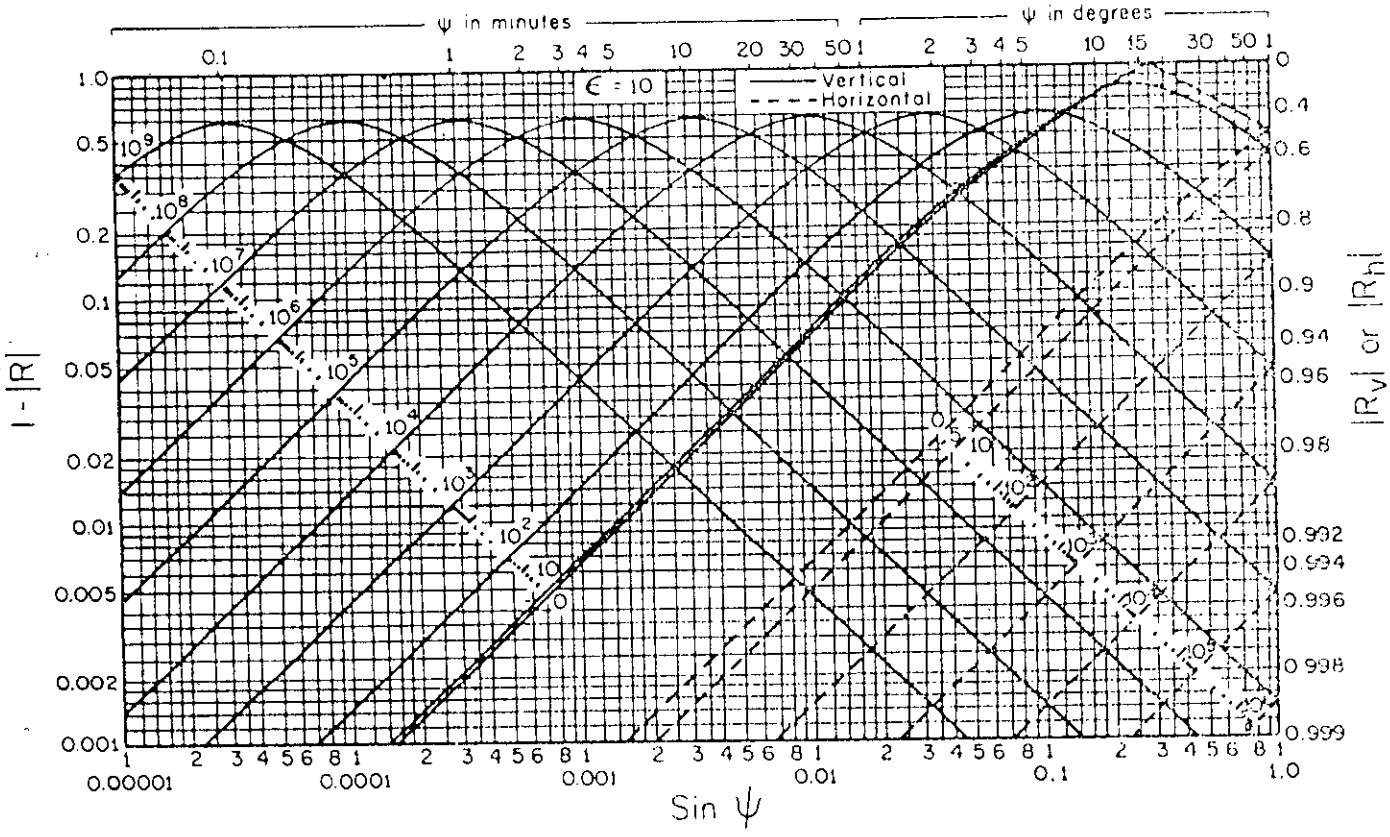


Fig.2.6 Magnitude of the reflection co-efficient for ϵ_r=15. The number of each curve gives the value $X=18x\sigma/f_{MHz}$. [Vertical polarization is shown by solid lines]

(This figure has been taken from reference 5)

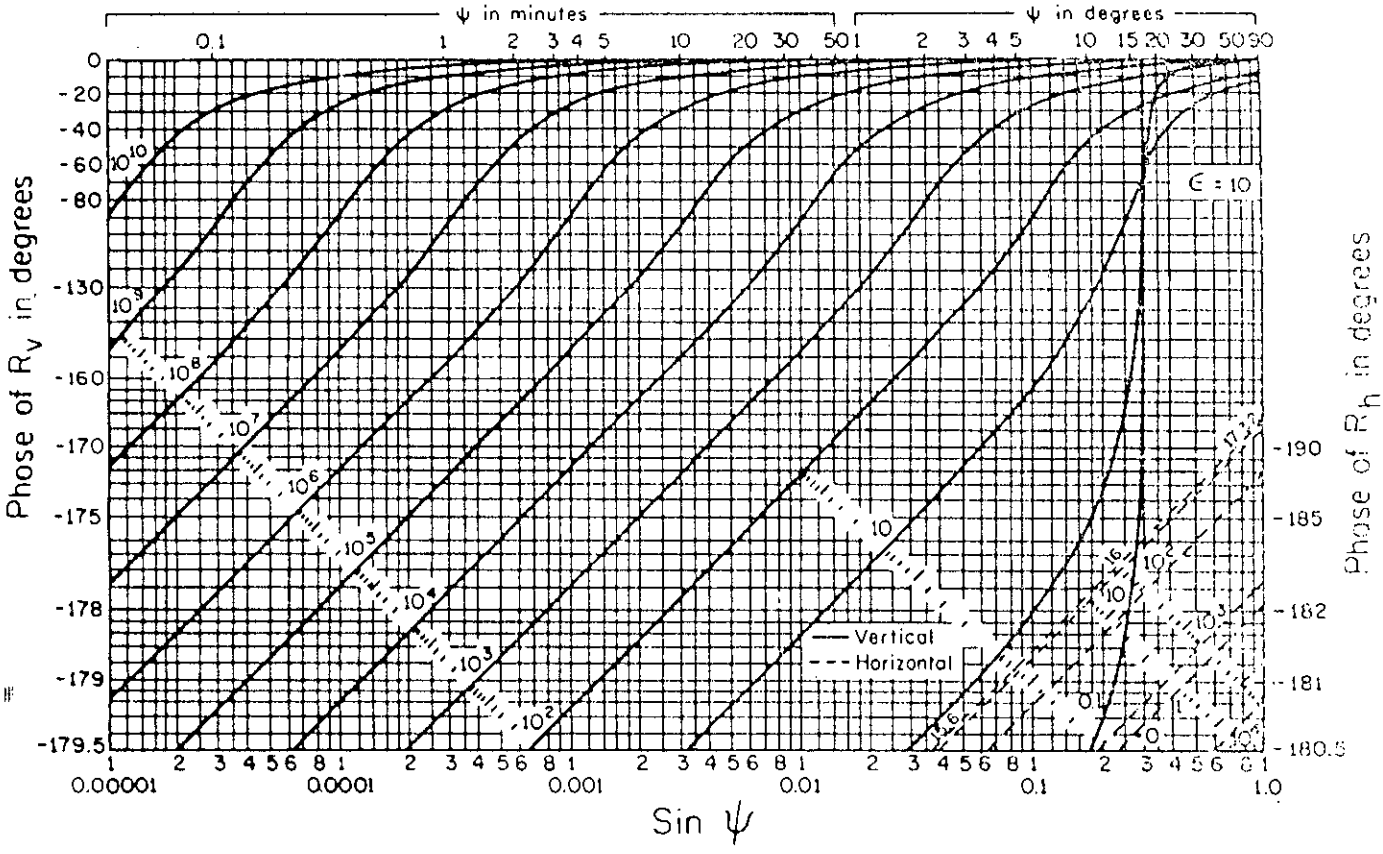


Fig.2.7 Phase of the reflection co-efficient for $\epsilon_r = 10$.
[Vertical polarization is shown by solid lines and horizontal polarization is shown by dotted lines]

(This figure has been taken from reference 5)

vector will be parallel to the reflecting surface and the reflecting co-efficient R_v and R_h should have the same value. But there is 180^0 phase difference. The magnitudes and phases of the reflection co-efficients are shown on a logarithmic scale for a relative dielectric constant $\epsilon = 10$ in fig.2.5 and fig.2.6 respectively. These curves are labelled directly in the value of X.

From fig.2.4 and fig.2.5 it is clear that there is particular significance of Brewster angle effect for vertical polarization, which causes ρ a minimum for values of φ below 15^0. The phase angle also goes a rapid change from 0^0 to 180^0. This effect makes $\rho e^{j\Phi}$ nearly equal to -1 for both vertical and horizontal polarization when the grazing angle φ tends to zero. When the frequency increases χ decreases (As $\chi = \sigma/w\epsilon_o$). As a result frequencies above 50 MHz the ground behaves very nearly like a dielectric medium.

2.4 PATTERNS OF COVERAGE DIAGRAM

Coverage diagram is the plot of relative field strength as a function of direction in space from the transmitting antenna. It is analogous to the field strength radiation pattern of an antenna. The fixed parameters are the height of the transmitting antenna (h_1) and the wave length (λ_0) or frequency (f). The

height of receiving antenna (h_2) and the distance d to the location of the receiving antenna are variable parameters. Each pair of h_2-d determines a point in space.

In general the coverage diagram is the plot of curves for F/r is constant in the h_2-d plane (Where r is the direct line-of-sight distance). In most situation the direct line-of- sight distance is equal to horizontal distance (d). Various curves of F/r are usually chosen to represent the same signal level which would be obtained a fractional or multiple of convenient free-space reference range r_f.

$$\text{i,e} \qquad F/r = m/r_f$$

$$\text{or,} \qquad F = mr/r_f$$

$$\cong md/r_f \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.11)$$

where m = $1, \sqrt{2}, 2, \ldots\ldots\ldots$or $1, 1/\sqrt{2}, 1/2, \ldots$etc.

The difference of successive curve is then 3.0 dB.

2.4.1 STUDY OF DIFFERENT CASES

Case 01 : Reflection- coefficient equal to -1.

The flat earth formulla is therefore,

$$F = 2|\sin(k_0 h_1 h_2/d|$$

$$= 2|\sin(k_0 h_1 \tan\varphi_o)|$$

$$\text{i,e} \quad 2|\sin(k_0 h_1 \tan\varphi_o)| = md/r_f \qquad \ldots\ldots\ldots (2.12)$$

Here d can be treated as radial co-ordinate and φ_o as the angle

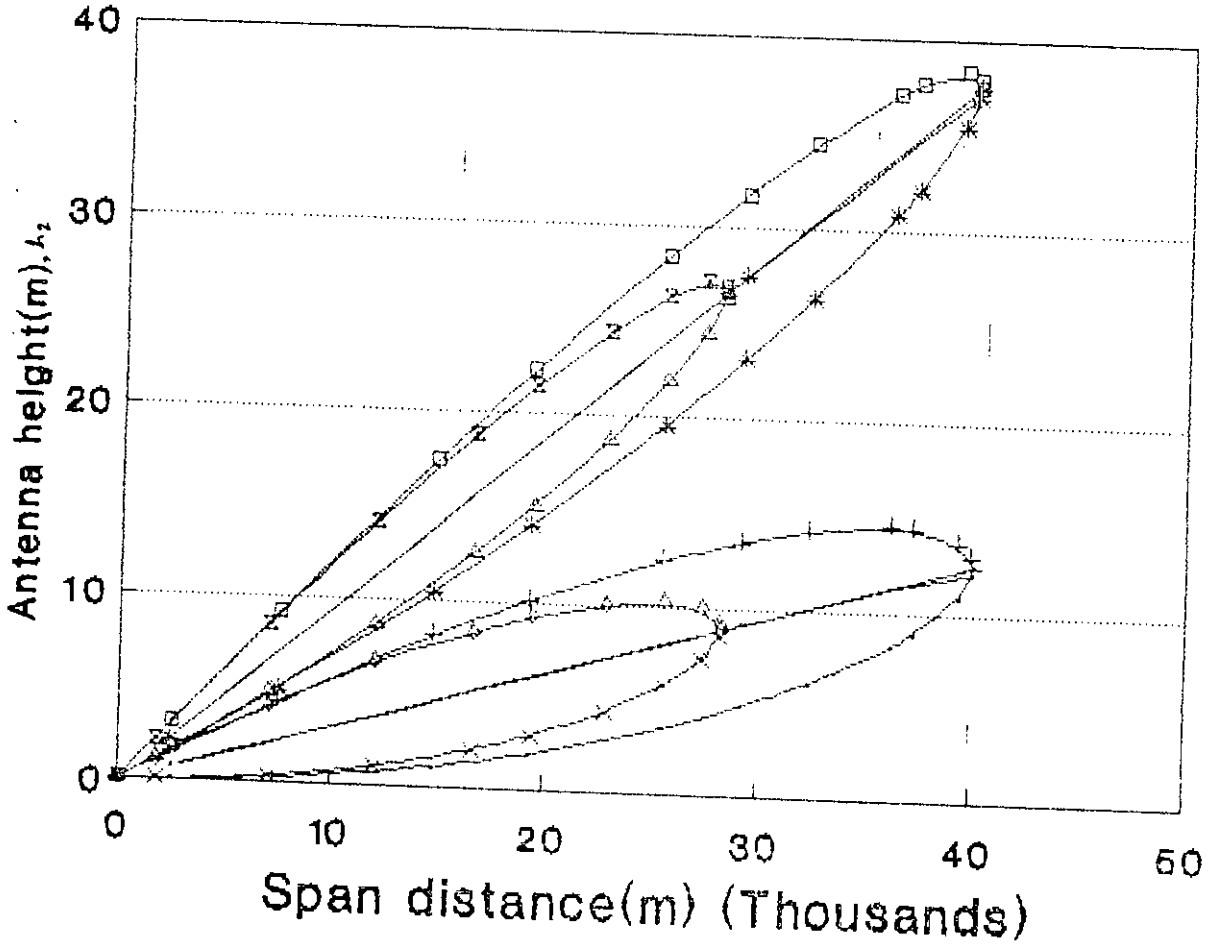


Fig.2.8 Coverage diagram for $h_1=800\lambda_0$, $r_f=20$km.
(It is the plot of curves for F/r is constant in the h_2-d plane)

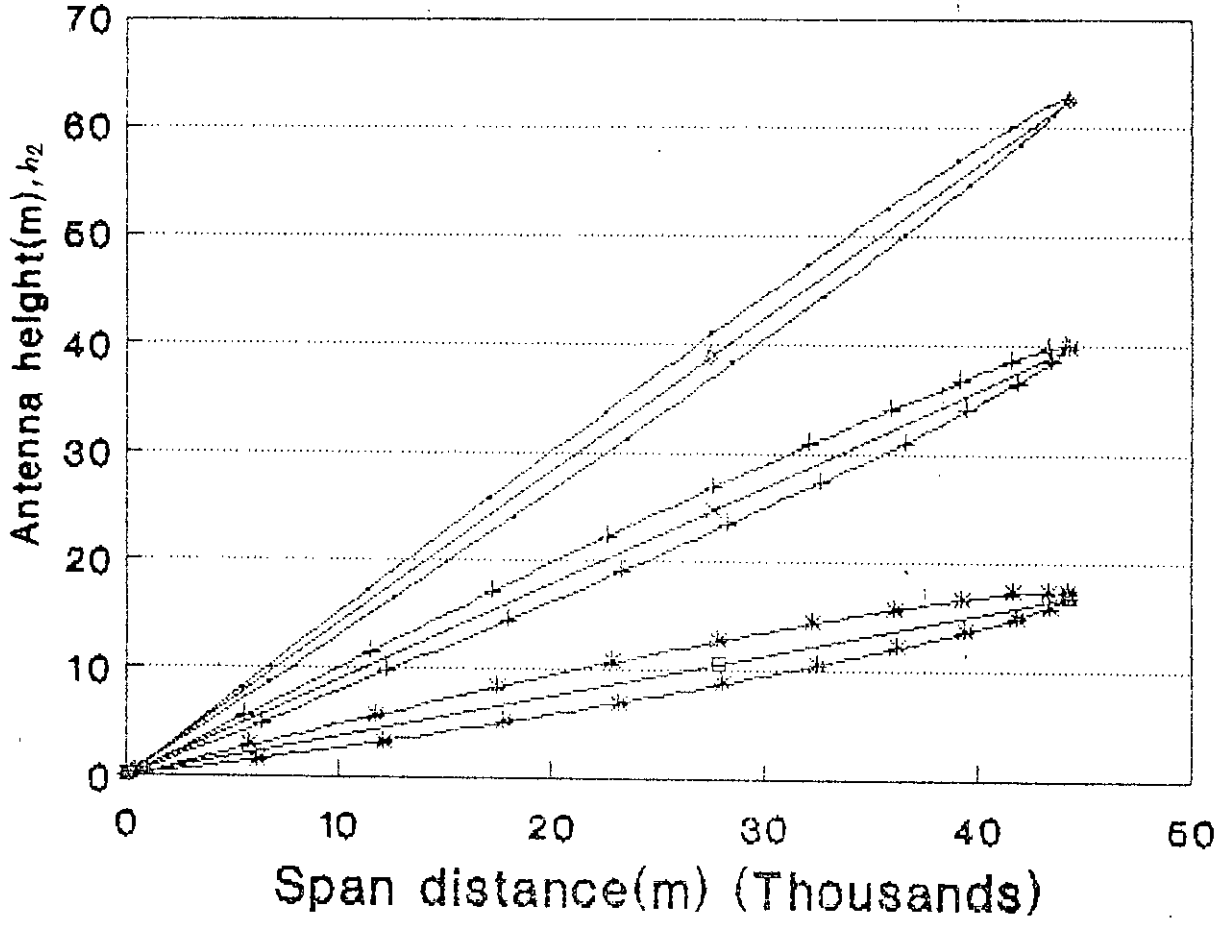


Fig.2.9 Coverage diagram for $h_1=1625\lambda_0$, $r_f=22.15$km.
(It is the plot of curves for F/r is constant in the h_2-d plane)

co-ordinate in a polar-co-ordinate reference frame. However the vertical scale representing by h_2 is usually expanded relative to that for d. Hence $_0$ appears much larger than its actual value.

when $h_1 \gg \lambda_0$ and n is small we have $\tan(\psi) = \psi$. From equation 2.06 and 2.07 a very fine lobe structure is obtained. The maximum interferance range is in this case is $2r_f$ which comes from the horizontal span $d = 2r_f\cos(\psi_0)$. Some curves are drawn shown in the Fig.2.8 and fig.2.9. Smaller lobes are drawn in the figure 2.8 represent a constant signal level 3 dB greater than that of the larger lobe. Several lobes are shown in the figure 2.9.

