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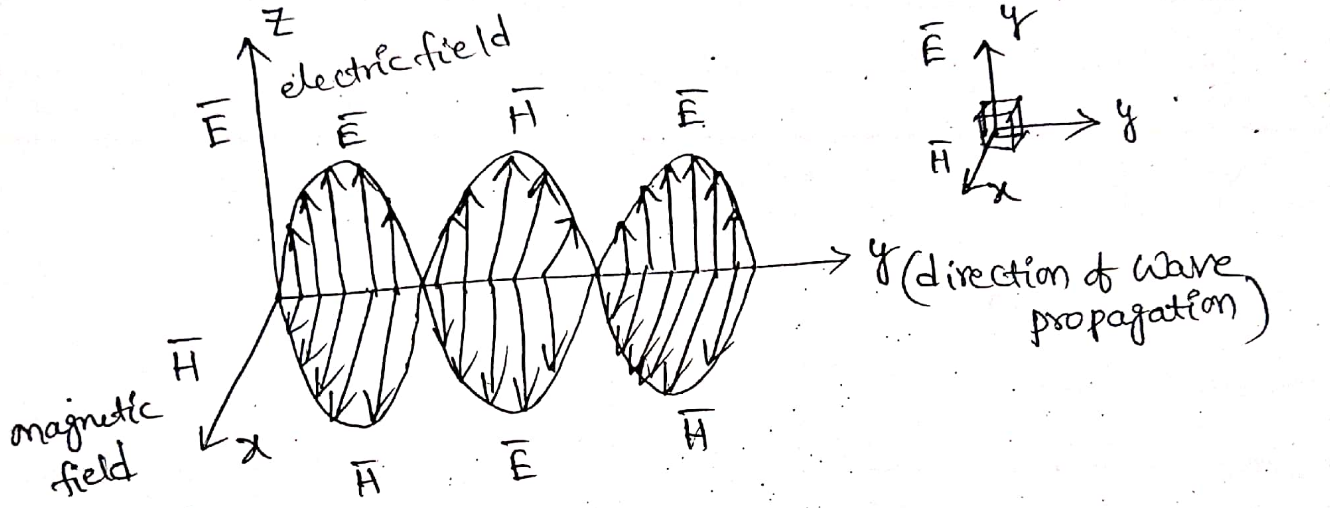
ECE

UNIT-6 (AWP)

S.M ①

WAVE PROPAGATION :-

Wave propagation :- The electromagnetic waves (or) Radio waves propagating from Transmitting antenna to Receiving antenna.
→ The power Radiated by the current carrying conductor then propagates in the free space in the form of EM waves. These Electromagnetic waves are oscillating in nature. In the free-space, EM waves travel at the speed of light.
→ The speed of light is $c = 3 \times 10^8$ m/sec (or) $c = 3 \times 10^{10}$ cm/sec



Frequency Ranges :-

symbol	frequency Range	Wave length (meters)	Type of propagation
ELF	< 300 Hz	> 1000 Km	Earth - Ionosphere Wave guide propagation
VLF	300 Hz – 3 KHz	1000 Km – 100 km	Ground wave propagation
ULF	3K – 30 KHz	100 km – 10 km	
LF	30K – 300 KHz	10 km – 1 km	
MF	300 KHz – 3 MHz	1 km – 100 m	Skywave propagation
HF	3 MHz – 30 MHz	100 m – 10 m	
VHF	30 MHz – 300 MHz	10 m – 1 m	Space wave propagation / Tropospheric scattering, LOS propagation.
UHF	300 MHz – 3 GHz	1 m – 100 mm	
SHF	3 GHz – 30 GHz	100 mm – 10 mm	
EHF	30 GHz – 300 GHz	10 mm – 1 mm.	

Radar frequency Band According to IEEE Standards :-

Letter Designation	Frequency Band (GHz)
L	1-2 GHz
S	2-4 GHz
C	4-8 GHz
X	8-12 GHz
Ku	12-18 GHz
K	18-27 GHz
Ka	27-40 GHz
V	40-75 GHz
W	75-110 GHz
mm	110-300 GHz

Structure of atmosphere :-

→ In the Radio wave propagation, the earth's environment between the Transmitting and Receiving antennas play a very Important Role.

→ The atmosphere of the earth mainly consists of 3 Regions.

(i) Troposphere.

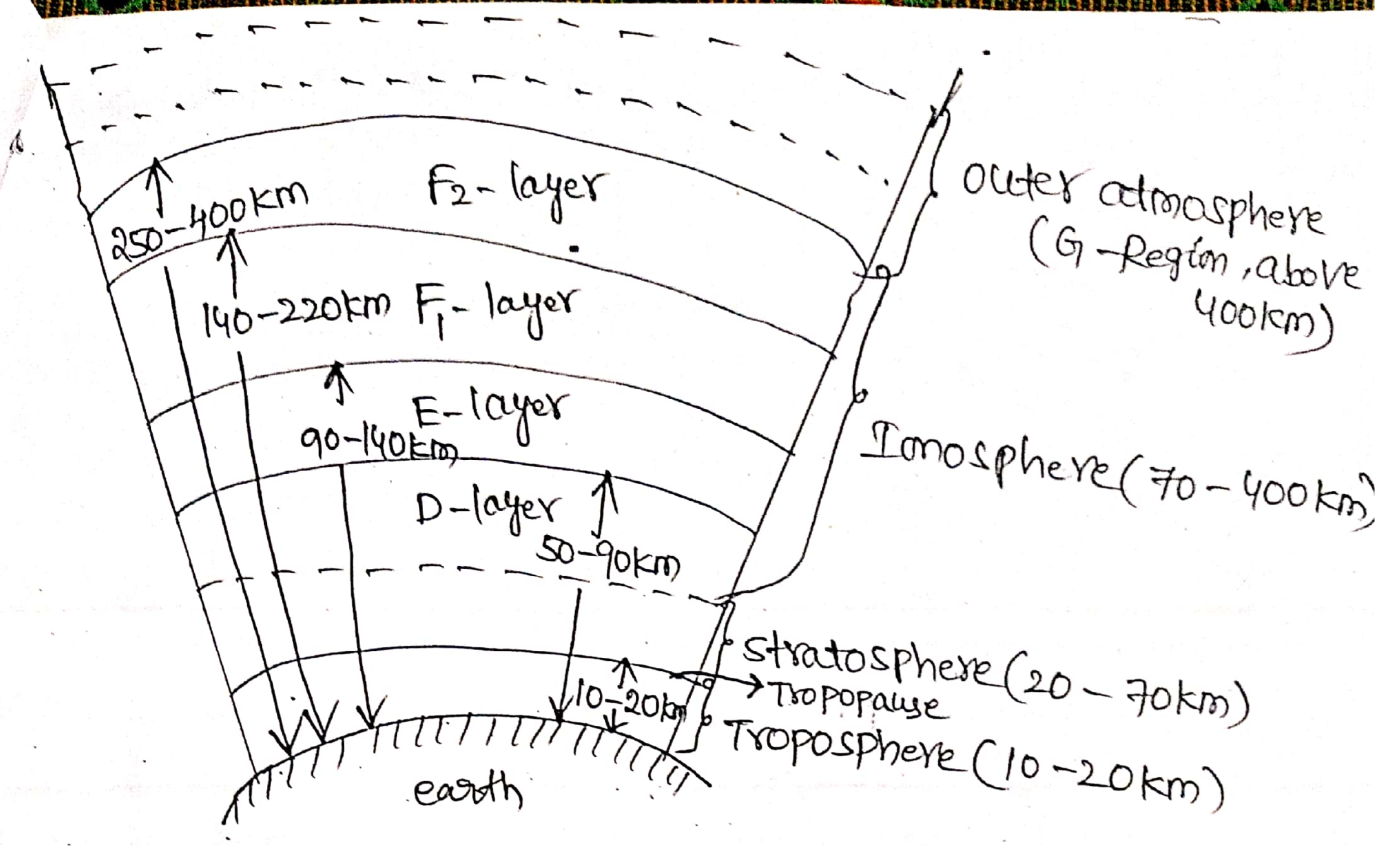
(ii) Stratosphere

(iii) Ionosphere.

→ The Troposphere is the nearest Region of the atmosphere to the earth's surface at about 10 to 20 km above the earth surface.

→ The stratosphere is the Region which is in between 20 km to 70 km of height from the earth's surface.

→ The Ionosphere is the last Region, which extends approximately 70km to 400km above the earth's surface.



Structure of Troposphere :-

→ This is the nearest Region in the atmosphere from the earth's surface around the 10km to 20km above the earth's surface.

→ The troposphere is also called " Region of change".

→ At a certain height called the critical height above troposphere the temperature remains constant for narrow region and then Increases afterwards.

→ The region between the top of troposphere and the beginning of stratosphere is called "Tropopause".

→ The Region between 20km to 70km above the earth's surface is called "Region of calm" (or) "stratosphere".