Case 02:- Reflection co-efficient not equal to -1.

Using Fresnel expression for reflection co-efficient we can develope a computer sub-program which supply essential datas to the main program. The procedure is same as in the case of 01.

2.5 EFFECT OF ROUGHNESS IN PROPAGATION

When the point of reflection occurs over a rough surface the field is scattered in a more diffuse manner and the specular reflected component and hence reflection co-efficient is reduced in value. Considering the effective wave length of the incident wave we can measure the surface irregularities that constitute a rough surface [5,11]. We can calculate the propagation factor

equal to $e^{jk_0 z \sin(\psi) - jk\, x \cos(\psi)}$ for incident wave, where z and x are the co-ordinate in the perpendicular to the surface and along the surface respectively. Hence in vertical direction the wave length λ_v is given by

$$\lambda_v = (2\pi)/(k_0 \sin\psi)$$

$$= \lambda_0/\sin\psi \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.12)$$

When the grazing angle ψ is small λ_v is large compare to λ_0. At larger wavelengths most surfaces appear to be smoth, but at microwave frequencies most surfaces would be rough and the reflection co-efficient would be smaller than that given by the Fresnel formulas.

2.6 VARIATION OF SPACE WAVE FIELD STRENGTH WITH DISTANCE

From fig.2.1 it is clear that the difference in path length between the direct and reflected rays decreases as the distance increases. It has been shown for small elevations the reflected wave suffers a phase change of very nearly 180^0 at the point of reflection. Therefore, where the path difference between the rays in an exact number of wave lengths the two rays will be 180^0 out of phase and so will substract. The two rays will not cancel each other completely since imperfect reflection at the ground makes the reflected wave of a smaller magnitude than the

direct ray. Thus the resultant amplitude of field strength is less than that of direct wave alone. When th path difference is exactly a half wave length or a odd number of half wave lengths the direct and reflected rays are in phase and the two will add giving a field strength greater than that of direct ray alone. If we simplify the equation no. 2.05b cosidering ψ_0 as low then the received signal vary as the inverse square of the distance as shown in fig.2.10 [1,5,6,11].

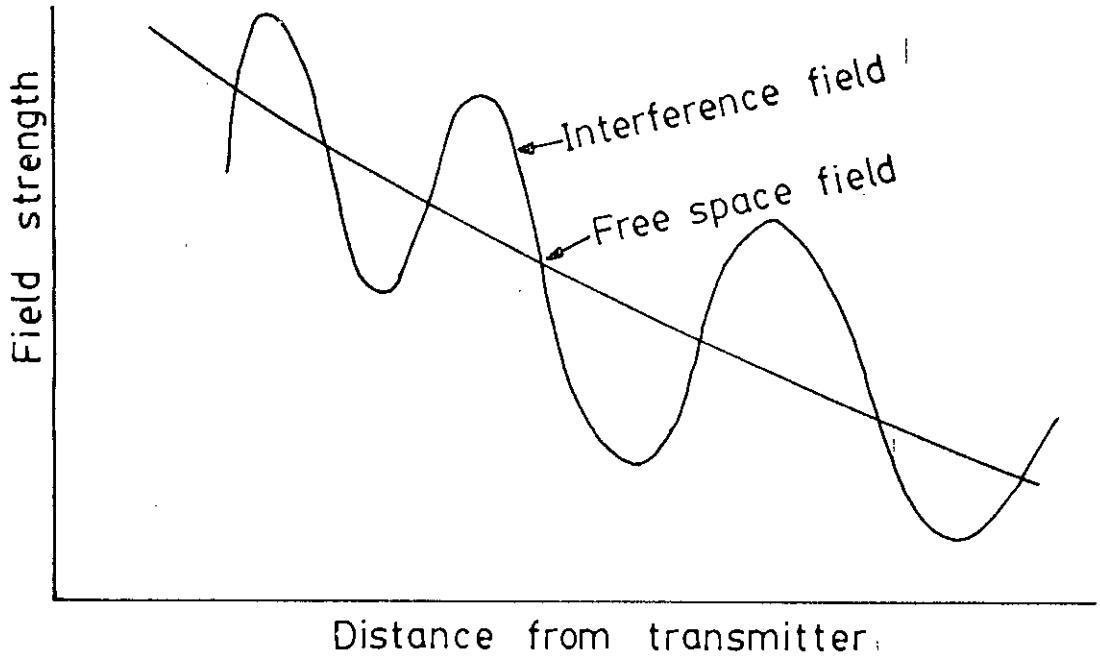


Fig.2.10 A typical plot of field strength against distance from transmitter.

CHAPTER 3

RADIOWAVE PROPAGATION PHENOMENA OVER SPHERICAL EARTH

3.1 EFFECT OF CURVATURE OF EARTH IN PROPAGATION AND ATMOSPHERIC EFFECTS

A radio wave travelling horizontally in the earth's atmosphere follows a path which has a slight downward curvature due to refraction of the wave in the atmosphere [1,3,12]. This curvature of the path tends to overcome partially the loss of signal due to curvature of the earth and permits the direct ray to reach points slightly beyond the horizon as determined by the straight line path.

The refraction of a radio wave in the atmosphere occurs because the dielectric constant and hence the refractive index of the atmosphere, varies with height above the earth. The dielectric constant of dry air is slightly greater than the value of unity that applies for a vacuum and the presence of water vapor increases the dielectric constant still further. For this reason the dielectric constant of the atmosphere is greater than unity near the earth's surface, but decreases to unity at great heights where the air density approaches zero. The refractive index n is related with the refractivity N by $N=(n-1)10^6$ (NU). The refractivity can be calculated through the relation.

$$N(n-1)10^6=\frac{77.6}{T}P+4810\ \frac{e}{T^2} \qquad \text{.....(3.01)}$$

where P = total pressure (m bar)

e = partial pressure of water vapor (m bar)

T = Absolute temperature (degree kelvin)

Under normal conditions of the atmosphere both temperature and pressure fall with the height above earth's surface in the troposphere region [5,6,12]. The gradient of index of refraction is associated with the temperature and pressure gradients and hence varies with height. Thus the communication through space wave propagation is obtained by beyound the line-of-sight as shown in fig.3.1.

The phenomena of ray curvature may be redily understood by dividing the atmosphere into layers, with discrete values for the index of refraction in each layer, as shown in Fig.3.2 [1,5,6]. For this staircase approximation to the continuous variation in the index of refraction Snell's law gives.

$$n_1\sin\theta_1=n_2\sin\theta_2=\ .....\ =n_n\sin\theta_n \qquad \text{.....(3.02)}$$

where $n_1>n_2>n_3>.....>n_n$

and $\theta_n>\theta_{n-1}>\theta_{n-2}>.....>\theta_2>\theta_1$

The empirical expression as:

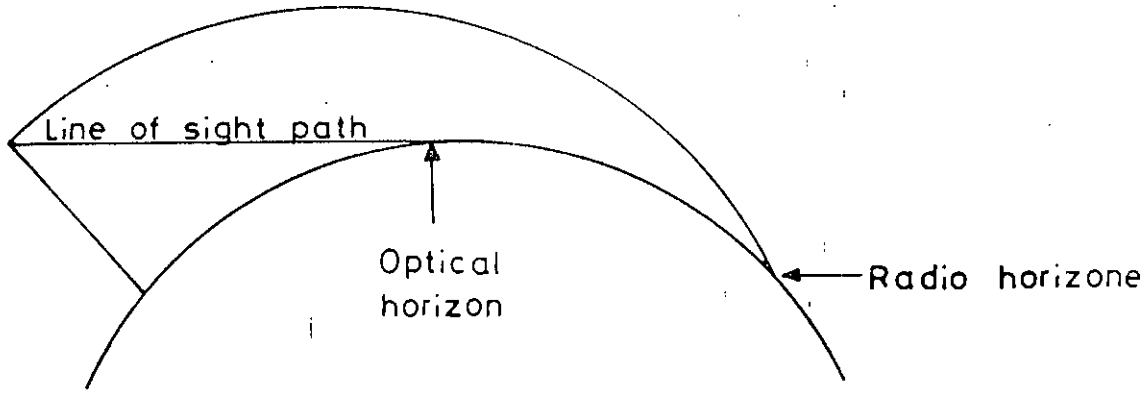


Fig.3.1 Illustration of radio horizon and optical horizon

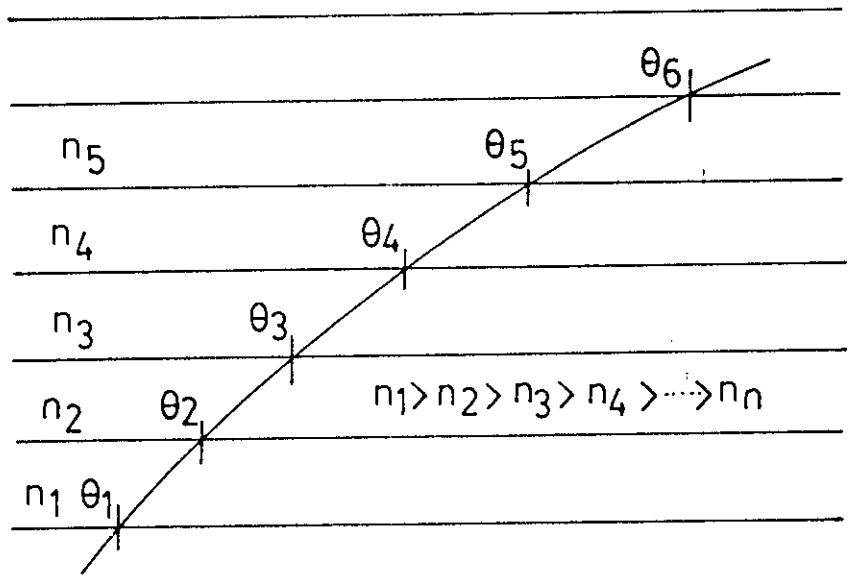


Fig.3.2 Illustration of ray curvature

$$N(h) = N_s e^{C_e h} \quad NU$$

$$C_e = \ln \frac{N_s}{N(1km)} = \ln \frac{N_s}{N_s + \Delta N}$$

where N_s is the refractivity at the earth surface and h is the height above ground (km). ΔN is the difference between the radio refractivity at the height of 1 km that at earth surface.

Under abnormal conditions the changes in temperature and moisture content in the atmosphere are such that the refractive index increases with height as a result in the bending of waves away from the earth. A typical abnormal condition occurs when there is warm air over water resulting in a high density of water vapor over the surface. Under this condition the atmosphere forms a wave guide that guides the waves over the surface.

3.2 MATHEMATICAL ANALYSIS FOR EFFECTIVE EARTH RADIUS

The effect of refraction in troposphere may be consider in terms of straight line path propagation by simply increasing the effective radius of the earth [5,6,12]. Consider a wave to be travelling almost horizontally in the troposphere. Its path bends into an arc due to variation of refractive index with height. Let r is the radius of curvature of the path at a height h above earth's surface and v be the velocity at that height.

From Figure 3.3

$$r d\theta = v dt$$

and $(r+dh)d\theta = (v+dv)dt$

Hence $dh d\theta = dv dt$.

Which gives $$\frac{d\theta}{dt} = \frac{dv}{dt} \qquad \text{.....(3.03)}$$

But refractive index $$n = \frac{\text{Velocity in vacuum}}{\text{Velocity in medium}} = \frac{C}{V}$$

*And ultimately we have, $$\frac{dn}{dh} = \frac{1}{r} \qquad \text{.....(3.04)}$$

If we assume that the actual path of Figure 3.4a is replaced by a straight line path over the earth of modified effective radius a_e as in Figure 3.4b, then the distance δh must be same in both cases.

From fig.3.4b, $(a_e+h)^2+d^2$

$$= (a_e+h+\delta h)^2$$

$$\Rightarrow \quad \delta h = \frac{d^2}{2(a_e+h)}$$

$$\cong \frac{d^2}{2a_e} \qquad \text{.....(3.05)}$$

[*Appendix B]

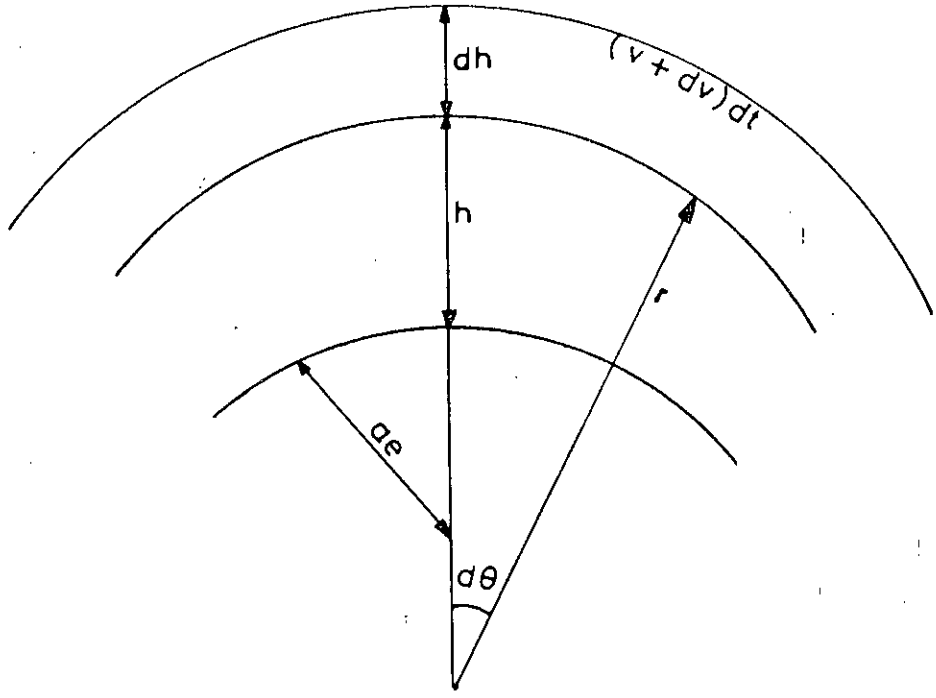


Fig.3.3 Illustration of refraction of tropospheric wave

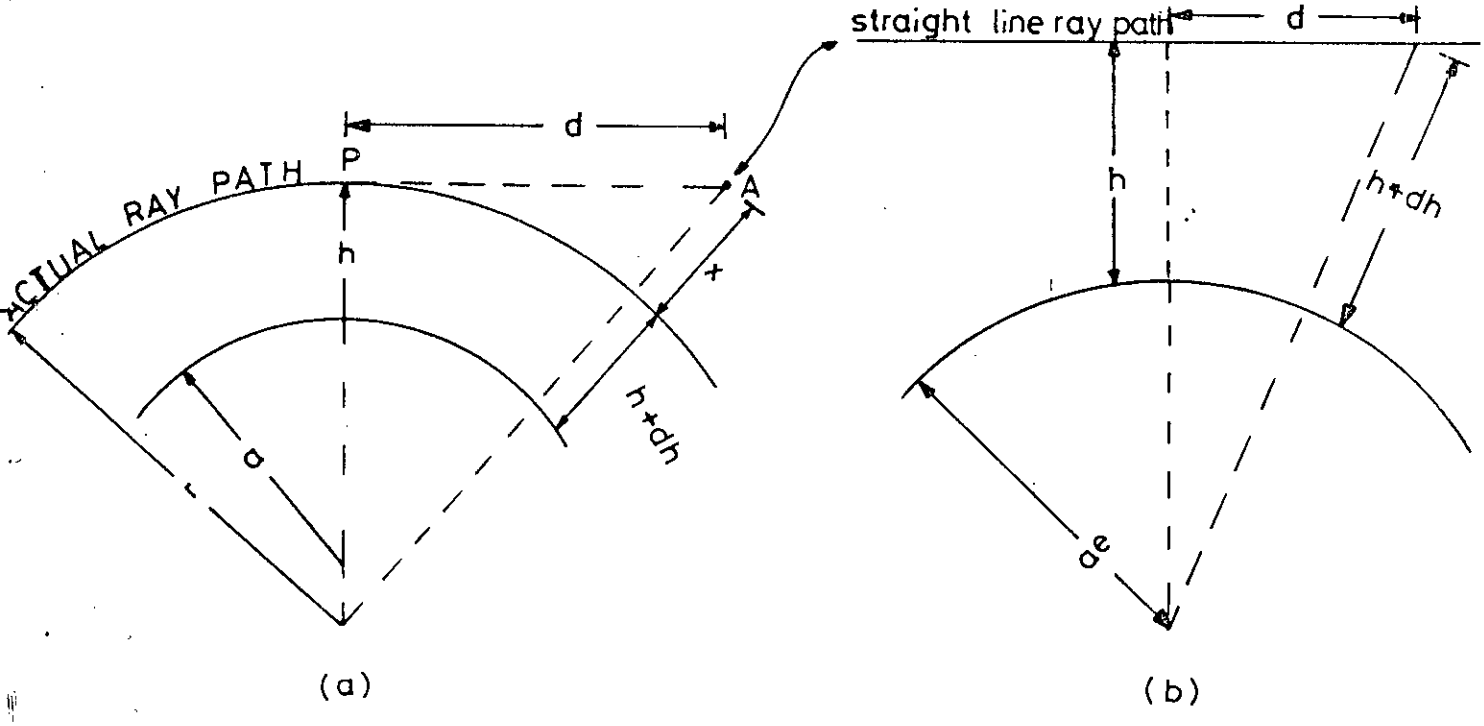


Fig.3.4 Illustration of equivalent ray paths over earth
(a) True radius 'a', (b) Modified radius a_e.

From fig.3.4a, $(a_e+h)^2+d^2=(a+h+\delta h+x)^2$

$$\Rightarrow \quad \delta h = \left(\frac{d^2}{2a} - x\right) \qquad \text{.....(3.06)}$$

$$\Rightarrow \quad \delta h = \frac{d^2}{2a} - \frac{d^2}{2r}$$

Hence $$\frac{1}{a_e} = \frac{1}{a} - \frac{1}{r}$$

$$\Rightarrow \quad \frac{1}{a_e} = \frac{1}{a} + \frac{\delta n}{\delta h}$$

Taking $a_e=ka$

$$k = \frac{1}{1+a\,\frac{dn}{dh}} = \frac{1}{1- a/r} \qquad \text{.....(3.07)}$$

But refractive index $\left(\frac{\delta n}{\delta h}\right)$ Corresponding to standard atmospheric conditions is $- 0.039\times10^{-6}$/meter and taking a=6,370 km we get k=4/3.

3.3 RANGE OF SPACE-WAVE PROPAGATION:

Neclecting the effect of refraction of troposphere the maximum range of transmission of a signal through space wave

propagation is the line-of-sight distance as shown in figure 3.5. Hence elevation of antennas determines the range.

Considering the transmitting and receiving antenna heights are h_1 and h_2 respectively and 'a' is the radius of earth. But for propagation studies a standard index-of-refraction profile is commonly chosen such that it is equivalent to increasing the radius of earth by a factor 4/3 as find out in previous article. Thus we can use a_e instead of 'a'.

From the geometry of figure 3.5 we have,

$$R^2+a^2_e=(a_e+h_1)^2$$

$$\Rightarrow R^2=h_1^2+2a_eh_1$$

But $a_e>>h_1$ and the slant distance R is nearly equal to the horizontal distance d_T to the horizon.

$$d_T^2=2a_eR_1$$

$$\Rightarrow d_T = (2a_eh_1)^{0.5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.08)$$

If d_T is expressed in miles and h_1 in feet we have,

$$d_T = (2h_1)^{0.5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.08a)$$

Taking 'a'=3960 miles the maximum line-of-sight distance in miles between two antennas at height h_1 and h_2 feet above a spherical

earth with standard refraction condition is then redily seen to be given by

$$d_M = (2h_1)^{0.5} + (2h_2)^{0.5} \text{ (miles)} \quad \ldots\ldots\ldots (3.08b)$$

This may be put as

$$d_M = 4.12[\ (h_1)^{0.5} + (h_2)^{0.5}\ ] \text{ (km)} \ldots\ldots\ldots (3.08c)$$

where h_1 and h_2 are in meters.

3.4 GENERAL FEATURE OF INTERFERENCE PHENOMEAN WITH ANTENNAS LOCATED OVER SPHERICAL EARTH

The antennas located over a spherical earth with an effective earth radius a_e to account for standard refraction, it is very difficult to derive the formulas for interference effect. The indirect wave is now reflected from a curved surface, and its energy is diverged more than in the case when it is reflected from a flat earth [1,5,6]. This means that the ground-relected wave reaching the receiver will be weaker than for a flat earth by the divergence factor D [1,15], which is less than unity. The grazing angle (ψ) which is relative to the tangent plane at the point of reflection plays an important role in order to evalute the reflection co-efficient.

The appropriate expression for the path gain factor F becomes

$$F = |\ 1+D\varrho\, e^{j\emptyset - jko\,\Delta R}\ |$$

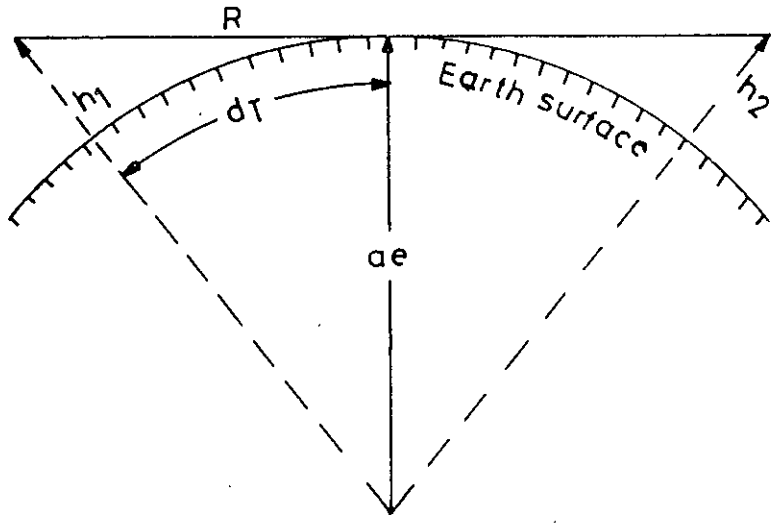


Fig.3.5 Illustration of horizontal range

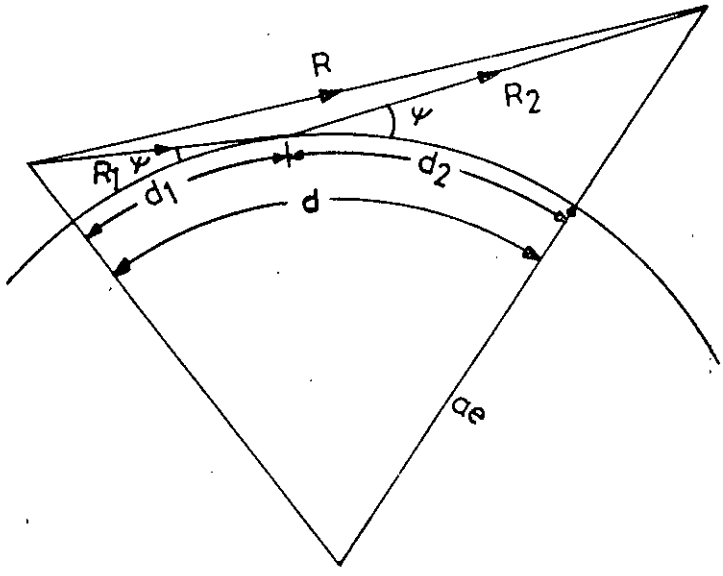


Fig.3.6 Illustration of reflection from a spherical earth.

$$\Rightarrow \quad F = [(1+D\rho)^2 - 4D\rho\sin^2\frac{\Phi - k_o \Delta R}{2}]^{1/2} \quad \ldots\ldots\ldots\ldots(3.09)$$

where D is the ray-amplitude divergence factor and ΔR is the path-length difference.

Here the known parameters are the two antenna heights h_1 and h_2 and the total range d. The point of reflection, which determines d_1, d_2, the grazing angle and the divergence factor D, is governed by a cubic equation. The new parameters J and K introduced here which are the functions of known parameter S and T.

Path-length difference $\Delta R = R_1 + R_2 - R$ $\ldots\ldots\ldots\ldots\ldots\ldots(3.10)$

$$\Delta R = \frac{2h_1h_2}{d} J(S,T) \quad \ldots\ldots\ldots\ldots(3.11)$$

$$\tan\varphi = \frac{h_1+h_2}{d} K(S,T) \quad \ldots\ldots\ldots\ldots(3.12)$$

$$\text{Divergence factor } D = [1 + \frac{4S_1S_2^2}{S(1-S_2)^2(1+T)}]^{0.5} \quad \ldots\ldots\ldots\ldots(3.13)$$

where $S_1 = \frac{d_1}{(2a_eh_1)^{0.5}}$ and $S_2 = \frac{d_2}{(2a_eh_2)^{0.5}}$

$$S = \frac{d}{(2a_eh_1)^{0.5} + (2a_eh_1)^{0.5}}$$

$$\Rightarrow \quad S = \frac{S_1 T + S_2}{1 + T}$$

$$T = (h_1/h_2)^{0.5} \quad <1$$

$$J(S,T) = (1-S_1^2)(1-S_2^2)$$

$$K(S,T) = \frac{(1-S_2^2)+T^2(1-S_1^2)}{1+T^2}$$

Here T is chosen less than unity, So h_1 is taken as the height of the lowest antenna. The range d_1 which determines $d_2=d-d_1$ and s_1, s_2 may be found by solving the equations given below:

$$d_1=\frac{d}{2} + p \cos\left(\frac{\phi+\pi}{3}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

where $$P= \frac{2}{\sqrt{3}}\left[a_e(h_1+h_2)+ \frac{d^2}{4}\right]^{0.5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.15a)$$

$$\phi=\cos^{-1}\left[\frac{2a_e(h_1-h_2)d}{P^3}\right] \qquad h_1 \leq h_2 \qquad \ldots\ldots\ldots\ldots (3.15b)$$

The phase difference between the direct and reflected ray is given by

$$K_o\Delta R= \frac{2k_o h_1 h_2}{d} (1-S_1^2)(1-S_2^2)$$

$$= \frac{4\pi h_1^{3/2}}{(2a_e)^{0.5}\lambda_o} \frac{h_2/h_1}{d/d_T}(1-S_1^2)(1-S_2^2)$$

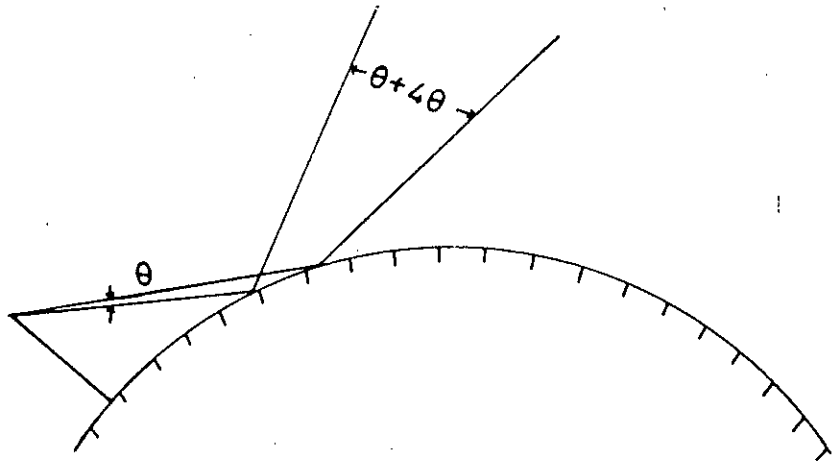


Fig.3.7 Illustration of ray divergence upon reflected from a spherical surface.

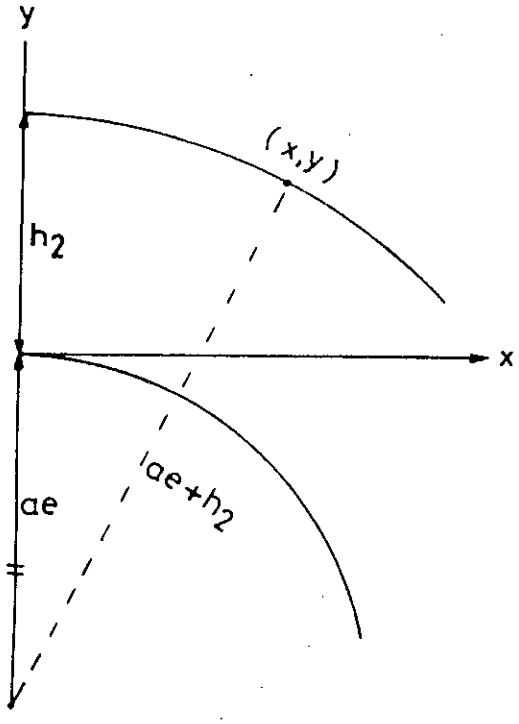


Fig.3.8 Illustration of constant height curve.

$$K_o \Delta R = V \sqrt{F} \qquad \text{.....(3.16a)}$$

$$\text{where} \quad V = \frac{4h_1^{3/2}}{(2a_e)^{0.5}\lambda_o} \qquad \text{.....(3.16b)}$$

$$\text{and } F = \frac{h_2/h_1}{d/d_T}(1-S_1^2)(1-S_2^2) \qquad \text{.....(3.16c)}$$

with $d_T=(2a_e h_1)^{0.5}$.

3.5 PATTERNS OF COVERAGE DIAGRAM

To draw the final pattern of coverage diagram the following constant curves contours must be drawing. They are as follows :

i) Constant height curve

ii) Constant values of divergence factor curve

iii) The path-difference phase variable.

iv) Curve F vs. d/d_T which supplies data for constructing a coverage diagram

v) Final coverage diagram.

3.5.1 CONSTANT HEIGHT CURVE

Plotting constant-height contours above the earth surface we consider the curve shown in fig.3.8. The constant height h_2

above the earth surface and hence we have

$$(y+a_e)^2-x^2 = (a_e+h_2)^2$$

$$\Rightarrow \quad y^2+2a_ey+x^2 = h_2^2+2a_eh_2$$

Since $y \ll a_e$ and $h_2 \ll a_e$ we easily get

$$y=h_2-\frac{x^2}{2a_e} \qquad \text{.....(3.17a)}$$

which is a parabola. We can express it in normalize form as.

$$\frac{y}{h_1} = \frac{h_2}{h_1} - x^2/d_T^2$$

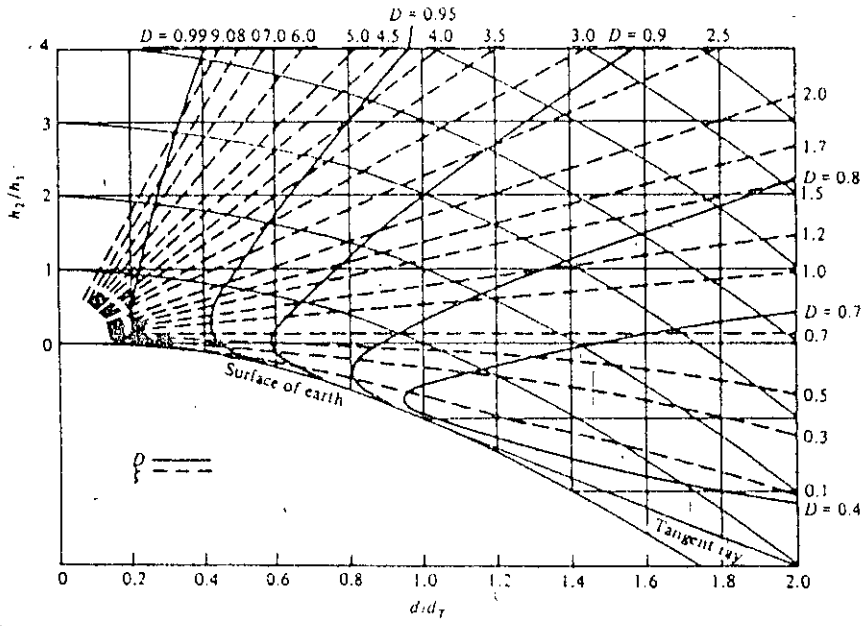
$$\Rightarrow \bar{y} = \frac{h_2}{h_1} - \bar{x}^2 \qquad \text{.....(3.17b)}$$

where $\bar{x}= x/d_T$ and $\bar{y}=y/h_1$

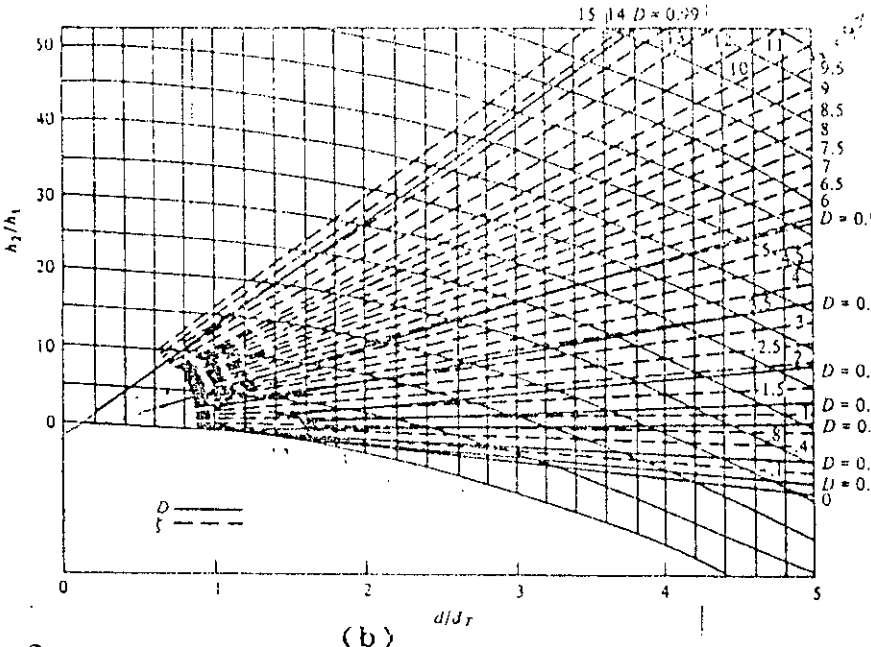
When the scale length of y changes relative to x then the shape of the parabolic curves changes.

3.5.2 CONSTANT VALUES OF DIVERGENCE FACTOR CURVE AND THE PATH DIFFERENCE PHASE VARIABLE CURVES

The constant values of divergence factor curve and the path-length phase-difference factor curve can be ploted by taking a series of values using the equation from 3.10 to 3.16. Such plots on curvilinear grid in which the horizontal co-ordiante is d/d_T



(a)



(b)

Fig.3.9 Contours showing constant values of divergence factor D and the path difference phase varible
(a) Contours for the value h_2/h_1 up to 4
(b) Contours for the value h_2/h_1 up to 50
(These figures have been taken from reference 1)

and vertical co-ordinate is h_2/h_1 shown in the figure 3.9. These curves supply the values of divergence factor and path difference phase variable to calculate path gain factor using formula 3.09.