Structure of Ionosphere :-

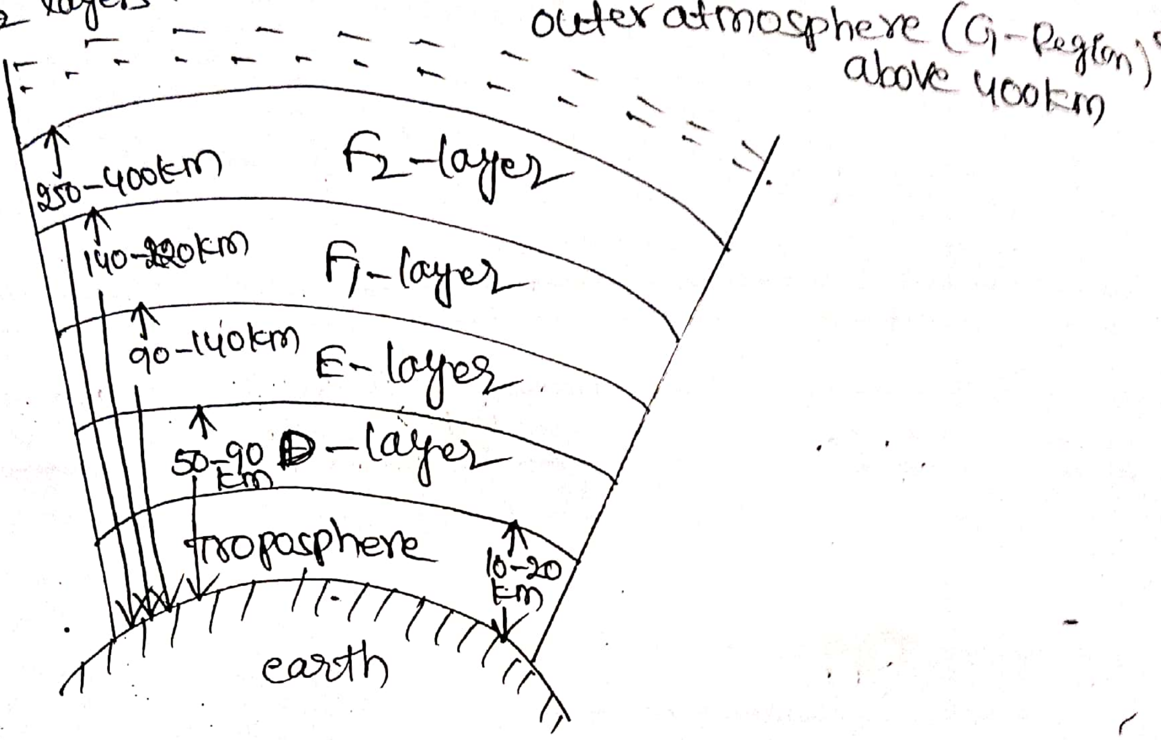
→ Ionosphere is the upper portion of the atmosphere of the earth.

→ It gets heated due to the large absorption of large energy radiated by the sun. After heating it get Ionized.

→ This Region is located about 70km above the earth surface and upto 400km.

→ There are different Variations in properties of the atmosphere such as temperature, pressure, density, composition etc.

→ Due to the Variation in these properties and the absorption of different Radiations by the Ionosphere, It becomes irregular distribution and thus four main layers namely D layer, E layer, F1 and F2 layers.



D-layer:- The D-layer is located about 50 to 90 km above the surface of earth and it is nearest layer to the earth's surface.

→ Its thickness is about 10km.

→ This layer is Ionized by photo Ionization of O_2 molecules.

→ The Ionic density about $400/cm^2$ and electron density of maximum value.

→ This layer reflect Very low frequency (VLF) and Low Frequency (LF) waves.

→ The critical frequency is about 100KHz. D-layer present at Day time only.

E-layer:- The E-layer is located about 90-140 KM above the earth surface.

→ Thickness is about 25 km.

→ This layer is Ionized by all gases by X-ray radiation takes place.

→ During night time its Ionization is weak.

→ The maximum electron density is about $4\times10^5/cm^3$ and is at height of 100 km.

→ It is useful for high frequency (HF) waves during day time.

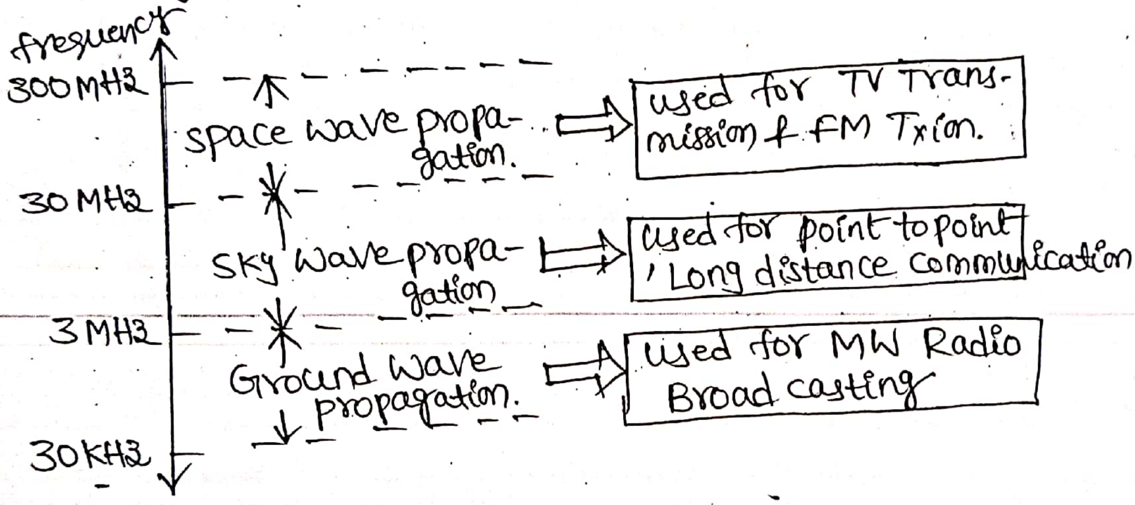
→ Critical frequency is about 3 to 5 MHz. It provides better Reception during night time.

F layer:- The F-layer is located at the height of 140 to 400km and it is mainly combination of F_1 layer (140 - 220km) and F_2 layer (250 to 400km). During night F_1-layer combines with F_2-layer and at height of 140-300 km, we get F layer.

- This layer only Ionized during day time aswell as night time.
- The maximum election density is 220km approximately
- critical frequency is 5 to 12 MHz.
- The F_1 layer reflects the high frequency waves.
- The F_2 layer reflects the high frequency Radio waves.

Modes of propagation:-

There are 3 different modes of propagation.
1) Ground wave propagation 2) Skywave propagation 3) Space-wave propagation.



Ground wave propagation:- [surface wave]

- The waves which are propagated near the earth's surface are called "ground waves".
- The frequency range of ground wave propagation is 300KHz to 3MHz.
- The ground wave propagation is possible when the Transmitting and Receiving antenna both are closed to the earth's surface
- This type of propagation is used for MW, Radio Broad casting.
- The ground waves are vertically polarized waves, It should require high power for Transmission.

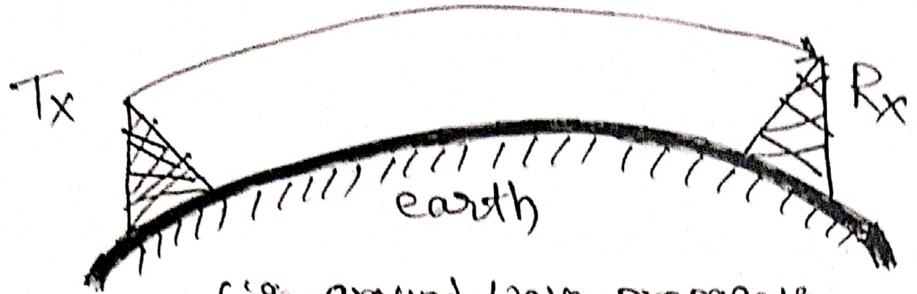


fig:- ground wave propagation.

→ The ground wave propagation is about LF and MF frequencies.

→ The ground wave is a vertically polarized wave that travels along the surface of the earth. For the ground wave propagation, vertical antennas are useful. If a horizontally polarized wave is propagated as ground wave, then the electric field of a wave gets short circuited due to conductivity of the earth. Hence the ground wave is always a vertically polarized wave. Hence, as the ground wave travels away from the transmitting antenna, it gets attenuated.

$$E = \frac{120\pi \, h_t \cdot h_r \cdot I_s}{\lambda d} \ V/m.$$

Where $120\pi = 377\,\Omega$ = Intrinsic impedance of free space.

h_t and h_r = Effective heights of the transmitting and receiving antennas respectively.

I_s = Antenna current

λ = wavelength.

d = Distance at a point from the transmitter.

Wave tilt :- Wave tilt is defined as the angle Normal to the ground wave and electric plane wave. Where the ground wave is vertically polarized.

Sky wave propagation :- (Iono-spheric propagation)

The skywaves are of practical importance for every long radio communications at medium and high frequencies. The sky wave propagation is about the frequency range of 3-30 MHz.

→ Sky wave propagation is also called as Ionospheric Propagation.

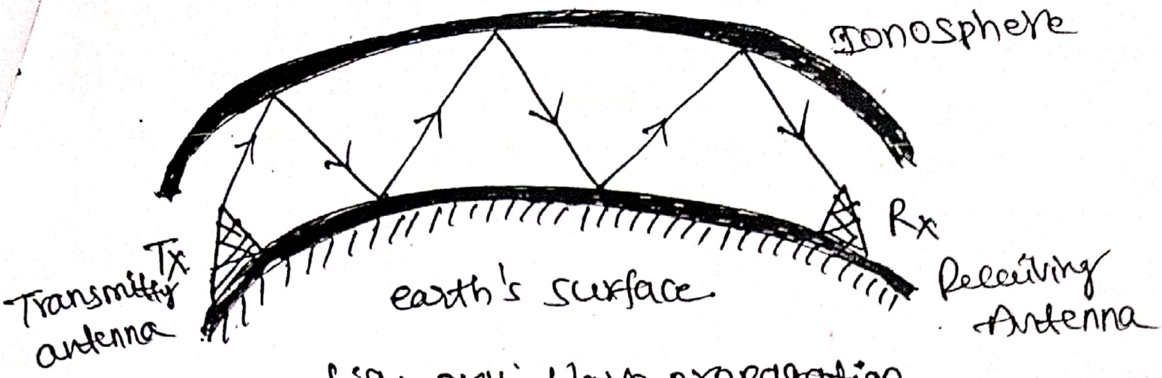


fig:- Sky - Wave propagation

→ this mode is used in HF band international broad casting.
→ In this mode the EM waves transmitted by the transmitting antenna reach the receiving antenna.
→ At very long distance away from transmitting antenna, after the reflection from the ionized region. in the upper part of the atmosphere of the earth.
→ This part is called ionosphere and it is located above earth's surface at about 70km to 400km height.
→ using the sky wave propagation, a long distance point to point communication is possible and hence it is also called point to point propagation (or) point to point communication.
→ The sky wave propagation is also called as iono spheric propagation. Because the waves reach the receiver after reflecting from earth to Iono sphere.
→ EM waves directed in upword at some angle from earth surface are called as sky waves.
→ sky wave propagation is used for long distance communication.
→ Iono sphere is the upper portion of atmosphere between 50km to 350km about the earth.