3.5.3 PATH GAIN FACTOR CALCULATION TO DRAW THE THE CURVE F vs. d/d_T

The path gain formula derived in section 3.04 is given.

$$F=[(1+D\rho)^2-4D\rho\sin^2\frac{\phi-k_o\Delta R}{2}]^{0.5} \qquad \ldots\ldots\ldots\ldots(3.09)$$

is a function of h_2/h_1 and d/d_T. Since D and depend on these parameters. If we choose a lobe corresponding to free-space range of $2d_T$, then the maximum value $X=d/d_T$ can achieve will be 4 when D=1 and we located in a lobe maximum.

For other values of D and we have

$$x=\frac{d}{d_T}=2F \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.18)$$

while for a free-space range of $\sqrt{2}d_T$ and d_T, $x=\sqrt{2}$ F and x=F respectively. To draw the curve F vs. d/d_T we compute F as a function of d/d_T for several values of h_2/h_1. We must follow the procedure as followed in flat-earth formula.

$$F=m\frac{d}{d_T}=\frac{d/d_T}{r_f/d_T}$$

$$\Rightarrow \quad \frac{d}{d_T} = (r_f/d_T) F\left(\frac{d}{d_T}, \frac{h_2}{h_1}\right) \qquad \text{.....(3.19)}$$

If we choose the reflection co-efficient approximately equal to -1 then the path gain formula becomes

$$F=[(1+D)^2-4D\cos^2(v\pi\zeta/2)]^{0.5} \qquad \text{.....(3.20)}$$

gives the values of F vs. d/d_T curves which supplies the data for constructing final coverage diagram. Taking the reflection co-efficient as -1 the coverage diagram is drawn in the figure 3.10 and 3.11. When the reflection co-efficient differs significantly from -1 then the coverage diagram describing the path gain factor F for that particular case must be constructed. The parameter D and ζ may still be found from Fig. 3.09a and 3.09b, but now the grazing angle φ must also be found in order to determine the reflection co-efficient. The tangent ray also be constructed which is a straight line intersects the h_2/h_1 curve at $d/d_T = 1 + (h_2/h_1)^{1/2}$. One can draw F vs. d/d_T curve either using flat-earth formula beyond the values ζ and D as shown in figure 3.9 or directly by the simple FORTRAN program as discussed in appendix C. Precaution must be follow when constructing coverage diagram in the region of diffraction zone i,e the region close to tangent ray is approached.

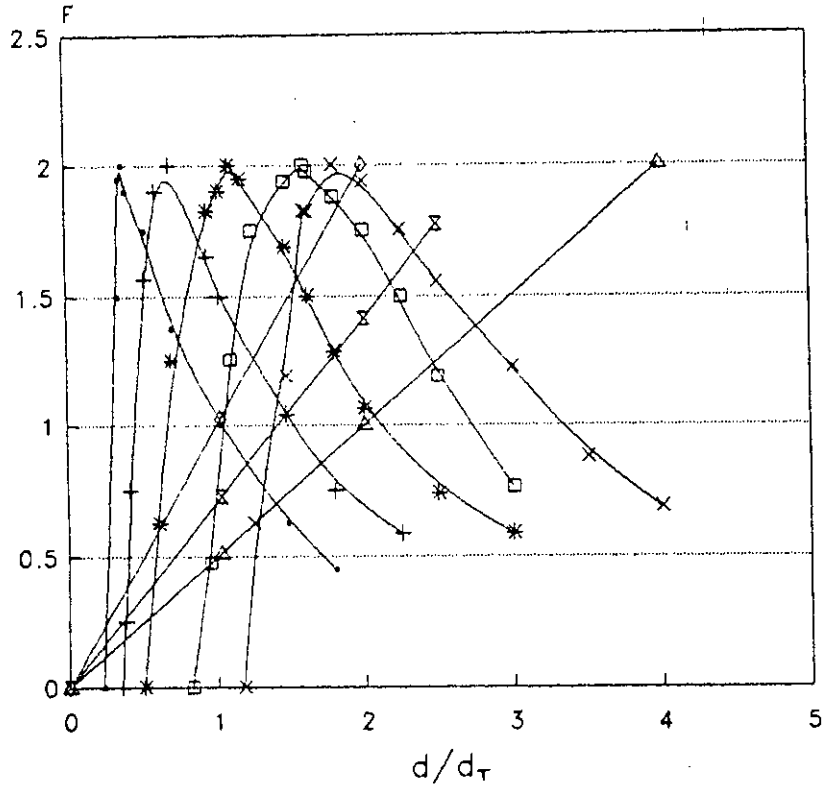


Fig.3.10 Data for constracting a coverage diagram for v=.268

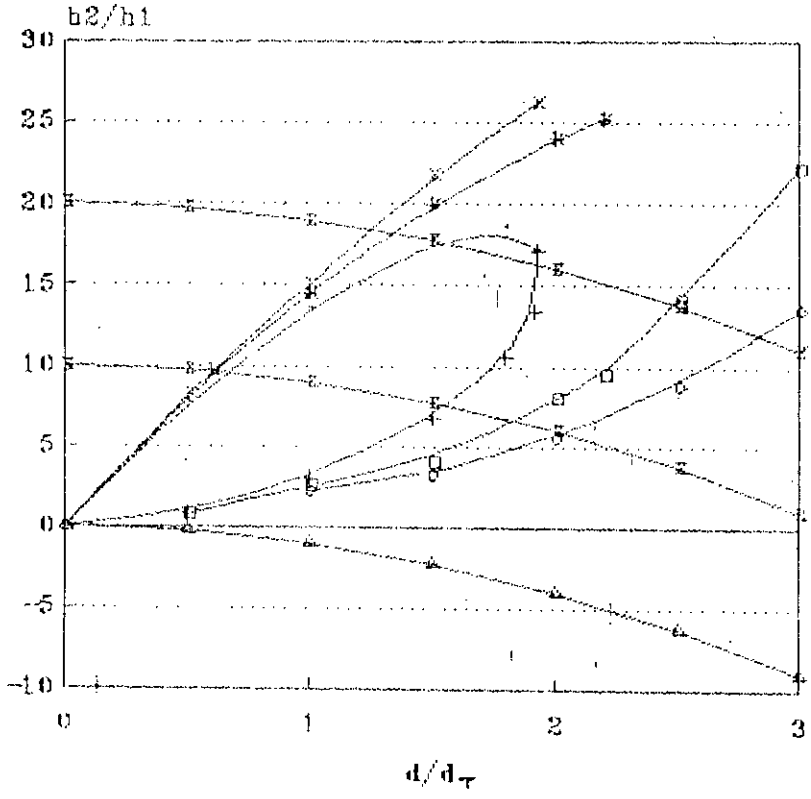


Fig.3.11 Coverage diagram for v=0.268 based on data in figure 3.10.

3.5.4 STEPS INVOLVED TO CONSTRUCT A COVERAGE DIAGRAM ARE AS FOLLOWS

a) To calculate the parameter v

b) Then to calculate v_ξ

c) To draw the tangent ray

d) To draw F vs. d/d_T curve

e) To draw final coverage diagram.

3.6 THE FIELD IN THE DIFFRACTION ZONE

Due to diffraction effects the radiated field penetrates into the shadow zone below the tangent ray although the field strength below the tangent ray will be zero according to the optics [1,11,18]. The field strength is influenced by diffraction effect in the region above and very close to the tangent ray. The field strength calculation in the vicinity of the tangent ray is thus complex and labourious. The simple procedure to calculate the value of d/d_T in the diffraction by putting $\pi\xi v/2 = \pi/2$ for first maximum and $F = 1+D$ and $F=(1+D)^{\frac{1}{2}}$ where $\pi v\}/2 = \pi/4$. Joining these by a smoth curve and several values of F is determined in the vicinity of diffraction zone for several values of d/d_T.

There is a formula to calculate F express as

$$F=V(X)U(Z_1)U(Z_2) \qquad \text{.....(3.21)}$$

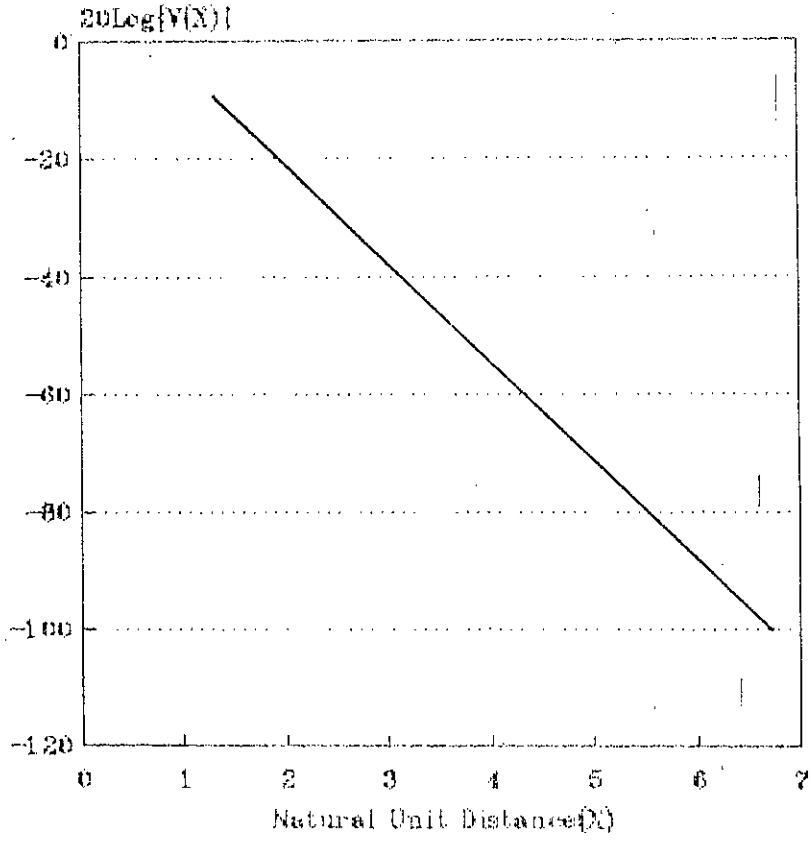


Fig.3.12 A typical plot of attenuation function V(X) (in dB) against distance (X)

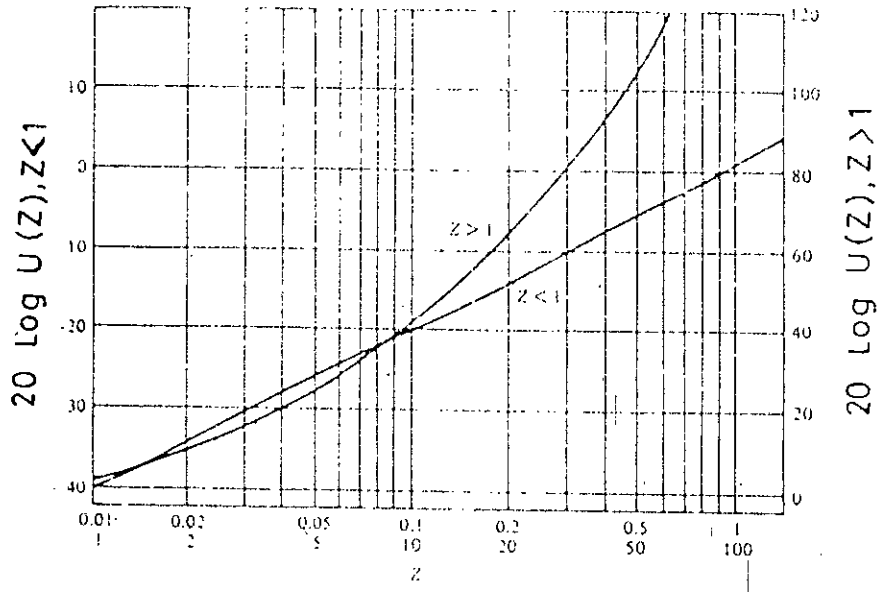


Fig.3.13 Illustration of the height gain function U(Z)
(This figure has been taken from reference 1)

where $V(X)=2(\pi X)^{0.5}e^{-2.02X}$ the main attenuation factor, and X is the distance measured in natural unit of L and Y and Z are the antenna heights measured in natural unit of height H. These are given by

$$L = 2(a_e/4K_0)^{1/3}$$

$$= 28.41\ \lambda_0^{1/3} \quad (km) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.22a)$$

$$H = (a_e/2k_0)^{1/3}$$

$$= 47.55\ \lambda_0^{2/3} \quad (m) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.22b)$$

where λ_0 is measured in meters $X = d/L$, $Z_{1,2} = h_{1,2}/H$ in natural unit. The incident power per unit area at the receiving terminal will be expressed by the following equation.

$$P_{in} = \frac{P_T G}{4\pi d^2}\left(\frac{Fd_T}{d}\right)^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3.23)$$

It is then easy to plot the curve 20 log F $-20\text{Log}(d/d_T)$. Every doubling of d beyond the point d/d_T the value is simply a reduction by 6 dB from 20log F. The path gain factor should be plotted as a function of d/d_T shown in figure 3.14. The calculating procedure of path gain factor is as follows :

(i) To calculate v

(ii) To calculate $\pi\zeta$ for maximum F and point of quarter of F

(iii) To calculate d in term of d_T using the curve 3.09a

(iv) To choose the diffraction zone in term of d_T

(v) To calculate X (With the help of Fig. 3.12)

(vi) To calculate Z (With the help of Fig. 3.13)

Putting the above calculating values of X and Z in equation 3.21 F may be calculated.

3.7 MIDPATH-OBSTACLE DIFFRACTION LOSS

The midpath obstacles such as tall land (earth bulgs), trees, tall buildings, hills etc. partially block the propagation path as a result field loss occur [1,3,6,18]. The effect of the hill can be modeled as a thin plane having the same clearance distance h_c from the line-of-sight path, provided there is no specular reflection from the top of the hill. (shown in figure 3.15). The thin plane model also shown in figure 3.16. It is very complex to compute the diffraction loss when the reflected field is diffracted by knife-edge.

Analyzing the firgures 3.15 the clearance height is given by

$$h_c = \left(\frac{d_2 h_1 + d_1 h_2}{d} - h\right)\cos\theta_c \quad \ldots\ldots\ldots\ldots (3.24)$$

where h is the height of obstruction.

There is a solution named optical phenomena which deals with the Fresnel surface. The nth Fresnel surface is that for which the sum of distances between transmitter and receiver and a point on the surface of the ellipsoid of revolution exceeds by $n\pi/2$, the distance between transmitter and receiver. To avoid

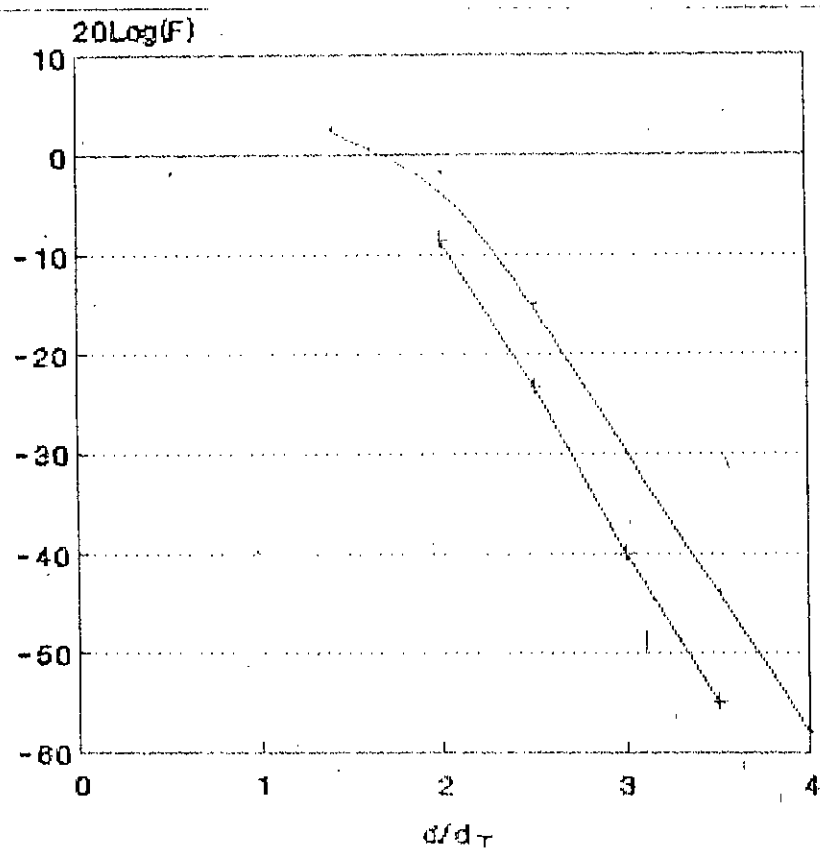


Fig.3.14 Path gain factor F in dB for h_1=24m, h_2=60m, f=3GHZ

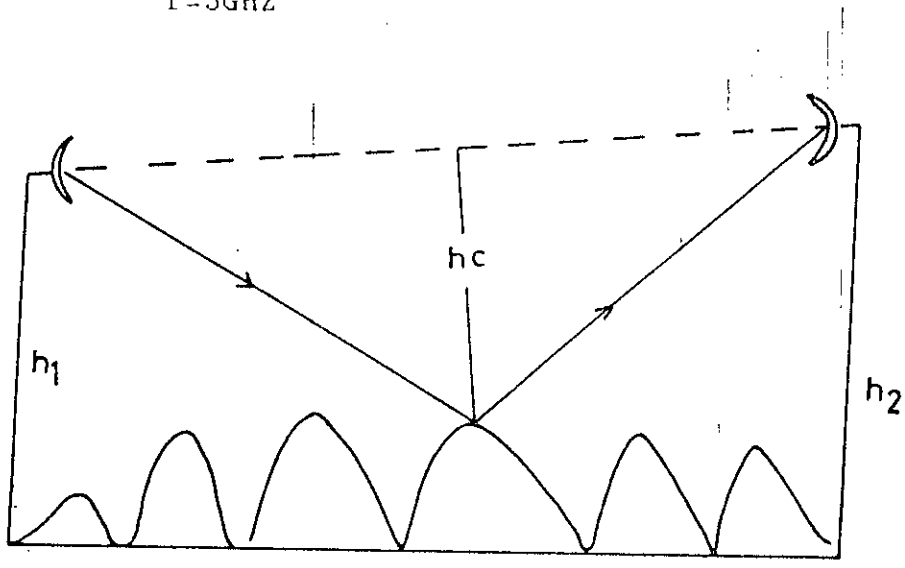
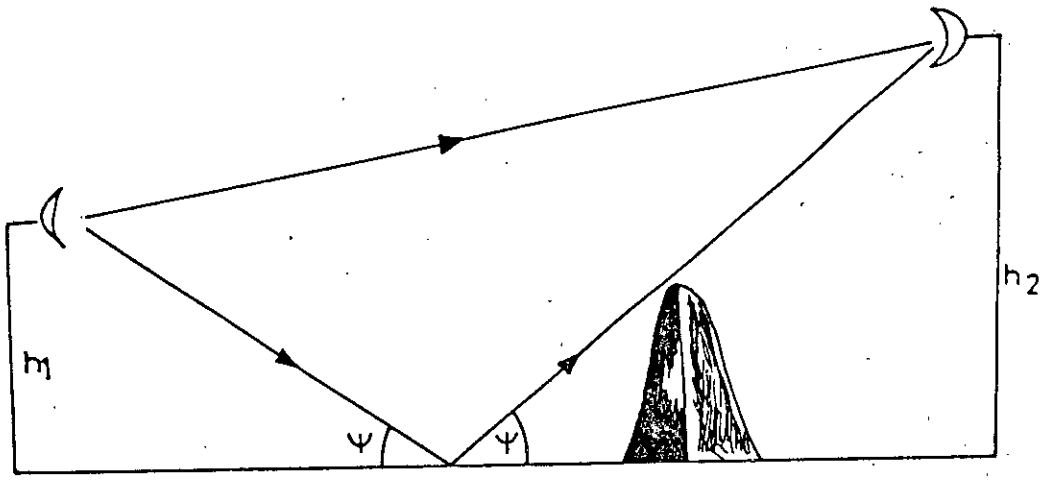
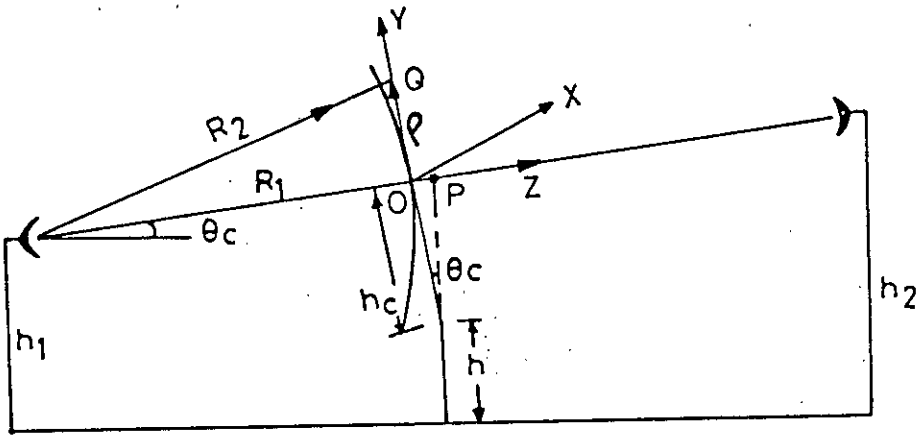


Fig.3.15 Illustration of midpath obstacle



(a)



(b)

Fig.3.16--(a) Knife-edge model (obstruction not blocking the reflected ray) (b) Knife-edge model showing propagation parameters.

intervening obstactes the clearance between the direct ray and the highest obstacle should be sufficient to ensure that the difference between the path lengths of a reflected ray and the direct rays exceeds a half wavelength. The minimum clearance distance shown in the Fig.3.17 is the radius of the first Fresnel zone [1,3]. It is given by

$$H_1 = [\lambda d_1(1 - d_1/d)]^{0.5} \quad \text{.....(3.25)}$$

where d = total path length

d_1 = The distance from the transmitter.

The amount of additional clearance needed over an obstacle is found to be 0.6R.

where $R=17.3(d_1 d_2/f_d)^{0.5}$

d_1=distance from transmitter

d_2=distance from receiver

The path gain factor due to diffraction is given by

$$F_d = (1/2)^{0.5} \left| \int_{-H_c}^{\infty} e^{-j\, u^2/2} du \right| \quad \text{.....(3.26)}$$

where $H_c = (2a/j\pi)^{1/2} h_c$. When $h_c = 0$, the above Fresnel integral equals 0.5 $(\pi/a)^{0.5}$ i.e. one half of the incident radiation blocked, which results in 6 dB loss.

The path gain profiles drawn using the above Fresnel integral caused by the knife-edge diffraction loss shown in the Fig.3.18. Under normal (standard) atmospheric conditions the clearance can be determined by plotting the path profile above an earth with

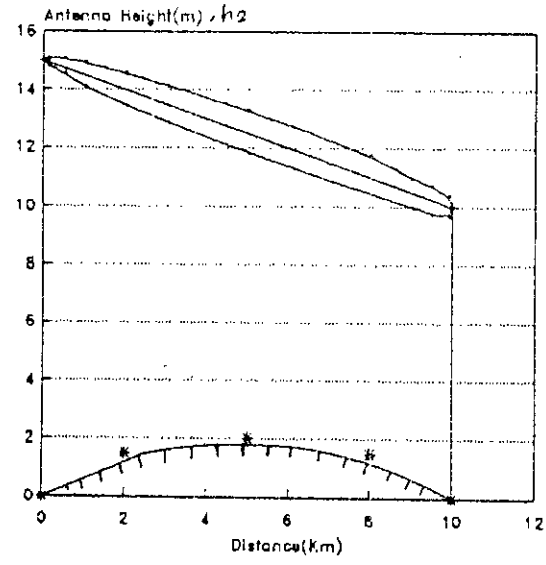


Fig.3.17 Illustration of first Fresnel zone.

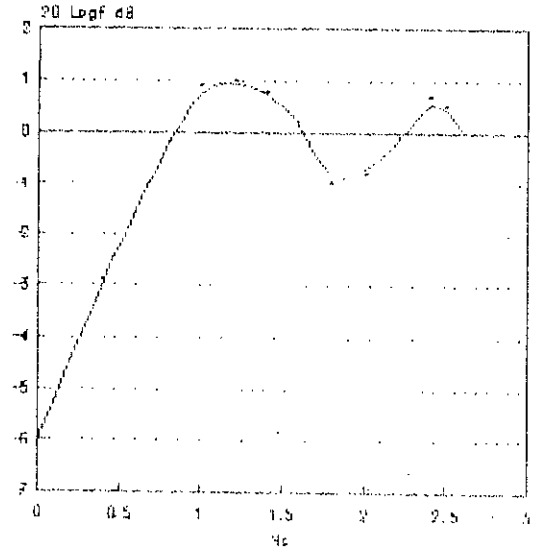


Fig.3.18 The path gain factor F_d caused by knife-edge diffraction loss in dB as a function of H_c.

effective radius equal to 4/3 the actual radius. If the refractive index is increased under some conditions the waves will then curve upward and thereby reduce the effective clearance. From Figure 3.18 it is cleared that path profile is drawn above an earth with effective radius the probability of fading owing to midpath obstacles diffraction loss will be negligible.

CHAPTER 4

MICROWAVE COMMUNICATION LINK PERFORMANCE CALCULATION

4.1 SYSTEM LINK MODEL

The general model of a mw link is shown in Figure 4.1. The signal is generated by the transmitter enters the feeder in which attenuation occurs. This attenuated signals enter the antenna and then transmitted. In the receiving side the receiving antenna received the signals. These signals pass through the feeder to the receiver input.

4.2 RADIO SYSTEM PERFORMANCE CALCULATION

The steps involved to evaluate the expected performance of a microwave channel are as follows:

a) Noise requirement (Signal to noise ratio)

b) Receiver noise figure and Noise power

c) Required received carrier level

d) System gain/(Link equation in dB)

e) Diversity calculation (Fading)

f) System performence.

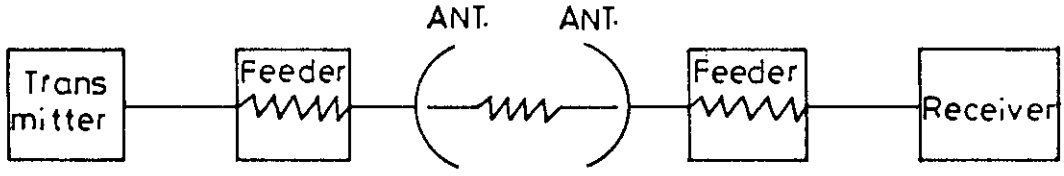


Fig.4.1 A microwave link model.

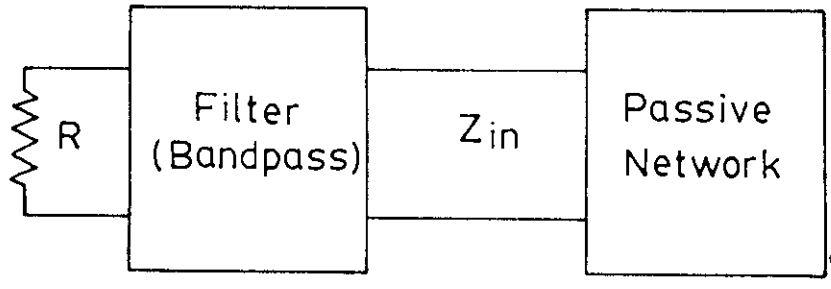


Fig.4.2 A resistor connected to a passive network.

4.3 NOISE REQUIREMENT

Any undesired signal in a communication circuit is called noise. The types of noises occurs in a communication system are as follows:

a) Thermal noise

b) Quantum noise

c) Intermodulation noise

d) Crosstalk noise

e) Impulse noise.

4.3.1 THERMAL NOISE

This type of noise occurs in all transmission and all communication equipment arising from the random electric motion. It is characterized by a uniform distribution of energy over the frequency spectrum. The random motion of electrons in a resistor R at an absolute temperature T exibits a random noise voltage across its terminals. The power spectral density of this noise voltage is given by Plank's distribution law [1,6,16,17]

$$P_n = \frac{4hfRB_n}{e^{hf/KT}-1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4.01)$$

where h is plank's constant=6.6254 x 10^{-34} Joules-sec.

k is Boltzmams constant=1.38 x 10^{-23} J/^{o}K

R is the resistance (ohm)

f is the frequency (Hz)

B_n is Band width in which noise is observed

According to the Nyquists formula the mean square value of generated noise voltage is given by

$$e_n^2 = 4KTB_nR \qquad \text{.....(4.02)}$$

Thermal noise is termed as white noise refering to the average uniform spectrum distribution of energy with respect to frequency. It is independent of frequency over the bandwidth.

Let a resister R be connected to a one-port network, as shown in Figure 4.02. We also assume that an ideal narrow-band lossless filter is inserted between R and the network. The resister R will deliver thermal noise to the network in a narrow band of frequency B_n centered of f. At system thermodynamic equilibrium the network must deliver an equal amount of noise power to R at the same frequency. The use of a lossless narrow band filter is simply a method used to demonstrate that the flow of noise energy from R to the network and from network to R must balance at each frequency.

4.3.2 QUANTUM NOISE

At high frequencies where hf>kT such as used in optical communication the thermal noise spectrum eventually drops to zero. But a quantum noise term equal to hf is added that to give inherent noise limitation at all frequencies.

4.3.3 INTERMODULATION NOISE

It is the results of the presence of intermedulation products. The products result where two or more signal mixed together while passing through a nonlinear device.

It may results from number of causes:

i) Improper level setting i.e. two high level input to a device derives it into nonlinear operating region.

ii) Improper alignment causing the device to function non-linearity.

iii) Non linear envelope delay

4.3.4 CROSSTALK NOISE:

Gross talk interference can be caused by unwanted coupling between two signal due to capacitance, leakage or mutual

inductance of lines. Low level cross talk can be intelligible and give the user the impression of a lack of secrecy. When cross talk energy is transferred from one channel to another it can usually be detected at each end of the disturbed channel as shown in figure 4.03. When the cross talk is propagated over the disturbed channel in the same direction as its own signal, the cross talk is called far-end cross talk. When it is in the opposite direction is called near-end crosstalk.

4.3.5 IMPULSE NOISE

It is non-continuous type of noise. It consists of irregular pulses or spikes of noise of short duration and of relatively high amplitude for voice telephone.

4.3.6 SIGNAL TO NOISE RATIO (S/N)

It is the amount by which a signal level exceeds its corresponding noise level. In dB_m the S/N ratio is equal to the difference between the level of signal in dB_m to the level of noise in dB_m.

4.4 NOISE FIGURE AND NOISE TEMPERATURE

In a system all network whether passive or active and all transmission media contribute noise to transmission system. Noise Figure is a measure of noise produced by the practical system compared to an ideal network [1,8,11,16].

System noise figure NF is defined as

$$NF = \frac{(S/N)_{in}}{(S/N)_{out}}$$

$$= \frac{S_{in}N_{out}}{S_{out}N_{in}} \qquad \text{.....(4.04a)}$$

But $N_{in} = KTB_n$ and $S_{out}/S_{in} = G$ (Gain)

$$\Rightarrow NF = \frac{N_{out}}{KTB_nG} \qquad \text{.....(4.04b)}$$

In deceibel unit,

$$(NF)_{dB} = 10\log(N_{out}) - 10\log(KTBnG) \qquad \text{.....(4.05)}$$

For conventional noisy receivers the concept of noise figure is enough to describe their performance. But for low noise receivers a more useful measure receiver noise is the effective input noise temperature (T_r) of the receiver [1,8,11,16]. Now consider the equivolent noisy transducer shown in figure 4.4. From equation 4.04b we can express noise figure as

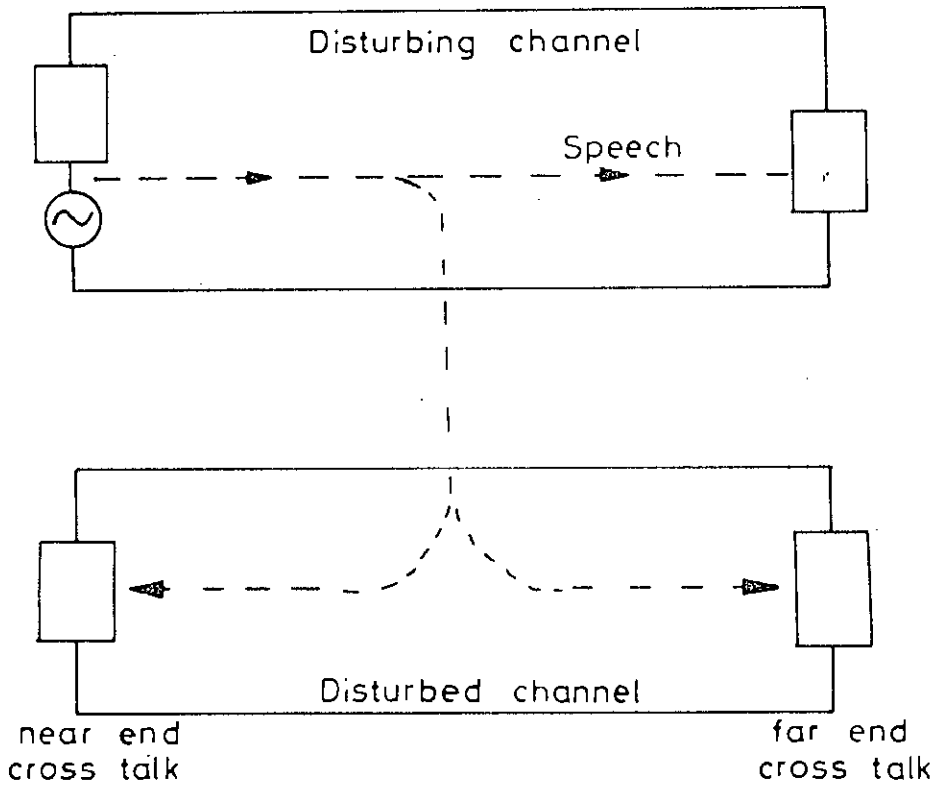


Fig.4.3- Illustration of cross talk noise.

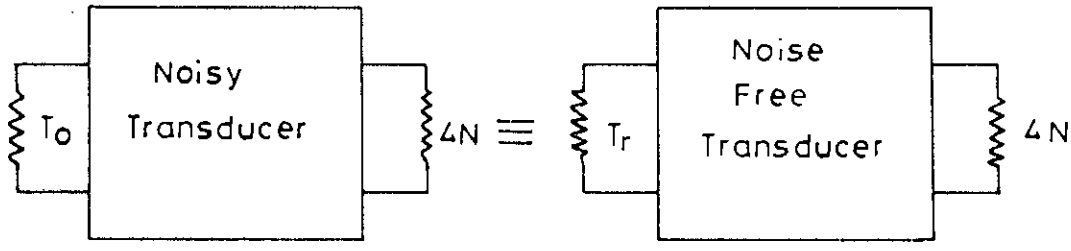


Fig.4.4 Equivalent noise free transducer model of a noisy transducer.

$$NF = \frac{N_{out}}{KTGB_n}$$

$$= \frac{KT_0GB_n + \Delta N}{KTGB_n}$$

where $\Delta N = KT_rGB_n$

Hence $$NF = \frac{KT_0GB_n + KT_rGB_n}{KT_0GB_n}$$

$$\Rightarrow T_r = (NF - 1)T_0 \qquad \text{.....(4.06)}$$

Then T_r refered to the input terminal is a termed which characterized the noiseless of a given receiver.