Maximum usable frequency (MUF)

→ It is defined as the sky waves are sent by the maximum frequencies at some incidence angles towards the Ionosphere then these waves will again reflected back to the earth by Ionospheric Layers. Maximum usable frequency exists in sky wave propagation. $f_{MUF} = \frac{f_{cr}}{\cos\phi_i}$ (or) $f_{MUF} = \sec\phi_i f_{cr}$

critical frequency :- [f_{cr}]

critical frequency is defined as the highest frequency that finally effect be reflected back to the earth by a particular layer for a vertical Incidence. It is denoted by 'f_{cr}'

→ The critical frequency is different for different layers.

$$f_{cr} = \sqrt{81 N_{max}} = 9\sqrt{N_{max}}$$

Where N_{max} is the no. of electrons expressed per cubic meter and the critical frequency f_{cr} is in Mega Hertz.

Mechanism of Reflection and Refraction :-

→ Basically the Reflection and Refraction of the Radio waves is the function of the frequency of the wave.

→ for very low frequencies the wavelengths are larger and for very high frequencies the wavelengths are very small.

(i) Reflection at Low Frequencies :-

The wavelength for low frequencies is very large, thus the changes in the Ionization density are considerably large the layer of Ionosphere acts as a dielectric having reflection coefficient given by

$$R_1 = \frac{\cos\theta - \sqrt{\left(\epsilon_r' + \frac{\sigma}{j\omega\epsilon_0}\right) - \sin^2\theta}}{\cos\theta + \sqrt{\left(\epsilon' + \frac{\sigma}{j\omega\epsilon_0}\right) - \sin^2\theta}}$$

$$R_V = \frac{\left(\epsilon_r' + \frac{\sigma}{j\omega\epsilon_0}\right)\cos\theta - \sqrt{\left(\epsilon_r' + \frac{\sigma}{j\omega\epsilon_0}\right) - \sin^2\theta}}{\left(\epsilon_r' + \frac{\sigma}{j\omega\epsilon_0}\right)\cos\theta + \sqrt{\left(\epsilon_r' + \frac{\sigma}{j\omega\epsilon_0}\right) - \sin^2\theta}}$$

Where $\epsilon_r' = 1 - \frac{Ne^2}{m\epsilon_0(\omega_0^2 + \omega^2)}$ and $\sigma = \frac{Ne^2\omega_0}{m(\omega_0^2 + \omega^2)}$

Where N = electron density $/m^3$

e = electron charge $= 1.6 \times 10^{-19}$ C , m = mass of electron $= 9 \times 10^{-31}$ kg

ω_0 = frequency of angular $= 2\pi f_0$

That Finally we concludes that, at Lower frequencies the reflection coefficient depends upon the
* Frequency of wave
* Angle of Incidence of wave
* polarization of wave (horizontal or vertical)

ii) Refraction at High frequencies:-

→ At high frequencies the wavelength is very small. The analysis at high frequencies carried out using ray optics if the change in the phase velocity is within short wavelength is very small.

The phase velocity of the wave within a medium is given by

$$V_p = \frac{1}{\sqrt{\mu\epsilon}} = \frac{1}{\sqrt{\mu_0\mu_r\epsilon_0\epsilon_r}} = \frac{1}{\sqrt{\mu_0\epsilon_0}} \times \frac{1}{\sqrt{\mu_r\epsilon_r}} \rightarrow (1)$$

$$\Rightarrow \boxed{V_p = \frac{c}{\sqrt{\mu_r\epsilon_r}}} \quad \text{where } c = \frac{1}{\sqrt{\mu_0\epsilon_0}} = \text{Velocity of light in freespace}$$

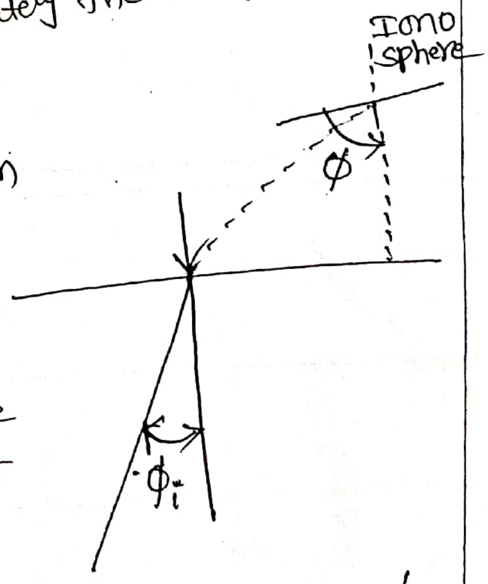
Assume that the permeability of the Ionosphere is unchanged due to the presence of electrons, hence $\boxed{\mu_r = 1}$.

$$\therefore \boxed{V_p = \frac{c}{\sqrt{\epsilon_r}}} \rightarrow (2)$$

From equation (2) It is clear that the phase velocity depends on ϵ_r.

→ The phase velocity also depends on electron density N.

→ Hence for the high frequency, the wavelength is shorter so that the change in electron density is small and ultimately the changes in phase velocity are smaller.



Application of Snell's Law

→ Now consider the wave is Incident on the lower edge of Ionosphere without any Reflection

→ But as the wave penetrates the Ionosphere, the wave follows the curved path and it moves away from region of greater electron density.

→ Thus at any point on the curved path the angle between the path and the normal at that point can be obtained by using the Snell's Law.

According to Snell's Law

$$\sin\phi_i = n\sin\phi \quad (\text{or}) \quad n = \frac{\sin\phi_i}{\sin\phi}.$$

(n = refractive Index.)

$$\Rightarrow \sin\phi = \frac{\sin\phi_i}{n}$$

→ The refractive Index of medium is given by

$$n = \frac{\text{Velocity of Light in free space}}{\text{phase Velocity in the medium}} = \frac{c}{V_p}$$

$$\therefore n = \frac{c}{\frac{c}{\sqrt{\epsilon_r}}} = \sqrt{\epsilon_r} \qquad \left(\because \text{ from eq } (2) \quad V_p = \frac{c}{\sqrt{\epsilon_r}}\right)$$

$$\boxed{n = \sqrt{\epsilon_r}}$$

Where

$$\epsilon_r = \left(1 - \frac{Ne^2}{\epsilon_0 m \omega^2}\right) \rightarrow (4)$$

for electron $m = 9 \times 10^{-31}$ kg = mass of electron

$\epsilon_0 = 8.854 \times 10^{-12}$ F/m

e = charge of electron = 1.6×10^{-19} C

$$\epsilon_r = \left(1 - \frac{N(1.6 \times 10^{-19})^2}{8.854 \times 10^{-12} \times 9 \times 10^{-31} \times (2\pi f)^2}\right)$$

$$\epsilon_r = 1 - \frac{81N}{f^2} \qquad \text{where } \omega = 2\pi f$$

$$\therefore \text{The Refractive Index } \boxed{n = \sqrt{\epsilon_r} = \sqrt{1 - \frac{81N}{f^2}}} \rightarrow (5)$$

Since if $\phi_i = 0$, then $\sin\phi_i = n \sin\phi$.

$$\sin 0 = n \sin\phi$$

$$n = 0.$$

$$\therefore \sqrt{1 - \frac{81N}{f^2}} = 0 \Rightarrow 1 - \frac{81N_{max}}{f_{cr}^2} = 0$$

$$\Rightarrow \frac{81N_{max}}{f_{cr}^2} = 1$$

$$81N_{max} = f_{cr}^2$$

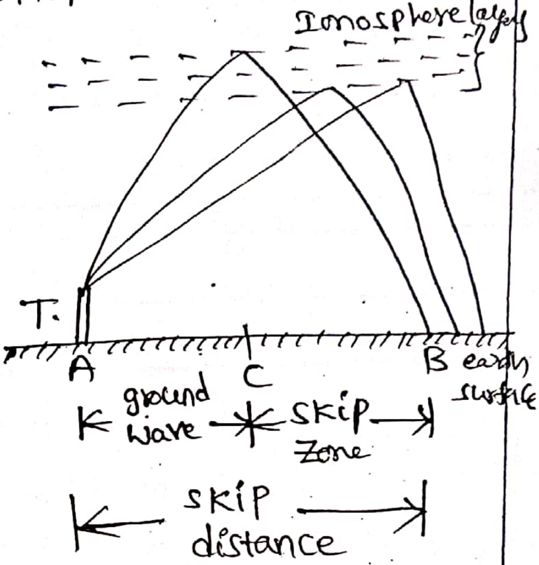
At $\phi_i = 0$, the critical frequency exists.

$$\boxed{f_{cr} = \sqrt{81N_{max}}} \rightarrow \text{critical frequency}$$

Skip distance:- (d_{skip})

The skip distance is the shortest distance from the transmitter, measured along surface of the earth, at which a sky-wave of fixed frequency will return back from Ionosphere to earth.

For a given frequency $f = f_{MUF}$, the skip distance can be calculated as follows.



$$f_{MUF} = f_{cr}\sqrt{1+\left(\frac{D_{skip}}{2h}\right)^2}$$

$$\Rightarrow \frac{f_{MUF}}{f_{cr}} = \sqrt{1+\left(\frac{D_{skip}}{2h}\right)^2}$$

$$\Rightarrow \left(\frac{f_{MUF}}{f_{cr}}\right)^2 = 1+\left(\frac{D_{skip}}{2h}\right)^2$$

$$\Rightarrow \left(\frac{f_{MUF}}{f_{cr}}\right)^2 - 1 = \left(\frac{D_{skip}}{2h}\right)^2$$

$$\therefore \frac{D_{skip}}{2h} = \sqrt{\left(\frac{f_{MUF}}{f_{cr}}\right)^2 - 1}$$

$$\boxed{D_{skip} = 2h\sqrt{\left(\frac{f_{MUF}}{f_{cr}}\right)^2 - 1}}$$

Fading:-

Fading is defined as the fluctuation in the received signal strength at the Receiver (or) a random variation in the Received signal.

Fading may be classified interms of duration of variation in signal strength as
- → Rapid fluctuations
- → short term fluctuations
- → Long term fluctuations.