4.5 REQUIRED RECEIVED CARRIER LEVEL

The required received carrier level for a minimum quality objective is defined

$$C_{min}=P_T-G_s \qquad \text{.....(4.07)}$$

where C_{min}=received carrier level(dB_m) for a minimum quality objective; it is called receiver threshold.

P_T=transmitter output power (dB_m), excluding antenna branching network

G_s=system gain in dB.

4.6 LINK EQUATION AND SYSTEM GAIN

4.6.1 LINK EQUATION

An isotropic antenna radiates power in all direction. But an directional antenna radiates power for particular direction. If P_T is the average power radiatas from an antenna in all direction we get the radiate power per unit area as

$$P_{Di} = \frac{P_T}{4\pi d^2} \qquad \text{.....(4.08)}$$

where d is the link range.

But all practical antenna are somewhat directional that is power density along the direction of maximum deviation is

$$P_D = P_{Di} G_T$$

$$= \frac{P_T G_T}{4\pi d^2} \qquad \text{.....(4.09)}$$

where G_T is the maximum density of gain.

Receiving power P_R can be expresse as

$$P_R = P_D A_{eff} \qquad \text{.....(4.10a)}$$

Where A_{eff} is effective area of receiving antenna.

$$\Rightarrow P_R = \left(\frac{P_T G_T}{4\pi d^2} \right) A_{eff} \qquad \text{.....(4.10b)}$$

But effective area can be expressed as

$$A_{eff} = G_R \lambda / 4\pi \qquad \text{.....(4.10c)}$$

Where G_R is the directivity gain of receiving antenna,

λ is the wave length.

$$\text{Hence} \quad P_R = \frac{P_T G_T G_R \lambda}{(4\pi d)^2} \qquad \text{.....(4.11)}$$

In decibel unit we get the ratio of the receiving and the transmitting power

$$(P_R/P_T)_{dB} = [\ 10 \text{ Log } G_T G_R\ ] - [20 \text{ Log } 4\pi d] + [10 \text{ Log} \lambda]$$

$$= \text{EIRP} - L_{dB} \qquad \text{.....(4.12)}$$

Where EIRP (Effective Interference Radiate Power) = $[G_T G_R]_{dB}$

L_{dB} = Line Loss

From equation 4.11 and 4.12 we have line loss as follows:

$$L_{dB} = 32.5 + 20 \text{ Log } F + 20 \text{ Log } d \quad [\ F \text{ in MHz, } d \text{ in Km }]$$

$$= 96.6 + 20 \text{ Log } F + 20 \text{ Log } d \quad [\ F \text{ in GHz, } d \text{ in mile }]$$

$$\text{.....(4.13)}$$

4.6.2 SYSTEM GAIN

System gain is the useful measure of performance because it incorporates many parameters of interest to the designer of microwave system. Its value must be greater than or at least equal to the sum of the gains and losses which are external to

the equipment. From equation 4.07 we have the mathematical expression as follows:

$$G_s = P_T - C_{min} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.07)$$

$$\Rightarrow G_s = L_{dB} + L_{Feed} + L_B - G_T - G_R \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.14a)$$

Unfaded received power P_R (C_{min}) is given by

$$P_R = P_T + G_T + G_R - L_{dB} - L_{Feed} - L_B \quad \ldots\ldots\ldots\ldots (4.14b)$$

Where P_T = Transmitter output power

G_T = Transmitting antenna gain

G_R = Receiving antenna gain

L_{dB}= Span loss

L_{Feed}= Feeder loss

$_B$ = Branching network loss

Receiver noise (N_0) is given by

$$N_0 = 10 \text{ Log } KTB + NF \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.15)$$

Where NF is the receiver noise figure.

Hence S/N_0 (Signal to noise ratio) = $P_R - N_0$ $\ldots\ldots\ldots\ldots (4.16)$

Antenna Gain: The gain of a parabolic antenna can be calculated as

$$G = \eta \left(\frac{\pi D}{\lambda} \right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.17a)$$

Where η = Antenna efficiency (Typically 0.55-.60)

D = Antenna diameter (Aperture Dia.)

λ = Wave length

At 55% efficiency we can express G in dB as

G_{dB} = 20 log D+20 log F+17.8 (D in m, Fin GHz) ....(4.17b)

4.7 UNFADED INTERFERENCE NOISE (S/I) CALCULATIONS

4.7.1 INTERFERENCE OF AN ADJACENT CHANNEL (S/I)X

This source of interference is suppressed by cross polarization discrimination (CPD) of antenna, transmitted spectrum shaping and selectivity within the desired receiver.

(S/I) unfaded=CPD+IRF(CPD) .....(4.18)

where CPD= Cross polarization discrimination of antenna.

IRF(CPD)= Interferece reduction factor of this radio for the minimum frequency spacing between cross polarized adjacent channels.

4.7.2 TRANSMITTER-RECEIVER INTERFERENCE S/I(X-R)

S/I(X-R) defines as the ratio of received power to the interference noise for the minimum frequency spacing between a transmitter and a receiver.

$$S/I(X\text{-}R) = P_R - P_T + L_B + L_{Feed(x)} + L_{Feed(x)} + D_{X\text{-}R} + IRF(X\text{-}R) \quad \text{.....(4.19)}$$

Where, P_R=Receiver Power

P_T=Transmitter power

L_B=Branching Network Loss

$L_{Feed(X)}$ = Transmitter Feeder Loss

$L_{Feed(R)}$ = Receiver Feeder Loss

D_{X-R} = Transmitter-Receiver Decoupling

IRF(X-R) = IRF for minimum frequency seperation of T_X and R_X.

It is also possile front- to- back antenna interferance. The design engineers must consider this case as well as the previous interferance effect.

4.8 FADE MARGIN REQUIREMENTS FOR A SPECIFIED SYSTEM AVAILABILITY

Fading is the fluctuation in transmitter line. Fading depends on temperature, pressure and humidity of air. The effect of fading on operational unvailability can be minimised by space or frequency diversity techniques. Both of these techniques are based on the hypothesis that simultaneous fading on both radio transmission paths is unlikely. The hop fade margin (dB) of non-diversity system (FM) can be solved from the following equation:

$$FM = 30 \log(d)+10 \log(6ABf)-10 \log(1-R)-70 \quad .....(4.20)$$

where A = Roughness factor

= 4 for very smooth terrain

= 1 for average terrain with some roughness

= ¼ for mountainous, very rough terrain

B = factor to convert worstmonth probability to annual probability

= ½ for Great Lakes or similar hot, humid areas

= ¼ for average inland areas

= 1/8 – for mountainous or very dry areas

1-R = Reliability objective for a 400 km route

It may be used on a worst-month basis by setting B=1, we may obtain the fade margin for an unprotected utility having 99.99% service reliability per hop.

=> (1-R) = 0.01% = 0.0001

$$FM=30 \log(d) + 10 \log(6A)+10 \log f-30 \text{ dB} \quad .....(4.21)$$

The system gain equation (equation no. 4.14) considering FM we can express as,

$$G_S \geq FM+L_{dB}+L_{FEED}+l_B-g_t-G_R \quad .....(4.22a)$$

which becomes,

$$G_S=50\ \log d+30\ \log f+10\ \log(6A)+62.4+L_{FEED}+L_B-G_T-G_R \quad ....(4.22b)$$

4.9 PARAMETERS FOR SYSTEM PERFORMANCE

Considering the system performance the estimatted parameters are as follows:

i) Frequency

ii) Hop distance

iii) Tower heights

iv) Antenna diameter

v) Transmitting power

vi) Receiver threshold

Calculating parameters are:

i) Free space loss

ii) Antenna gain

iii) Noise Figure

iv) Feeder Loss

v) Branching Network Loss

vi) Received Power

vii) Noise

viii) Threshold S/N

ix) S/I ratio

x) Fade margin of S/N, S/I.

CHAPTER 5

CALCULATION FOR A MICROWAVE LINK IN BANGLADESH

5.1 INTRODUCTION

This chapter deals with the verification of interference patterns calculation which are discussed in the previous chapter for microwave communication link. This is devoted to a treatment of a microwave communication link in Bangladesh. Available datas are taken from Bangladesh T & T Board and specified results have been obtained for a UHF and a SHF links.

5.2 CALCULATION OF AN UHF LINK

This section deals with the performance calculation of an UHF link of Bangladesh.

5.2.1 DATAS AND PARAMETERS

Transmitting Antenna Height...60.0 m
Hop Distance .....25.0 km
Antenna Diameter ..... 1.2 m
Transmitting Power .....30.0 dBm
Transmitting Frequency ..... 1.5 GHz
Noise Threshold ..... 4.5 dBm(max.)
Receiving Power.....From -25.0 dBm to -40.0 dBm
Branching Loss ..... 4.5 dB

5.2.2 PATTERNS OF COVERAGE DIAGRAM

Using the formulla 2.11 for the datas mentioned above we can draw the constant F/r curve in the h_2-d plane which is the coverage diagram. Such a diagram is shown in the fig.5.1. In

the first lobe the receiving antenna height is 22 m at the span distant 25 km which is very close to the height calculated by the Fujitsu Ltd., Tokyo, Japan for UHF link for Bangladesh. The coverage diagram in spherical earth phenomena is also shown in figure 5.2

5.2.3 FRESNEL ZONE CALCULATION

To calculate the midpath obstacle loss it is necessary to draw the path profile for Fresnel zone. To design UHF link for Bangladesh it is considered that terrain the is flat with trees of about 15 m height on the average. To avoid intervening obstacles such a path profile is drawn in the fig.5.3.

5.2.4 PERFORMANCE CALCULATION

ANTENNA GAINS:

$$G_{dB} = 20\log(F) + 20\log(D) + 17.8 \quad [F \text{ in GHz, } D \text{ in meter}]$$
$$= 22.9 \text{ dB.}$$

PATH LOSS:

$$L_{dB} = 20\log(F) + 20\log(d) + 92.5 \quad [F \text{ in GHz, } d \text{ in km}]$$
$$= 123.98 \text{ dB.}$$

RECEIVER NOISE:

$$N_{O(dB)} = 10\log(KTB) + NF \quad [T = 318^{O}k]$$
$$= -102.13 \text{ dBm}$$

RECEIVER POWER:

$$P_{r(dB)} = 22.9 + 22.9 + 30 - 123.98 - (5.5 + 5.5) - 4.5$$
$$= -63.7 \text{ dBm.}$$

SIGNAL TO THERMAL NOISE RATIO:

$$(C/N)_{TH} = -63.7-(-102.13)$$
$$= 38.43 \text{ dBm.}$$

5.2.5 A comparision for the specified results for 25 km UHF link shown in the table 5.01.

Table-5.01

	Receiving Antenna Height(h) (m)	Antenna Gain (dB)	Path Loss (dB)	Receiver Input Power (dBm)
Calculated Values	22.00 (From First Lobe)	22.90	123.98	-63.70
Values Collected From T&T Board	24.00	23.40	123.90	-65.70

5.3 CALCULATION FOR A SHF LINK (Manikganj-Dhaka Radio Link)

This section deals with the performance calculation of Manikganj to Dhaka radio link. The diffraction loss and attenuation by atmospheric hydrometeors are consider necligible.

5.3.1 Hop Characteristics

Hop Length .....44.30 km
Output Power .....30.00 dBm
Branching Losses..... 4.50 dB
Obstraction Losses ..... 6.00 dB

5.3.2 Station Parameters:

Antenna Diameter ..... 3.70 m

Frequency Used ..... 6.77 GHz

Feeder Loss ..... 4.20 dB (Transmitting Side)
5.00 dB (Receiving Side)
Noise Figure ..... 3.00 dB

5.3.3 Results

[Coverage Diagram is shown in the Fig.5.5 and Fig.5.6]

Antenna Gain ..... 46.00 dB
Path Loss ..... 142.00 dB
Receiver Noise ..... -102.13 dBm
Received POwer..... -33.70 dBm
$(S/N)_{Th}$..... 68.13 dBm

5.3.4 A comparison between the calculated results and results calculated by Fujitsu Ltd. is shown in the table 5.02.

Table-5.02

	Path Loss (dB)	Received Power (dBm)	Antenna Gain (dB)	Received Antenna Height(m)
Calculated Value	142.00	-33.70	46.00	61.00
Calculated by Fujitsu Ltd.	141.00	-34.25	45.7	63.00

5.4 DISCUSSIONS

The span length is very large compared to the antenna height and in above two cases the grazing angle is very small as

below one degree. Hence taking the reflection co-efficient taking -1 gives the accurate result of coverage diagram. The magnitude and phase of reflection co-efficient in 3-12 GHz range MW frequencies are shown in figures 5.7 and 5.8.

There is a thumb rule to determine the conditions under which the flat-earth formulas will serve a good results with acceptable accuracy. It is required that the flat-earth formula be accurate to within i,e $(2k_0 h_1 h_2/d - \pi\zeta v) < 0.15\pi$. In both cases it is not exactly satisfactory. Hence the spherical earth approximation is the exact solution for both the links.

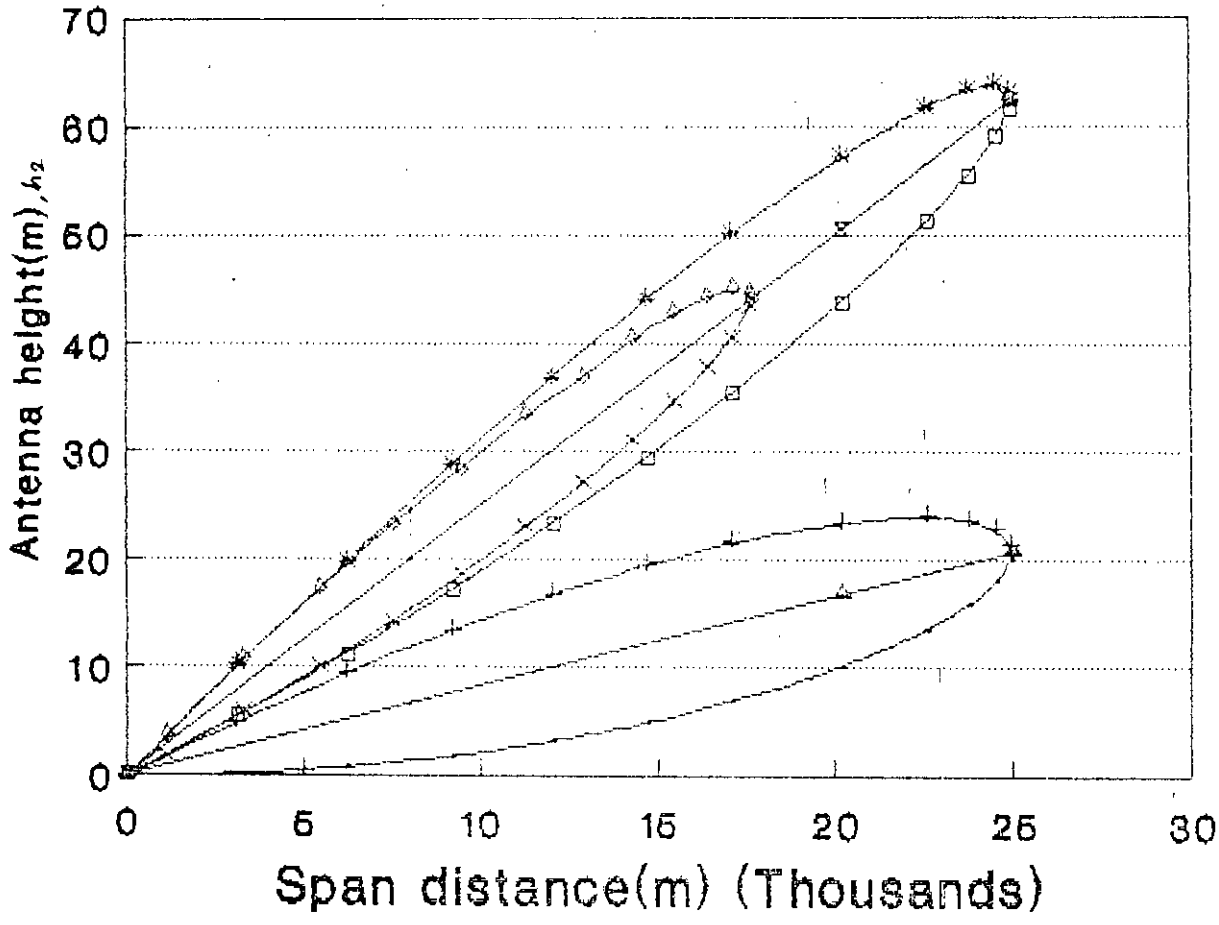


Fig.5.1 Coverage diagram (Flat earth approximation) for an UHF link ($h_1=300\lambda_0$, $r_f=12.5$Km)

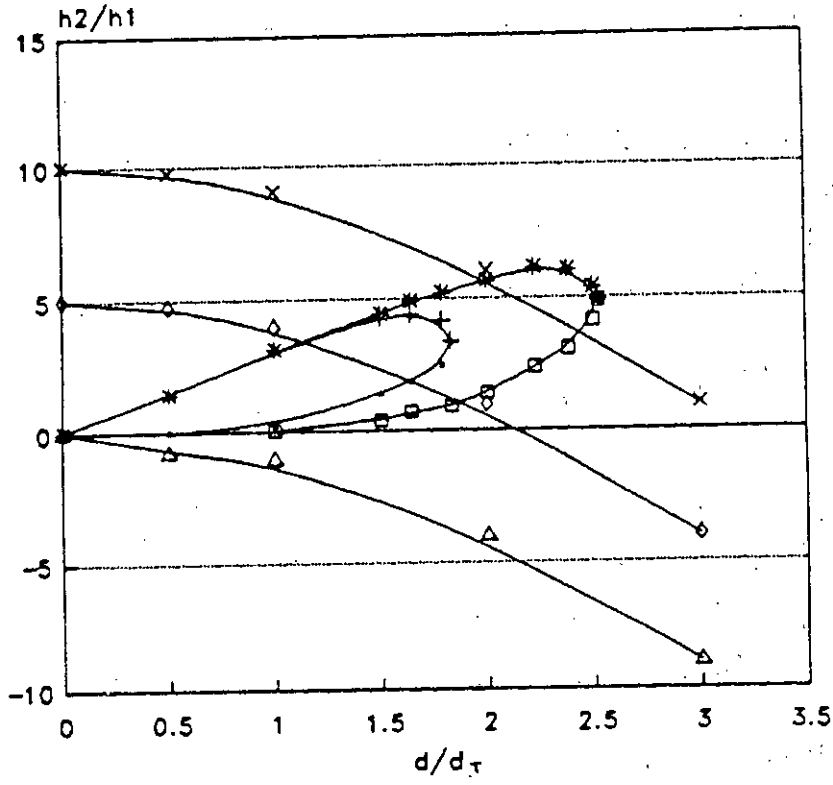


Fig.5.2 Coverage diagram (Spherical earth approximation) for an UHF link (v = 0.57)

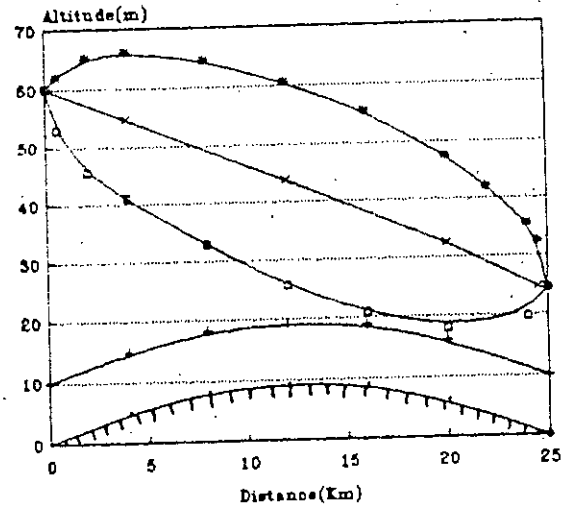


Fig.5.3 First Fresnel zone for an UHF link (f=1.5 GHz, d=25.0Km, k=1.33, h_1=24.0m, h_2=60.0m)

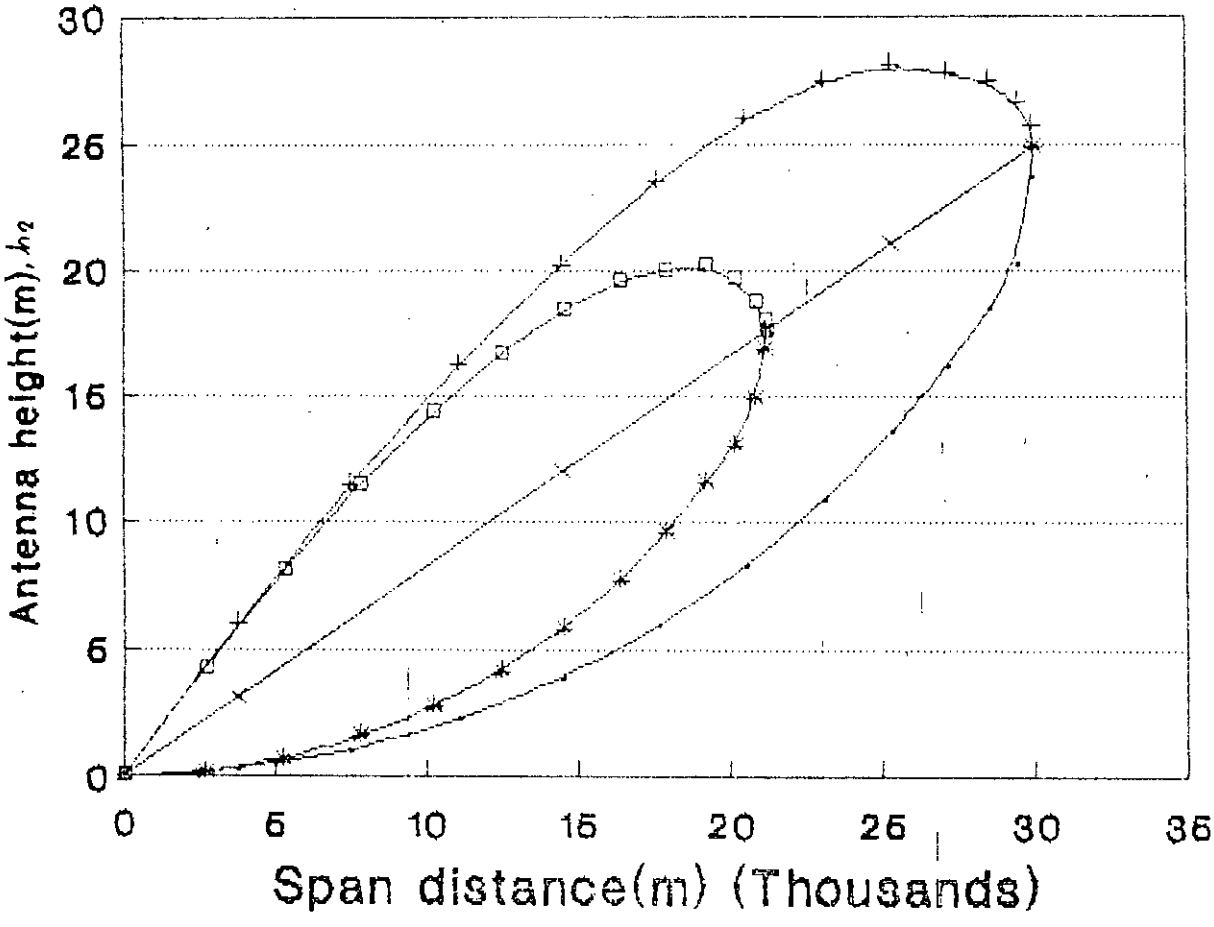


Fig.5.4 Coverage diagram for an UHF link (h_1=300λ_c, r_f=15Km)

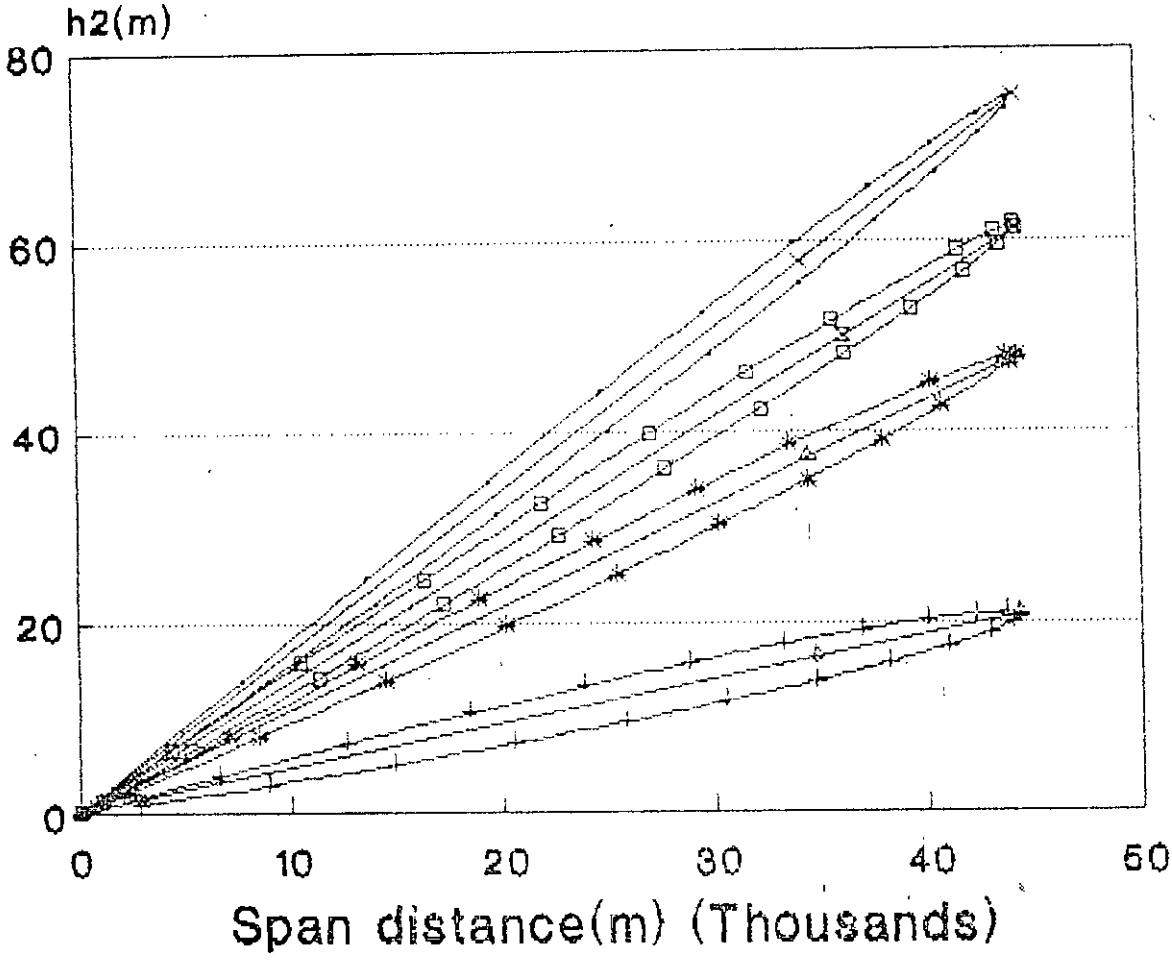
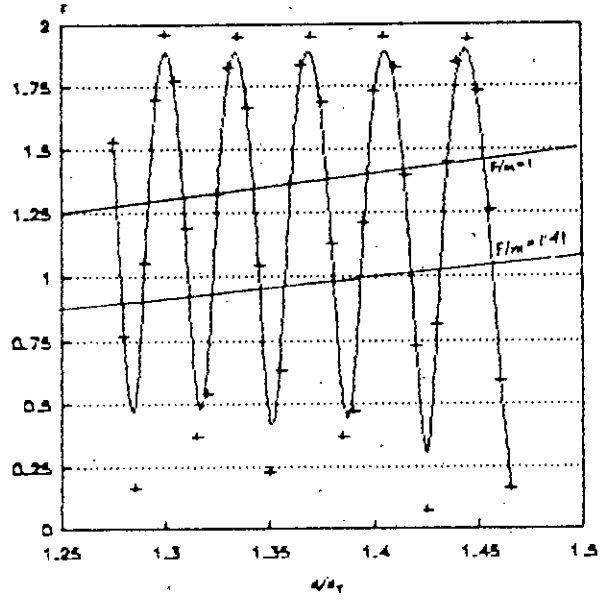
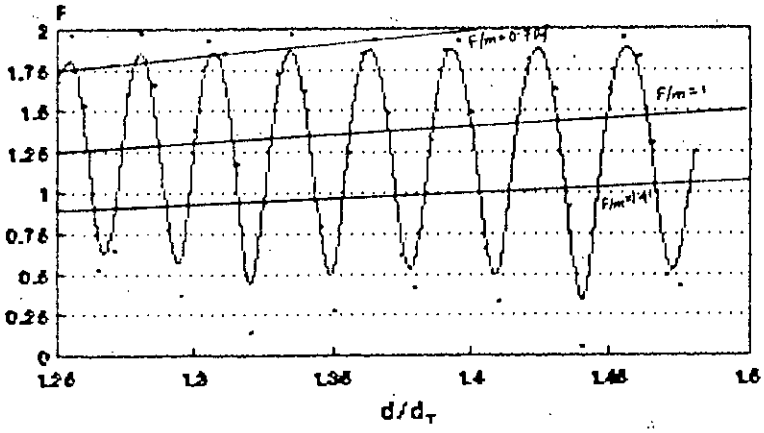


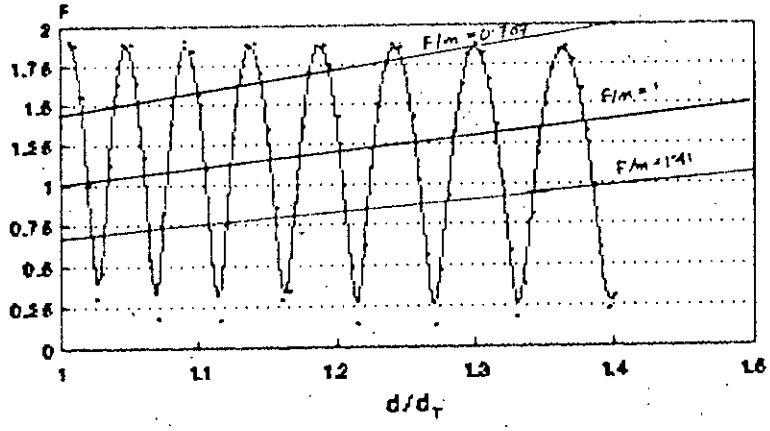
FIg.5.5 Coverage diagram for Manikganj-Dhaka mw link. (h_1=86.0m, f=6.77 GHz, r_p=22.15 Km)



$h_2/h_1 = 8$

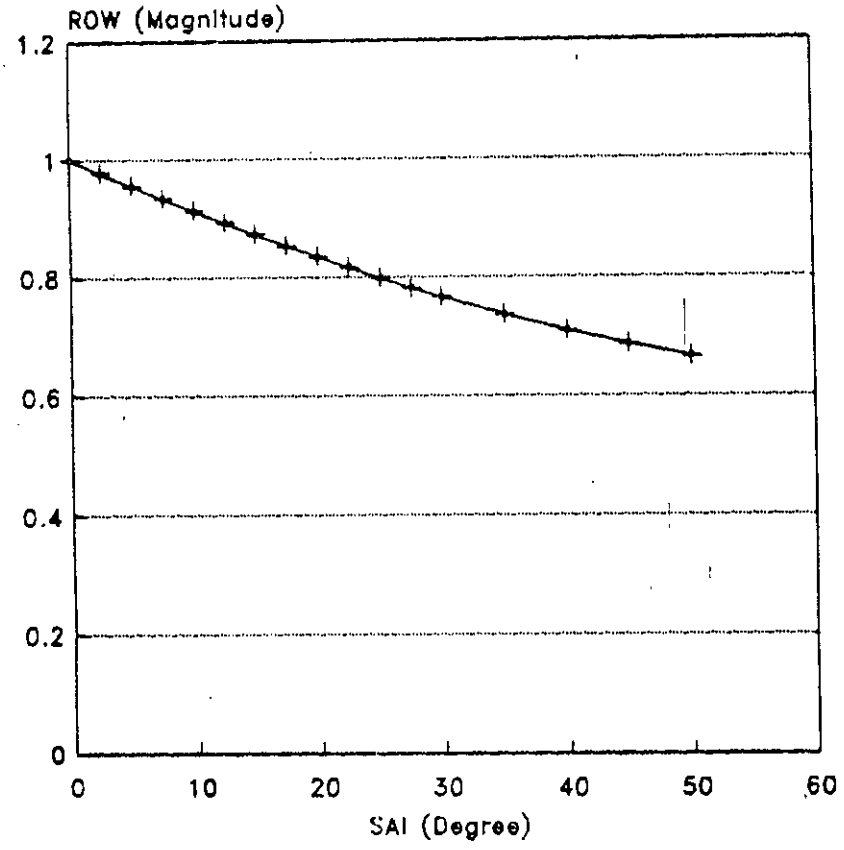


$h_2/h_1 = 6$

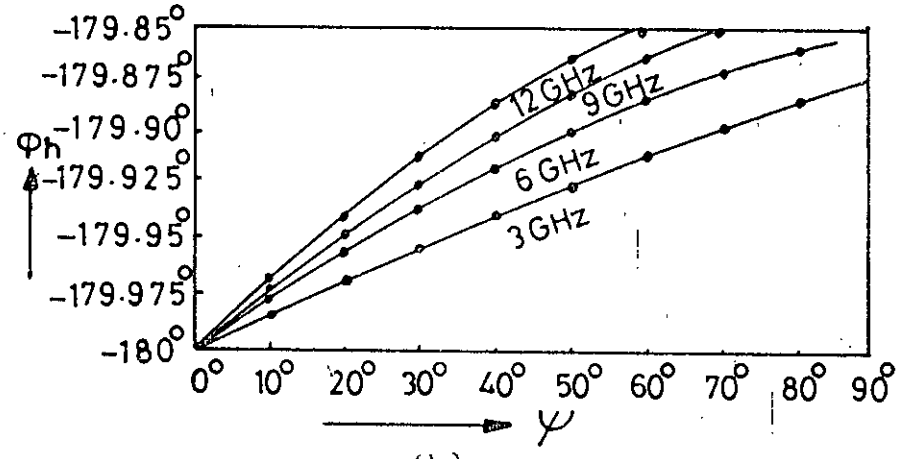


$h_2/h_1 = 2$

Fig.5.6 Data for constructing coverage diagram for Manikg-anj-Dhaka MW link (Spherical earth) for v = 10.856.