The various types of fading are as follows.

1. selective fading
2. Absorption fading
3. Interference fading
4. polarization fading
5. Skip fading.

→ The fading is caused due to interference between two wav[es] of different path lengths.

→ Fading is caused due to variations in height and density of the ionizing in different layers.

1. Selective fadings:- It is more dominant at high frequencies for which sky wave propagation is used. The selective fading produces serious distortion of modulated signal. The fading frequen[cy] selective, hence the portion or frequency also be faded independent.

2. Absorption fading :- This type of fading occurs due to the var[i]ations of single strength with the different amount of absorption of waves absorbed by the transmitting medium.

3. Interference fading :- It is the fading produced because of upper and lower rays of the sky wave interfering with each other. This is the most serious fading.

4. Polarization fading :- When the sky wave reaches after the reflection, the state of polarization is changing. The polarization of sky wave coming down changes because of the superposition ~~and~~ of the ordinary and extra-ordinary waves, which are oppositely polarized. Thus polarization of wave changes.

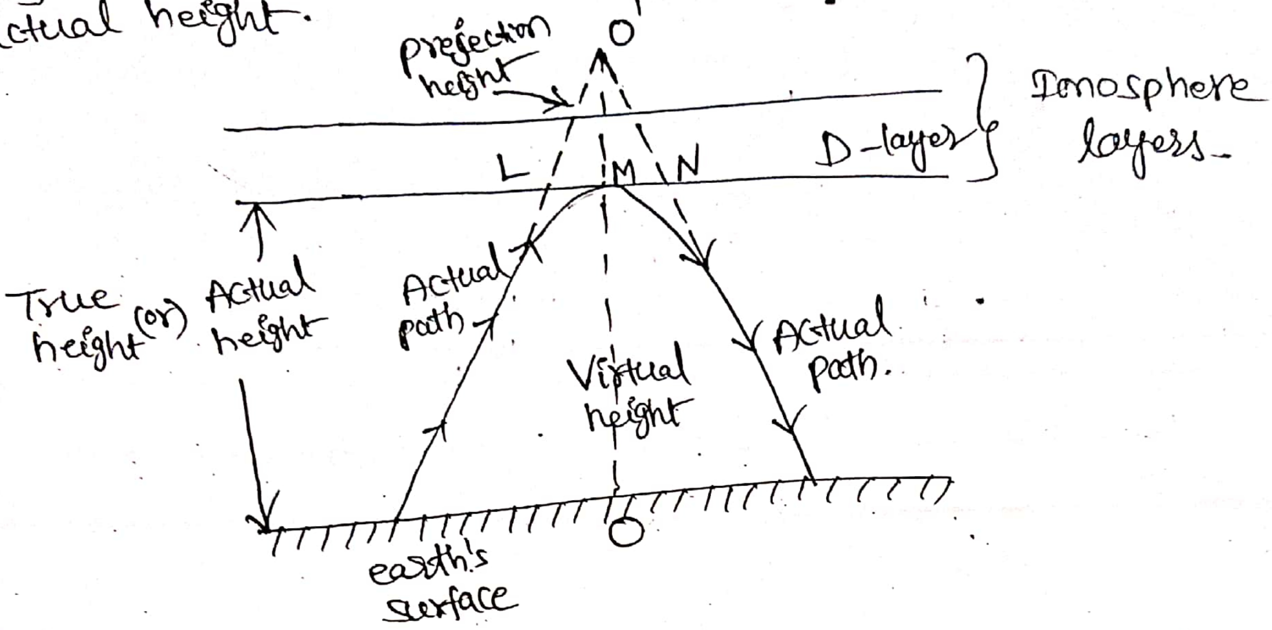
5. Skip fading:- At distances near the skip zone, the fading occurs, which is called skip fading.

→ To minimize the skip fading, the most common method is to use automatic voltage control and Automatic Gain control (AVC or AGC)

Actual height, Virtual height:-

Actual height:- The height at which the wave bending down to the earth surface. It is called as Actual height (or) True height

Virtual height :- It is defined as the height to which, a short pulse of energy Transmitt along Vertically upwards and a wave travelling with the speed of light. The Virtual height is greater than actual height.

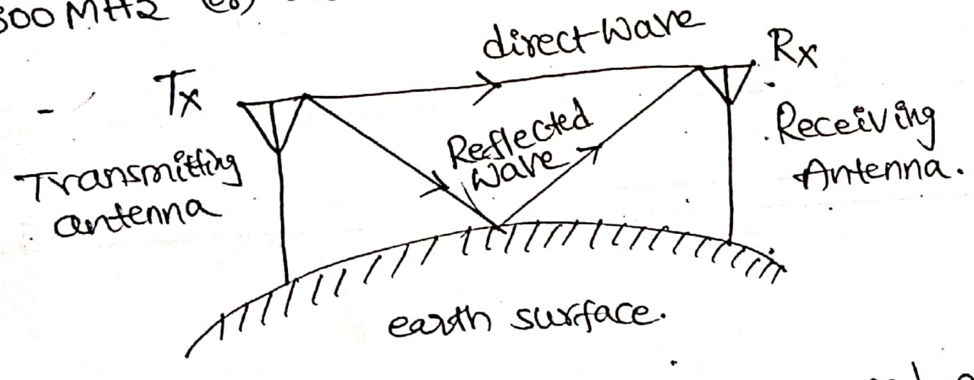


Space Wave propagation :-

→ The radio waves which are having high frequencies are called as space waves.

→ space waves are the combination of direct wave and Reflected wave.

→ The frequency range of space wave propagation is about 30MHz to 300MHz (or) above 30MHz frequencies.



→ The space wave propagation is composed of direct wave propagation and reflected wave propagation.

→ The space wave propagation is through troposphere, hence such propagation is limited to few hundreds of kilometers.

→ The space wave propagation propagates through the frequency Bands of HF and VHF frequency Bands.

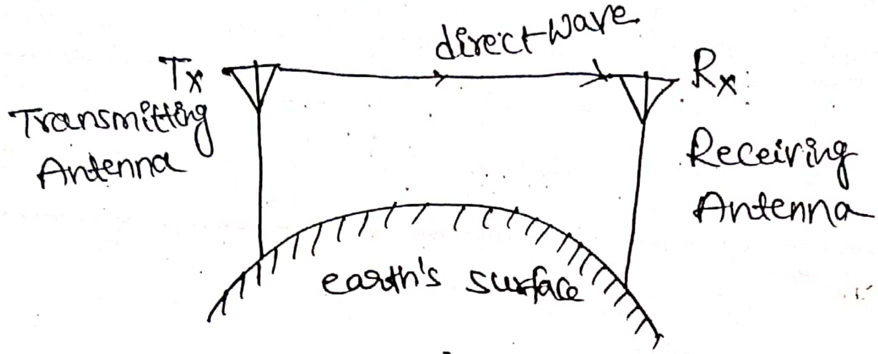
LOS Propagation :- [Radio Horizon] :-

↳ line of sight.

→ The LOS propagation is also called as "Direct Wave propagation"

→ LOS propagation is a characteristic of electromagnetic radiation (or) Accoustic Wave Radiation.

→ The frequency Range of LOS propagation is above 30MHz



→ The Transmitter and Receiver are placed within the line of sight distance.

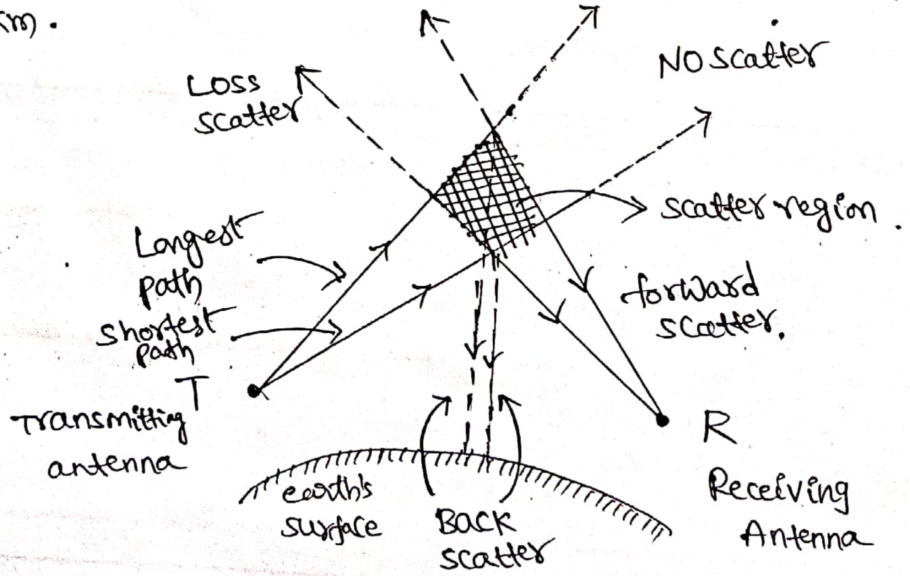
→ The waves are travelling in a direct path from transmitter to Receiver.

→ The Refraction takesplace in the LOS propagation.

Tropospheric scattering propagation :- (forward scattering Propagation).

→ The tropospheric propagation (or) tropospheric scattering propagation is nothing but the propagation of VHF, UHF and microwave signal beyond the horizon (LOS).

→ The troposphere is nearest portion of atmosphere about 15Km.



Tropospheric scattering propagation is also called as forward scatter propagation. (8)

→ The scattering propagation depends on two accepts. (i) Ionospheric propagation (ii) out come of scattering layers from troposphere.

3. → The Tropospheric scatter propagation occurs due to air-turbulance, irregular and discontinuities in the atmosphere, to divert a small fraction of Radio energy transmitted towards Receiving antenna.

→ Generally the radio waves diffract (or) bend along the curved surface of earth.

→ Due to such disturbances & discontinuities there is a small irregularity in the refractive Index.