(a)

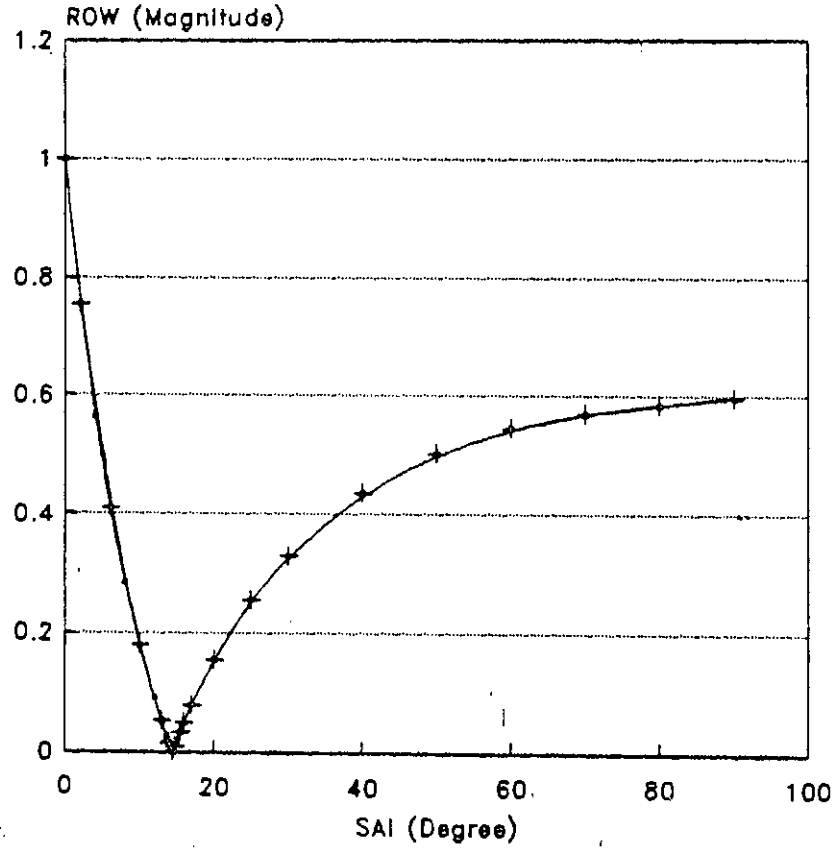


(b)

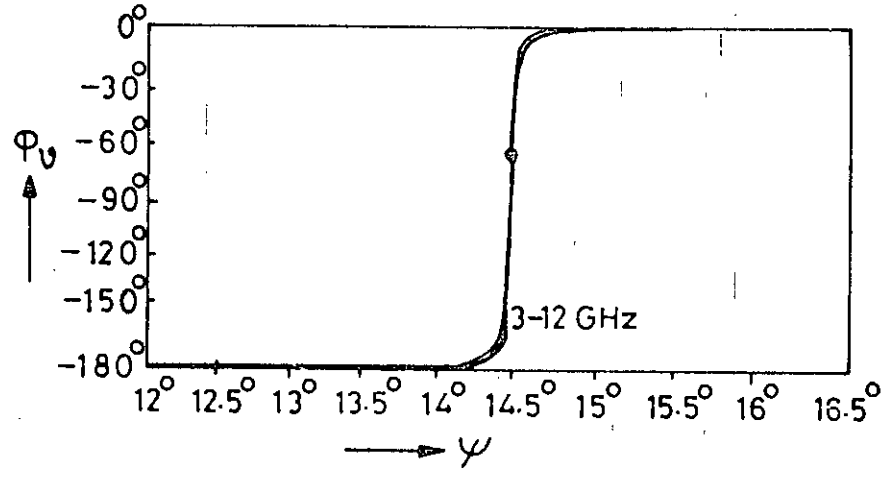
Fig.5.7 Magnitude and phase of reflection co-efficient horizontal polarization in 3-12 GHz range (ϵ_r = 15; σ = 0.009 S/m)

(a) Magnitude of the reflection coefficient

(b) Phase of the reflection coefficient



(a)



(b)

Fig.5.8 Magnitude and phase of reflection co-efficient for vertical polarization in 3-12 GHz range (ϵ = 15, σ = 0.009).

(a) Magnitude of reflection co-efficient
(b) phase of reflection co-efficient

CHAPTER 6
CONCLUSIONS

6.1- SUMMARY:

Throughout the thesis work the patterns of coverage diagram and the required field strength in the receiving side has been found by using the radio wave propagation phenomena over flat earth and spherical earth. To draw the patterns of coverage diagram and to find the field strength using flat-earth formula has been discussed in chapter two and the spherical earth phenomena has been discussed in chapter three. The performence calculation has been discussed in chapter four. Chapter five deals with the calculation for a number of microwave links in Bangladesh and the results are compared with the datas taken from the Bangladesh T.& T. Board. The agreement between the two results is found to be satisfactory.

6.2-SUGGESTION FOR FUTURE WORK:

At very high frequencies, several gigahertz and up, attenuation and scatter by rain and atmospheric gases, predominantly water vapor, must also be considered. Uncondensed water vapor and oxygen both have various absorption lines in the centimeter and millimeter wave regions. Consequently, there are frequencies where high attenuation occurs and which are separated

by windows or frequency bands where the attenuation is much lower. Figure 6.01 shows the attenuation by oxygen and water vapor (uncondensed) at 20^{0}C at sea level. In those bands where the attenuation exceeds 10 dB/km the range over which communication can take place is severely restricted. By a proper choice of frequencies it is possible to achieve much less attenuation. For frequencies above 300 GHz the minimum attenuation is still large, 6 dB per kilometer, and places a great restriction on the application of millimeter and submillimeter-wave radiation for terrestrial line-of-sight paths. Scattering and diffraction of radio waves by hills, buildings, trees etc., is also much more pronounced at the higher frequencies (above several GHz and up). The present thesis work can be extended for the studies of above phenomena in several gigahertz and up.

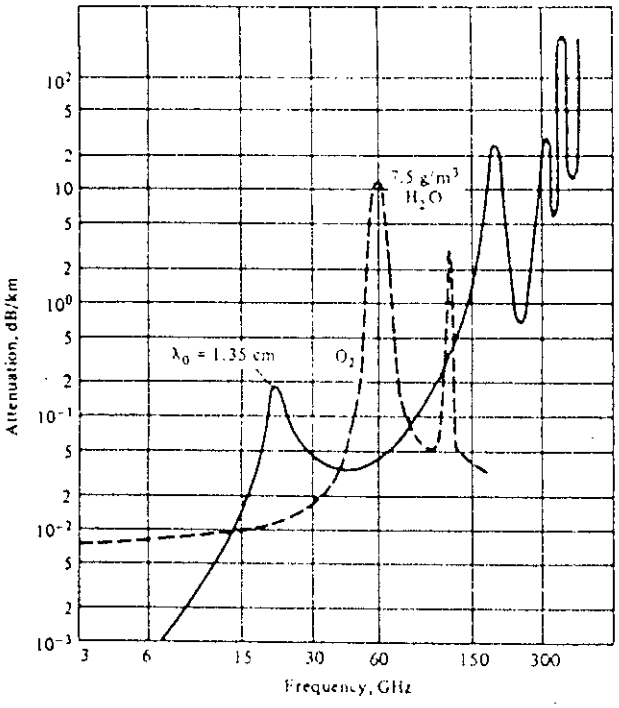


Fig.6.1 Attenuation by oxygen and water vapor at sea level. T = 20^{0}C. (This figure has been taken from reference 1)

APENDIX A

MICROWAVE FREQUENCY BAND DESIGNATION

The range of microwave frequencies is broken down into several bands designated by letters is shown below:

Frequency	Band designation OLD	NEW
500 - 1000 MHz	VHF	C
01 - 02 GHz	L	D
02 - 03 GHz	S	E
03 - 04 GHz	S	F
04 - 06 GHz	C	G
06 - 08 GHz	C	H
08 - 10 GHz	X	I
10 - 12.4 GHz	X	J
12.4 - 18 GHz	Ku	J
18 - 20 GHz	K	J
20 - 26.4 GHz	K	K
26.4 - 40 GHz	Ka	K

APENDIX B

CALCULATION OF (EFFECTIVE EARTH CORRECTION FACTOR) CONSTANT K

From figure 3.03 we have

$$rd\theta = vdt \qquad \text{.....(B.1)}$$

and $(r + dh)d\theta = (v + dv)dt$ .....(B.2)

Hence $dhd\theta = dvdt$

$$\Rightarrow \quad \frac{d\theta}{dt} = \frac{dv}{dh} \qquad \text{.....(B.3)}$$

But refractive index $n = \frac{c}{v}$

$$= \frac{\text{velocity in vacuum}}{\text{velocity in medium}}$$

$$= \frac{1/(\mu_0 k_0)^{1/2}}{1/(\mu k)^{1/2}}$$

$$= \left(\frac{\mu k}{\mu_0 k_0}\right)^{1/2}$$

The permeability of troposphere and vacuum is same . Hence

$$n = (kr)^{1/2}$$

$$\Rightarrow \quad (kr)^{1/2} = c/v = n$$

$$\Rightarrow \quad v = c/n \qquad \text{.....(B.4)}$$

$$\Rightarrow \quad dv/dh = -c/n^2 dn/dh$$

$$\Rightarrow \quad dv/dn.dn/dh = -c/n^2.dn/dh$$

$$\Rightarrow dv/dh = -(v/n).dn/dh$$

Since n is nearly equal to unity then we have

$$dv/dh = -v.dn/dh \qquad \ldots\ldots\ldots\ldots (B.5)$$

From (B.1) we have

$$\dot{r} = v/(d\theta/dt)$$

$$= v/(dv/dh) \qquad [\text{Using } (B.2)]$$

$$= -1/(dn/dh) \qquad [\text{Using } (B.5)]$$

$$\Rightarrow 1/r = -dn/dh \qquad \ldots\ldots\ldots\ldots (B.6)$$

From figure 3.04a,

$$(a + h)^2 + d^2 = (a + h + \delta h + x)^2$$

$$\Rightarrow d^2 = (x + \delta h)^2 + 2(a + h)(\delta h + x)$$

But $d >> x$ or h & $a >> x$ or δh. Hence neclecting higher power of δh

$$2a(\delta h + x) = d^2$$

$$\Rightarrow \delta h = \{d^2/(2a) - x\} \qquad \ldots\ldots\ldots\ldots (B.7)$$

From figure 3.04a,

$$(a_e + h)^2 + d^2 = (a_e + h + \delta h)^2$$

$$\Rightarrow (\delta h)^2 + 2h\delta h + 2a_e\delta h = d^2 \qquad [\text{Neclecting higher power of } h]$$

$$\Rightarrow \delta h = d^2/2(a_e+h)$$

$$= d^2/(2a_e) \qquad [\text{As } a_e >> h] \qquad \ldots\ldots\ldots\ldots (B.8)$$

But from figure 3.04a,

$$r^2 + d^2 = (r + x)^2$$

$$\Rightarrow d^2 = 2rx \qquad [\text{ As } r >> x \text{ }]$$

$$\Rightarrow x = d^2/(2r) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (B.9)$$

Hence using (B.7) & (B.9) we have

$$\delta h = (d^2/2)(1/a - 1/r) \qquad \ldots\ldots\ldots\ldots (B.10)$$

Equating (B.8) & (B.10)

$$1/a_e = 1/a - 1/r$$

$$= 1/a + dn/dh \quad [\text{Using (B.6)}] \ldots (B.11)$$

Now we can put $a_e = ka$ where k is the correction factor. Then we have

$$1/k = 1 + a.dn/dh$$

$$\Rightarrow k = \frac{1}{1 + a.dn/dh} \qquad \ldots\ldots\ldots\ldots\ldots (B.12)$$

The gradient of refractive index (dn/dh) corresponding to standard atmospheric conditions is $- 0.039 \times 10^{-6}$ per meter and the radius of earth (a) is 6372 km.

Hence $k = 1/(1 - 6372 \times 10^3 \times 0.039 \times 10^{-6})$

$\simeq 4/3.$

APPENDIX C

LISTING OF COMPUTER PROGRAM

```
C       PROGRAM FOR THE CALCULATION OF COVERAGE DIAGRAM
C       FLAT-EARTH PHENOMENA FOR 30KM LINK
C
        OPEN(UNIT=1,STATUS='OLD',FILE='INPUT')
        OPEN(UNIT=2,STATUS='NEW',FILE='OUTPUT')
        READ(1,3) ALMDA, H1
    3   FORMAT(3F10.3)
        WRITE(2,4) ALMDA, H1
    4   FORMAT(3X,'ALMDA=',F10.3,3X,'H1='F10.3)
        PI=3.14159
C       'FR' IS USED HERE FOR THE RATIO OF PATH GAIN FACTOR WITH 'R'
C
        AO=2*PI/ALMDA
        DO 60 FRR = 1, 8, 1
        FR=FRR/15000
C       HD=RECEIVING ANTENNA HEIGHT DIVIDED BY DISTANT
C
        DO 50 DH = 1, 200, 1
        HD=DH/15000
        F=2*ABS(SIN(AO*H1*HD)
        R=F*15000/FRR
        DSTANT=((HD*H1)+((HD**2*H1**2)+(1+HD**2)*(R**2-H1**2))**0.5)/
       +(1+HD**2)
        HT=HD*DSTANT
        WRITE(2,5) FRR, F, DSTANT, HT
    5   FORMAT(2X,'FRR=',F10.3,2X,'F=',F8.5,2X,'DSTANT=',F8.1,2X,
       + 'HT=',F6.2)
   50   CONTINUE
   60   CONTINUE
        STOP
        END


C
C       REFLECTION CO-EFFICIENT CALCULATION
C
        COMPLEX C,TT
        OPEN(UNIT=1,STATUS='OLD',FILE='INPUT')
        OPEN(UNIT=2,STATUS='NEW',FILE='OUTPUT')
```

```
      READ(1,3) AK, E1, SIGMA
    3 FORMAT(3F10.3)
      WRITE(2,4) AK, E1, SIGMA
    4 FORMAT3X,'AK=',F10.3,3X,'E1=',F10.3,3X,'SIGMA='F10.3)
      PI=3.14159
      DO 60 FRQ = 3, 12, 3
      DO 50 SAI =0, 360, 1
      FREQ=FRQ/2
      SI=SAI*PI/720
      SAII=SAI/4
      AX=18*SIGMA/FREQ
      X1=-ABS((COS(SI))**2)+AK
      Y1=-AX
      C=CMPLX(X1,Y1)
      TT=CSQRT(C)
      X2=REAL(TT)
      Y2=AIMAG(TT)
      X3=AK*ABS(SIN(SI))
      Y3=Y1*ABS(SIN(SI))
      TAI1=X3-X2
      PAI1=Y3-Y2
      TAI2=X3+X2
      PAI2=Y3+Y2
      TAI=SIN(SI)-X2
      PAI=-Y2
      TA2=SIN(SI)+X2
      PA2=Y2
      RW1=((TAI1**2+PAI1**2)/(TAI2**2+PAI**2))**0.5
      XX=PAI1/TAI1
      YY=PAI2/TAI2
      FII1=((ATAN(XX)-ATAN(YY))*180)/PI
      RW2=((TAI**2+PAI**2)/(TA2**2+PA2**2))**0.5
      WW=PAI/TAI
      ZZ=PA2/TA2
      FII2=((ATAN(WW)-ATAN(ZZ))*180)/PI
      WRITE(2,5) RW1, RW2, SAII, FII1, FII2, AX
    5 FORMAT(2X,'RW=',F9.5,1X,'RW2=',F9.5,1X,'SAII=',F5.2,1X,
     +'FII1=',F10.5,/1X,'FII2='F10.5,1X,'AX='F15.5)
   50 CONTINUE
   60 CONTINUE
      STOP
      END
```

```
C
C       THIS SAME PROGRAM CAN BE USED FOR  CALCULATION  REFLECTION
C       CO-EFFICIENT AT DIFFERENT PARAMETERS .


C
C        AVAILABLE DATA FOR THE INTERFERENCE PATTERNS OF MW LINK  IN
C        CASE OF SPHERICAL EARTH (DHAKA TO MANIKGANJ)
C
C


        OPEN(UNIT=1,STATUS='OLD',FILE='INPUT')
        OPEN(UNIT=2,STATUS='NEW',FILE='OUTPUT')
        READ(1,3) H1, FREQ
    3   FORMAT(2F10.3)
        WRITE(2,4) H1, FREQ
    4   FORMAT(3X,'H1=',F10.3,3X,'FREQ=',F10.3)
        PI=3.14159
C       ALAMDA=GREECK LAMDA, DSTNT=SPAN LENGTH,HH=H2/H1,DDT=DSTNT/DT
C
        ALMDA=0.3/FREQ
        V=(H1**1.5)/(1030*ALMDA)
        DT=4120*H1**0.5
C       THIS LOOP IS USED FOR CALCULATION PARAMETERS WITH INCREASING
C       RECEIVING ANTENNA HEIGHT.
        DO 40 H2 =63, 1000, 126
        HADD =H1+H2
        HMNUS=H1-H2
        T=(H1/H2)**0.5
        HH=1/T**2
C       THIS LOOP IS USED FOR CALCULATION PARAMETERS WITH INCREASING
C       DISTANCE
        DO 24 DD =25, 400, 1
        DDT=DD/200
        DSTNT=DT*DDT
        P=((2*(4120**2)*HADD+DSTNT**2)/3)**0.5
        SAI=ACOS((4120**2*HMNUS*DSTNT)/P**3)
        D1=DSTNT/2+P*COS((SAI+PI)/3)
        D2=DSTNT-D1
        SI=D1/DT
        S2=D2/(4120*H2**0.5)
        S=(S1*T+S2)/(1+T)
        D=1/(1+(4*S1*S2**2*T)/(S*(1-S2**2)*(1+T)))**0.5
        GTA=HH*(1-S1**2)*(1-S2**2)/DDT
```

```
      F=((1+D)**2-4*D*(COS((PI*V*GTA)/2)**2))**0.5
      FDDT=DDT/F
      YH=HH-DDT**2
      WRITE(2,5) HH, DDT, DSTNT, F, GTA, D, YH
 5    FORMAT(1X,'HH=',F4.1,1X,'DDT=',F6.3,1X,'DSTNT=',F10.2,1X,
     +'F=',F8.5,1X,'GTA=',F8.5,1X,'D=',F7.5,1X,'YH=',F8.5)
24    CONINUE
40    CONTINUE
      STOP
      END
```

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