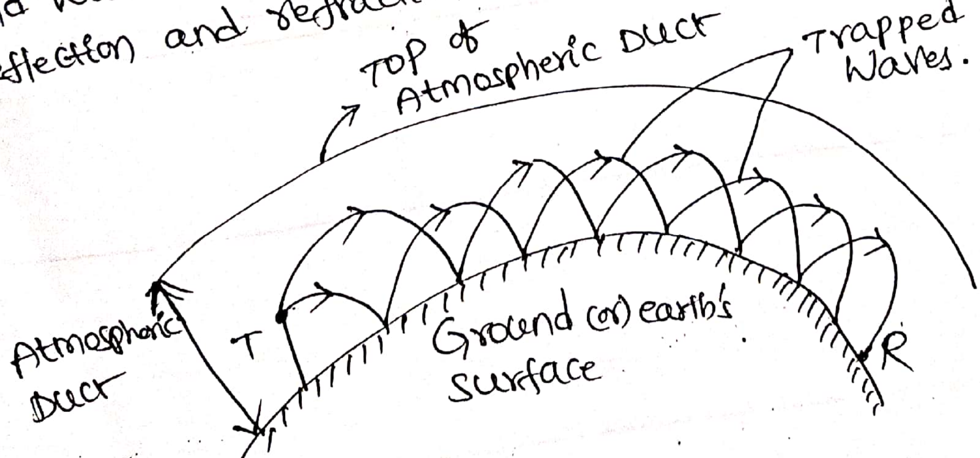
Duct propagation :- [Super Refraction]

→ The Duct is a leaky waveguide through which E.M waves move in the air by successive reflection and refraction. when the signal move through different layers, signal may suffer from some Loss.

→ The VHF, UHF and Micro Wave frequencies, which cannot propagate along earth surface and cannot reflect from Ionosphere.

→ In the air region there are different temperature conditions and water vapours states besides these conditions scattering, reflection and refraction combinely called as "Duct propagation".

→



T = Transmitting antenna

R = Receiving Antenna

→ In the Air Region $\frac{d\mu_m}{dh}$ (or) $\frac{dM}{dh}$ is negative. So the height is Increased and μ_m is decreased. If the height is decreased then μ_m is Increased.

→ The energy originating from air region, the electromagnetic Waves are propagating around the curved surfaces.

→ In the troposphere dielectric constant is greater than unity

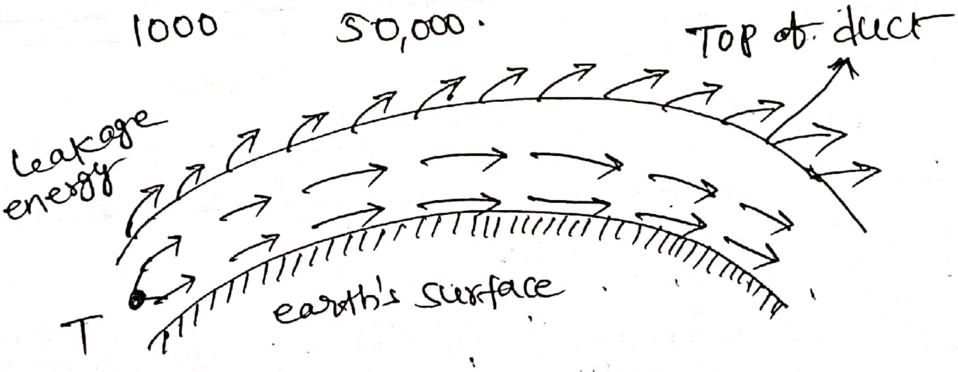
→ In the Normal atmosphere (or) standard atmosphere the dielectric constant is decreased With a height Value of unity at which the air density is zero.

→ Finally the Duct effect can be removed by exceeding the maximum Wavelength.

It is given by $\lambda_{max} = 2.5\, h_d \sqrt{\Delta\mu_m \times 10^{-6}}$

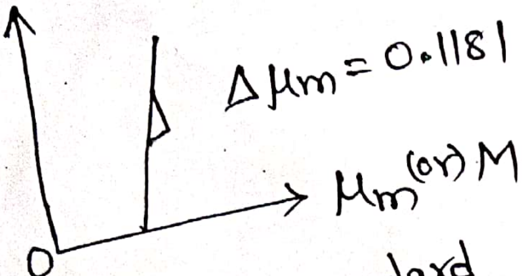
$\mu_m = M$ = modified refractive Index.
h_d = height of duct
λ_{max} = maximum Wavelength.

λ_{max}	h_d (m)
1	500
10	2300
100	10,700
1000	50,000.

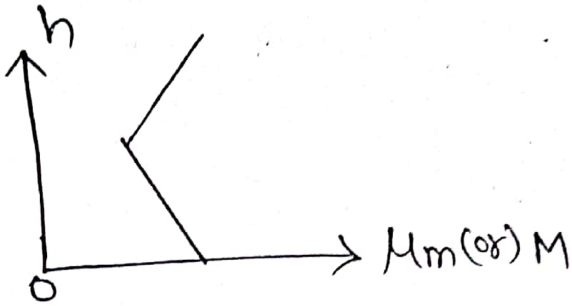


characteristics of M-curves :-

(a) ground standard atmosphere
(b) Refraction at low height
(c) Ground based duct
(d) elevation duct.



(a) ground standard atmosphere.

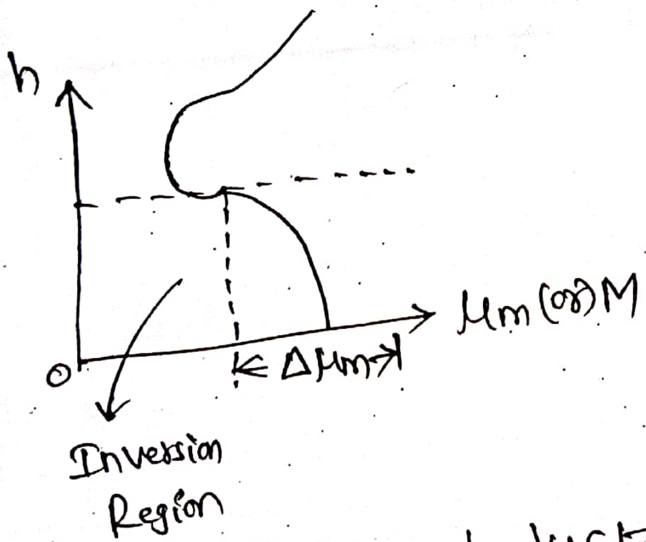


(b) Refraction at low height

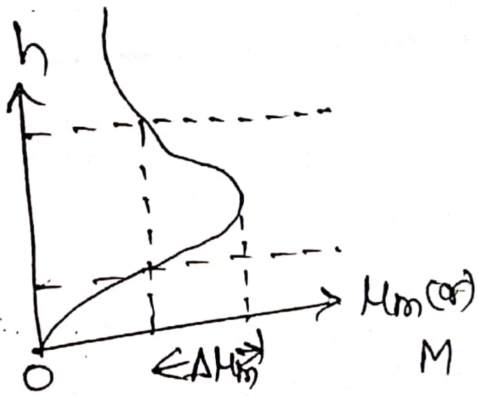
where

$\mu_m = M =$ modified Refractive Index

$h =$ height of duct

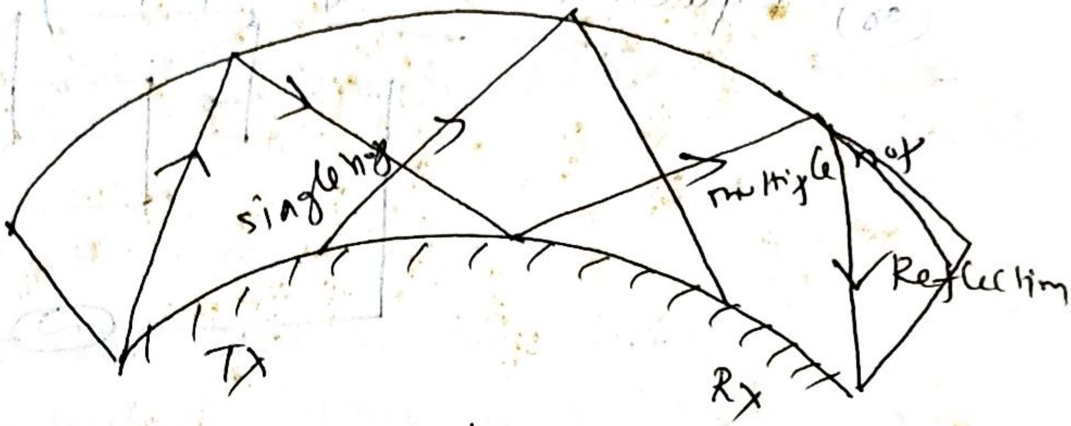


(c) ground Based duct



(d) Elevation Duct

Sky wave propagation :-



propagation over long distance an order of thousand kilometers is not possible by ground wave and space wave propagation.

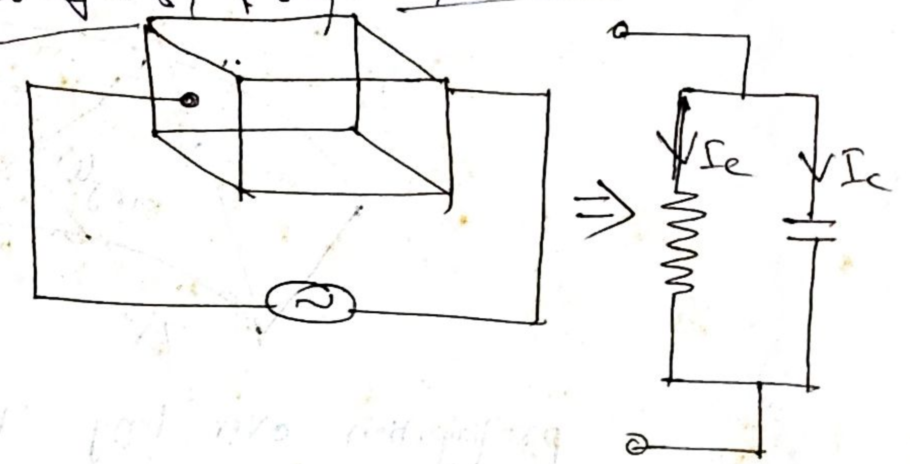
sky wave are reflected from some of ionization layers of ionosphere and return back to earth in single hop (or) multiple hops. maximum range of communication using single hop is approximately 4000 km. By using the multiple-hops communication we can cover whole world. So, by using ionosphere we can cover any distance around the earth as shown in figure.

propagation of Radio waves through the Ionosphere

(or) Expression for the Refractive index of the Ionosphere.

(or) Mechanism of Reflection & Refraction

(or) Reflection & law of high frequency.



In an ionized medium having free electrons and ions when the radio wave pass through, it set these char-ged particles in motion. The radio waves passes through the ionosphere is influenced by the electrons only and the electrons of ionosphere get motion due to the electric field of radio waves. These electrons vibrate simultaneously parallel to the electric field of the radio wave and these represent a AC current proportional to the velocity of vibration that current will be indu-ctive type. The actual current flowing through a volume of the space in the ionosphere consists usually capaci-ve current which leads the voltage by 90° and hence electron current subtracted from the capacitive current.

Thus free electron in space decrease the current and so the dielectric constant of the space is also reduced below the value that would be in the absence of electron. So, this reduction causes the path of radio waves to bend toward earth i.e from high electron density to lower density.

Let an electric field of volume

$$E = E_m \sin \omega t \quad V/m$$

is acting across a cubic metre of space in the ionosphere.

Force exerted by electron field on each electron is given by

$$F = -eE \quad (N)$$

Let us assume that there is no collision, then the electron will have velocity v m/sec. in the direction opposite to the field.

$$\text{force} = \text{mass} \times \text{Acceleration}$$

$$-Ee = m \frac{dv}{dt}$$

$$\frac{dv}{dt} = -\frac{eE}{m} \quad (or) \quad dv = -\frac{eE}{m} dt$$

integrating both sides, we get

$$v = \int -\frac{e E_m \sin \omega t}{m} dt$$

$$v = \frac{e}{m\omega} E_m \cos \omega t$$

If cubic have the N the number of electrons per cubic metre, then

$$i_e = -Nev \quad A/m^2$$

$$i_c = -\left(\frac{Ne^2}{m\omega}\right) E_m \cos \omega t \quad (A/m^2)$$

which shows that i_e lags behind the electric field by 90°, Beside this Inductive (or) conduction current

displacement current (or) Capacitive current (I_c)

$$I_c = \frac{\partial D}{\partial t} = \frac{d}{dt}(K_0 E) = K_0 \frac{d}{dt}(E_m \sin \omega t)$$

$$D = \varepsilon_0 E = K_0 E$$

$$I_c = \varepsilon_0 \omega E_m \cos \omega t$$

The total current I that flow through a cubic metre of ionized medium is,

$$i = i_c + i_e = K_0 \omega E_m \cos \omega t - \frac{Ne^2}{m\omega} E_m \cos \omega t$$

$$= \omega E_m \cos \omega t \left[K_0 - \frac{Ne^2}{m\omega^2} \right]$$

$$i = \omega E_m \cos \omega t K$$

K = effective Dielectric constant

$$K = K_0 - \frac{Ne^2}{m\omega^2} = K_0 \left[1 - \frac{Ne^2}{m\omega^2 K_0} \right]$$

Relative dielectric constant $K_r = \frac{K}{K_0} = 1 - \frac{Ne^2}{m\omega^2 K_0}$

Thus the relative refractive index of the ionosphere w.r.t Vaccum

$$\mu = \sqrt{K_r} = \frac{\sqrt{K}}{\sqrt{K_0}} = \sqrt{1 - \frac{Ne^2}{m\omega^2 K_0}}$$

$$v = \frac{c}{\sqrt{K_r}} = \frac{c}{\mu}$$

$m = 9.107 \times 10^{-31}$ kg $e = 1.602 \times 10^{-19}$ C

$K_0 = 8.854 \times 10^{-12}$ F/M $\omega = 2\pi f$

$$\boxed{\mu = \sqrt{1 - \frac{81 N}{f^2}}}$$

Where N — no of electrons per cubic meter (or) Ionic density

f — frequency in Hz

Radio wave bending by the Ionosphere

The bending of radio waves by the ionosphere can be easily understood by the refractive index.

$$\mu = \sqrt{K_r} = \sqrt{1 - \frac{81N}{f^2}}$$

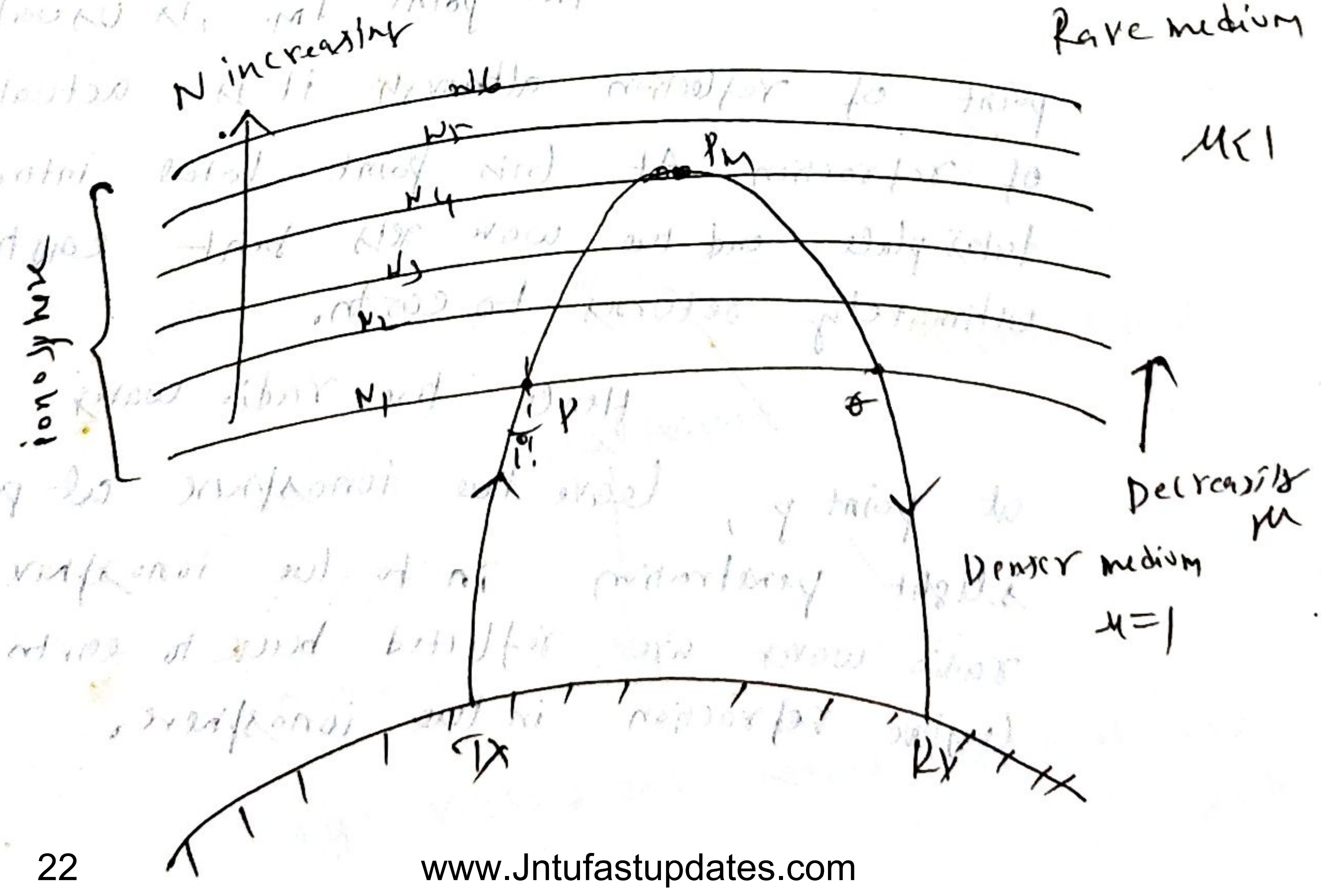
If $f^2 > 81N$, then $\mu < 1$ (real values)

If $f^2 < 81N$, then μ is imaginary which means under given conditions the radio waves are attenuated at this frequency and ionosphere is not able to transmit (or) bend the radio waves.

The bending of radio waves by the ionosphere is governed by Snell's law.

$$\mu = \frac{\sin i}{\sin r}$$

i – incident angle
r – refraction angle.



since $\mu < 1$ for the ionosphere, so $\sin i < \sin r$ i.e. angle of refraction will go on deviating from the normal as the wave will encounter rarer medium as shown in fig.

If successive layers of the ionosphere are of higher electron density i.e. $N_6 > N_5 > N_4 > N_3 > N_2 > N_1$ it means μ will go on decreasing and decreasing i.e $\mu_1 > \mu_2 > \mu_3 > \mu_4 > \mu_5 > \mu$. Thus a wave enters at say point p will be deviating more and more and a point will reach where it travels parallel to earth (at P_m). Here the angle of refraction is 90° and the point P_m is the highest point in the ionosphere reached by the radio wave.

$$\mu_M = \sin i_m$$

The point P_m, is usually called as point of reflection although it is actually a point of refraction. At this point total internal reflection takes place and the wave gets bent earthward and ultimately returns to earth.

Hence the radio waves once enter at point p, leave the ionosphere at point Q after slight penetration in to the ionosphere and thus radio waves are reflected back to earth after successive refraction in the ionosphere.

CRITICAL FREQUENCY (f_c):-

The critical frequency of ionized layer of the ionosphere can be defined as the critical frequency in the highest frequency which can be reflected back to earth by a particular layer at vertical incidence. critical frequency is different for different layers, it is denoted by f_c.

$$\mu = \frac{\sin i}{\sin r} = \sqrt{1 - \frac{81N}{f^2}}$$

By definition $i = 0$, $N = N_{max}$ & $f = f_c$

$$\frac{\sin 0}{\sin r} = \sqrt{1 - \frac{81N_{max}}{f_c^2}}$$

$$f_c = 9\sqrt{N_{max}}$$

where f_c - MHz
N_{max} - per cubic metre.

VIRTUAL HEIGHT

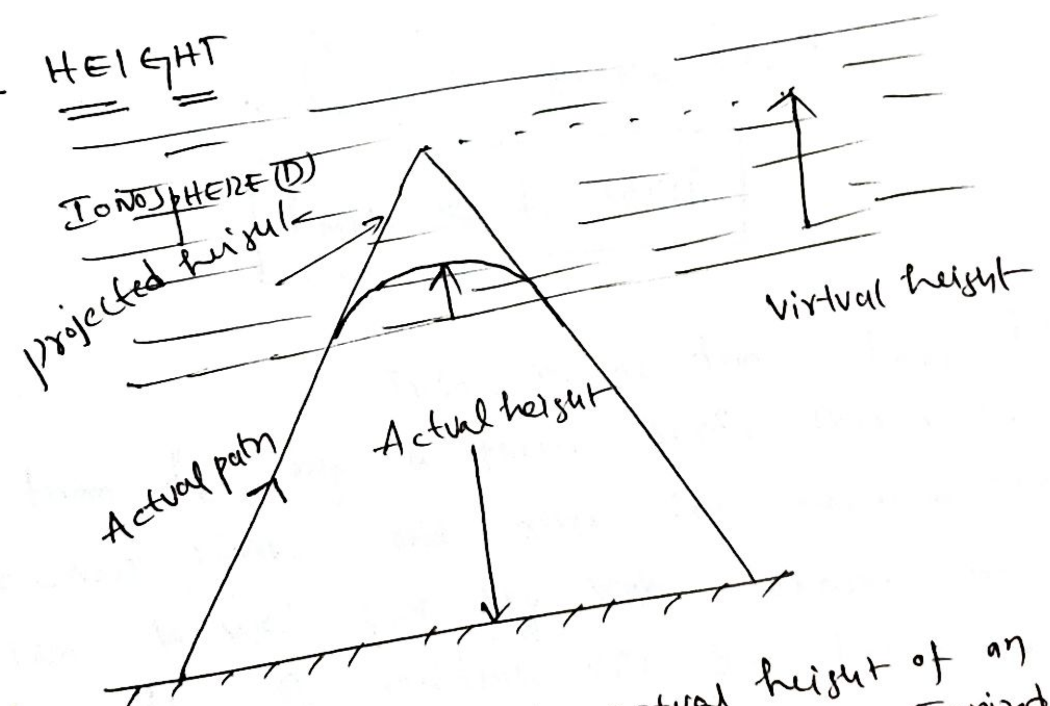


Fig: virtual and actual height of an Ionized layer.

MAXIMUM USABLE FREQUENCY (MUF)

critical frequency is the maximum frequency of the radio wave which is returned from a ionized layer at vertical incidence.

MUF :- ~~It~~ is the maximum possible value of frequency for which reflection takes place for a given distance of propagation, is called as the maximum usable frequency. for that distance, and for the given ionosphere layer.

For a sky wave to return to earth, angle of reflection i.e $(r) = 90^\circ$

$$\mu = \frac{\sin i}{\sin r|_{r=90^\circ}} = \sqrt{1 - \frac{81 N_m}{f_{muf}^2}}$$

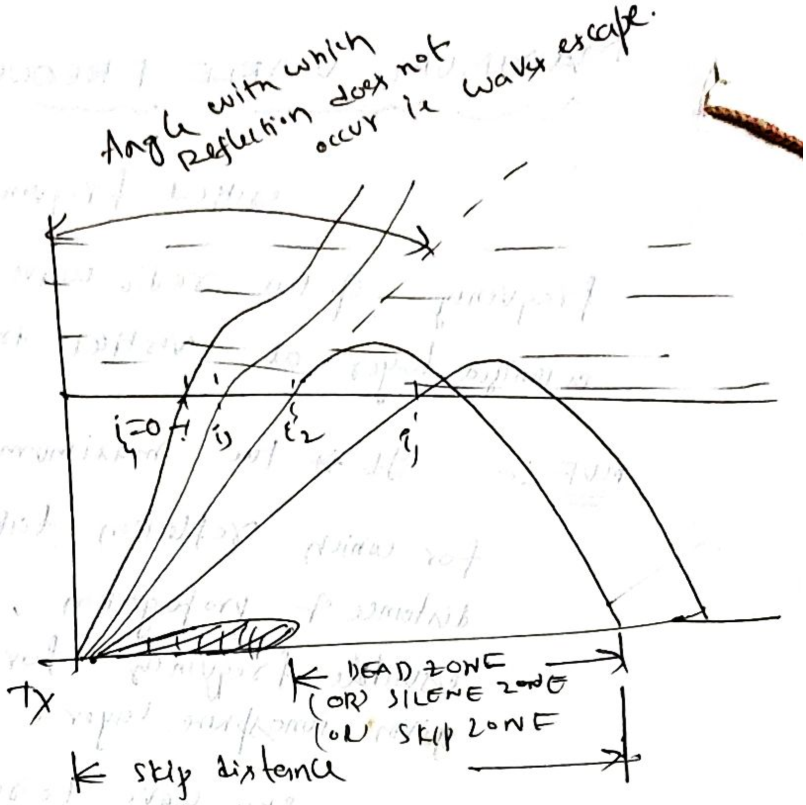
$$1 - \sin^2 i = \frac{81 N_m}{f_{muf}^2}$$

$$f_{muf}^2 = 81 N_m \sec^2 i$$

$$\boxed{f_{muf} \leq f_c \sec(i)}$$

This means that f_{muf} is greater than f_c by a factor $\sec i$. This is known as SECANT LAW and gives the maximum frequency which can be used for sky wave communication for a given angle of incidence (i) b/n two points on the earth.

SKIP DISTANCE



skip distance: The distance at which surface wave becomes negligible and the distance at which the first wave returns to earth from the ionospheric layer, there is a zone which is not covered by any wave. This is skip zone and distance across it is the skip distance.

The skip distance is the shortest distance from a transmitter, measured along the surface of the earth, at which a sky wave of fixed frequency will be returned to earth is known as skip distance.

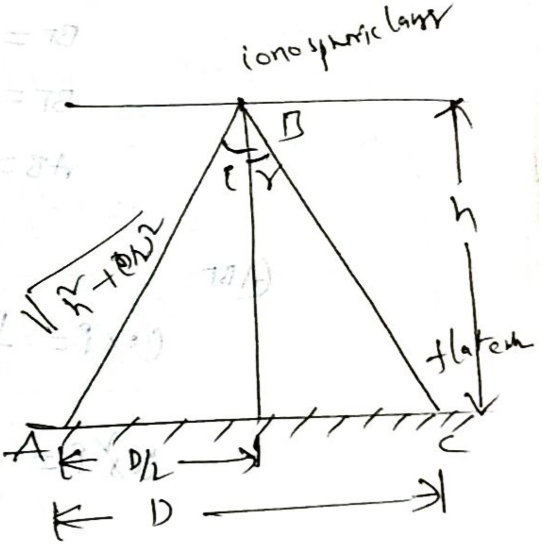
As the angle of incidence at the ionosphere decreases, the distance from the transmitter, at which the ray returns to ground first decreases. This behavior continues until eventually an angle of incidence is reached at which the distance becomes minimum. The minimum distance is called skip distance 'D'.

with further decrease in angle of incidence, the wave penetrates the layer and does not return to earth, infact, skip distance is the distance skipped over by the sky wave.

CALCULATION OF MUF & SKIP DISTANCE

case(i): when earth is flat:-

The ionized layer may be assumed to be thin layer with sharp ionization density gradient, which gives mirror like reflection of radio waves as shown in fig. For shorter distance the earth can be assumed to be flat.



From $\angle OAB$

$$\cos i = \frac{BO}{AB} = \frac{h}{\sqrt{h^2+(D/2)^2}}$$

The MUF for which the wave is to be reflected from the layer for returning to earth

$$\mu = \sin i = \sqrt{1 - \frac{81N_m}{f_{muf}^2}}$$

$$\cos^2 i = \frac{f_c^2}{f_{muf}^2}$$

h – height of layer

D – propagation distance (skip)

$$\frac{f_{muf}^2}{f_c^2} = \frac{4h^2+D^2}{4h^2}$$

$$\boxed{f_{muf} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}} \text{ (Hz)}$$

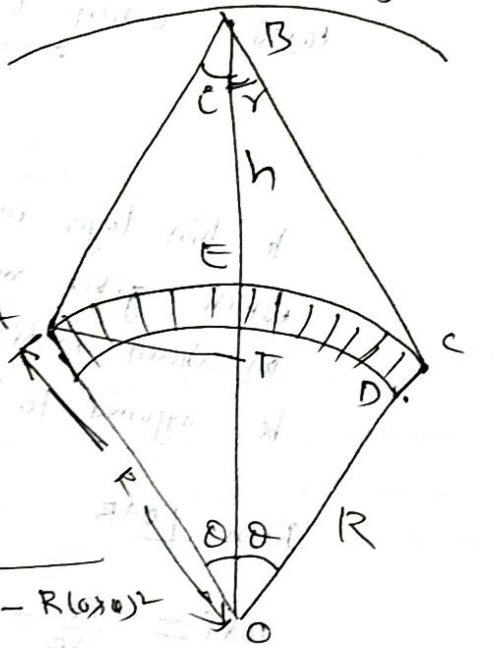
The skip distance

$$\left(\frac{D}{2h}\right)^2 = \frac{f_{muf}^2}{f_c^2} - 1$$

$$\boxed{D = 2h\sqrt{\left(\frac{f_{muf}}{f_c}\right)^2 - 1}} \text{ (m)}$$

Case ②: when earth is curved :-

It earth is curved, then reflecting region is consider to be concentric with earth as shown in the figure. In this figure transmitting wave leaves the transmitter tangentially to the earth. Let 2θ be the angle substanded by the transmission distance 'D' at the centre of the earth O then



Arc = Angle x radius

$$D = 2\theta \times R$$

$\triangle OAT$: $AT = R\sin\theta$

$OT = R\cos\theta$

$BT = OE + EB - OT$

$BT = R + h - R\cos\theta$

$AB = \sqrt{AT^2 + BT^2}$

$= \sqrt{(R\sin\theta)^2 + (R+h-R\cos\theta)^2}$

$\triangle ABT$

$$\cos i = \frac{BT}{AB} = \frac{h+R-R\cos\theta}{\sqrt{(R\sin\theta)^2 + (h+R-R\cos\theta)^2}}$$

$$\cos^2 i = \frac{f_c^2}{f_{muf}^2} = \frac{h+R-R\cos\theta}{(R\sin\theta)^2 + (h+R-R\cos\theta)^2}$$

The curvature of earth limits both MUF and skip distance D and the limit is obtain when waves leave the transmitter at a grazing angle ($\angle OAB = 90°$)

Thus when D is maximum, θ is maximum

$$\cos\theta = \frac{OA}{OB} = \frac{R}{R+h}$$

However actual value of 'θ' is very small,

$$\cos\theta = \frac{R}{R(1+\frac{h}{R})} = (1+\frac{h}{R})^{-1}$$

$$\cos\theta = 1 - \frac{h}{R} \quad \text{Because } \frac{h}{R} << 1$$

$$1 - 2\sin^2\frac{\theta}{2} = 1 - \frac{h}{R}$$

$$1-2\left(\frac{\theta}{2}\right)^2 = 1-\frac{h}{R}$$

$$1-\frac{\theta^2}{2} = 1-\frac{h}{R}$$

$$\theta^2 = 2\frac{h}{R}$$

$$D^2 = 4R^2\theta^2 = 4R^2 \times \frac{2h}{R} = 8Rh$$

$$h = \frac{D^2}{8R}$$

$$\cos\theta = 1-\frac{D^2}{8R^2}$$ and as θ is small

$$\sin\theta = \theta = \frac{D}{2R}$$

$$\frac{f_c^2}{(f_{muf})_{max}^2} = \frac{h+R-R\left(1-\frac{D^2}{8R}\right)}{\left\{R^2 \cdot \frac{D^2}{4R^2} + \left[h+R-R\left[1-\frac{D^2}{8R}\right]\right]\right\}^2}$$

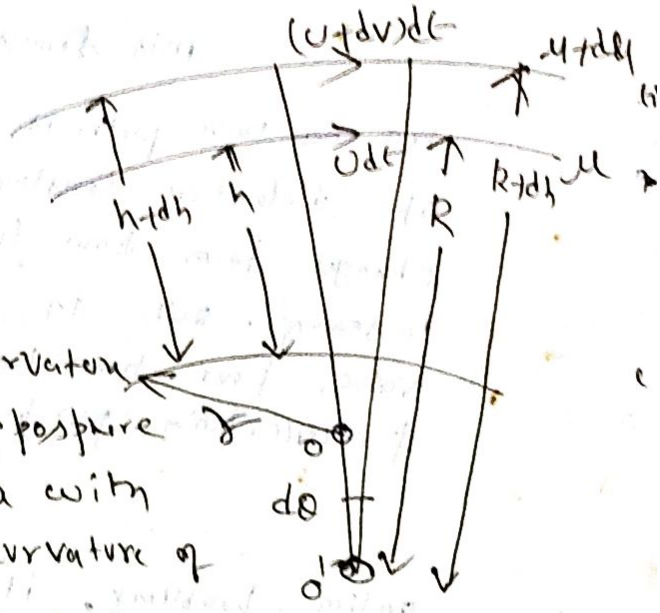
$$= \frac{\left[h+\frac{D^2}{8R}\right]^2}{\frac{D^2}{4}+\left[h+\frac{D^2}{8R}\right]^2}$$

$$(f_{muf})_{max} = \frac{\sqrt{\frac{D^2}{4}+\left[h+\frac{D^2}{8R}\right]^2}}{\sqrt{\left[h+\frac{D^2}{8R}\right]^2}}$$

$$(D_{skip})_{max} = \sqrt{8hR}$$

$$D = 2\left(h+\frac{D^2}{8R}\right)\sqrt{\left(\frac{f_{muf}}{f_c}\right)^2_{max} - 1}$$

Effective Earth's Radius



Refraction of Radio waves in the troposphere.

Let us now derive a relation b/n the radius of curvature of the ray path in the troposphere & and charge of refractive index with height by assuming the curvature of the earth. Consider a radio wave which is travelling nearly horizontally in the troposphere and its path is bent into an arc by the variation of the refractive index with height as shown in fig.

v – velocity of propagation

h – Height above the earth

R – Radius of curvature of the ray path

r – Actual radius of earth.

$$d\theta = \frac{v\,dt}{R}$$ radius × angle = arc

$$R\,d\theta = v\,dt$$

$$(R+dh)\,d\theta = (v+dv)\,dt$$

$$dh\,d\theta = dv\,dt \quad (\text{or}) \quad \frac{d\theta}{dt} = \frac{dv}{dh}$$

$$v = \frac{c}{\sqrt{\epsilon_r}} = \frac{c}{\mu}$$

μ – refractive index at height h,

$$\frac{dv}{dh} = -\frac{c}{\mu^2}\frac{d\mu}{dh} = -\frac{v}{\mu}\frac{d\mu}{dh}$$

$$\boxed{\frac{dv}{dh} \simeq -v\frac{d\mu}{dh}} \quad (\because \mu \simeq 1)$$

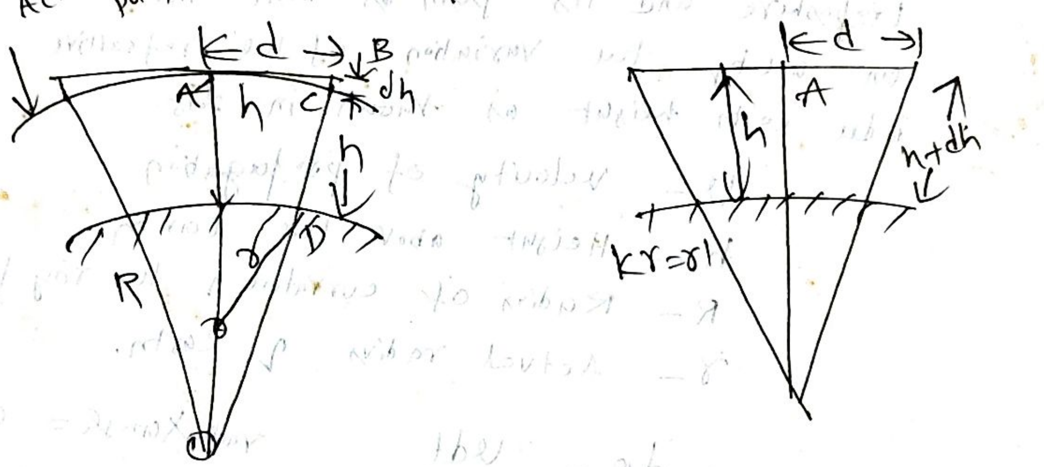
$$R = \frac{v\cdot dt}{d\theta} = \frac{v}{\frac{d\theta}{dt}} = \frac{v}{-v\frac{d\mu}{dh}}$$

$$\boxed{R = -\frac{dh}{d\mu}}$$

This shows that radius of curvature of the wave path is a function of the rate of change of dielectric constant (or) refractive index with height, changes from hour to hour, day to day and season to season. But in practice, however, an average value, four times the radius of the earth is used for calculation purposes.

In actual working with propagation problems, it is usually convenient to represent ray path as straight lines instead of being curved,

Actual Ray path kr – dielectric const.



$$d^2 + (r'+h)^2 = \{r'^2 + (h+dh)\}^2$$

$$d^2 = 2\delta h\,(r'+h) \quad \because \delta h^2 << 2\delta h\,(r'+h)$$

$$dh = d^2/2r'$$

$$DC = d^2/2R \qquad BD = \frac{d^2}{2r}$$

$$k = \frac{1}{1-\frac{r}{R}} \qquad BC = \delta h = BD - DC$$

$$dh = \frac{d^2}{2r} - d^2/2R$$

$$r' = \frac{r}{1-\frac{r}{R}} \qquad \frac{d^2}{2r'} = \frac{d^2}{2r} - \frac{d^2}{2R}$$

$$k = \frac{1}{1+r\frac{d\epsilon}{dh}} \qquad \frac{1}{r'} = \frac{1}{kr} = \frac{1}{r} - \frac{1}{R}$$

$$\frac{d\epsilon}{dh} = 0.046\times10^{-6}\ \text{per/mtr} \qquad k = r'/r$$

if radius of curvature R of ray path is equal to 4 times the actual earth's radius, then effective radius of earth is $\frac{4}{3}$ times the actual radius of earth

$$\frac{d\mu}{dh} = 0.040\times10^{-6} \text{ per/metre}$$ for standard atmosphere & $r = 6370km$.

$$k = \frac{1}{1-6.37\times10^{6}\times0.040\times10^{-6}}$$

$$k = \frac{4}{3} \Rightarrow k = \frac{r'}{r} = \frac{4}{3}.$$

Hence for a standard atmospheric refraction the effective earth's radius is $\frac{4}{3}$ times the actual earth's radius.

$$d = \sqrt{2r}\left[\sqrt{h_t}+\sqrt{h_r}\right]$$

So the modified eqn

$$d = \sqrt{2r'}\left[\sqrt{h_t}+\sqrt{h_r}\right]$$

$$= \sqrt{2\times\frac{4}{3}6370\times10^{3}}\left(\sqrt{h_t}+\sqrt{h_r}\right)$$

$$\boxed{d = 4.12\left[\sqrt{h_t}+\sqrt{h_r}\right] \text{ KM}}$$

This is the eqn for calculating radio horizon (or) line of sight distance. when h_t & h_r given in meters.

$$\boxed{d = 1.414\left[\sqrt{h_t}+\sqrt{h_t}\right] \text{ miles}}$$

when h_t & h_r in feets.

Effect of Earth's curvature on Tropospheric propagation

on the tropospheric propagation

the following two effects are introduced by the curvature of the earth.

(i) The difference in path lengths b/n direct and ground reflected waves is reduced as the point of reflection on the ground is raised. As a result it tends to reduce the signal strength at receiving point.

(ii) Further, since the reflection at the ground takes place at a spherical point rather than a flat point and hence the reflected ray becomes divergent which results in weaker at receiving point. this tends to increase the field strength at the receiving points of the total space wave