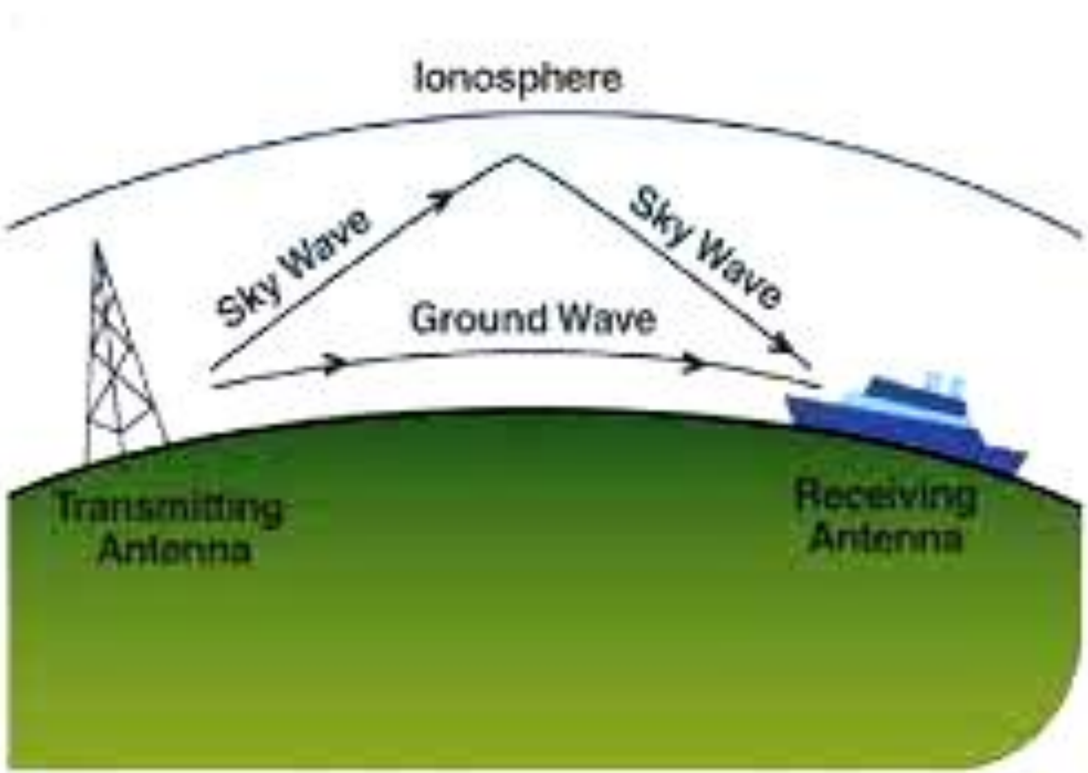
7REC02 Antennas and Propagation



Unit – 5

Wave Propagation

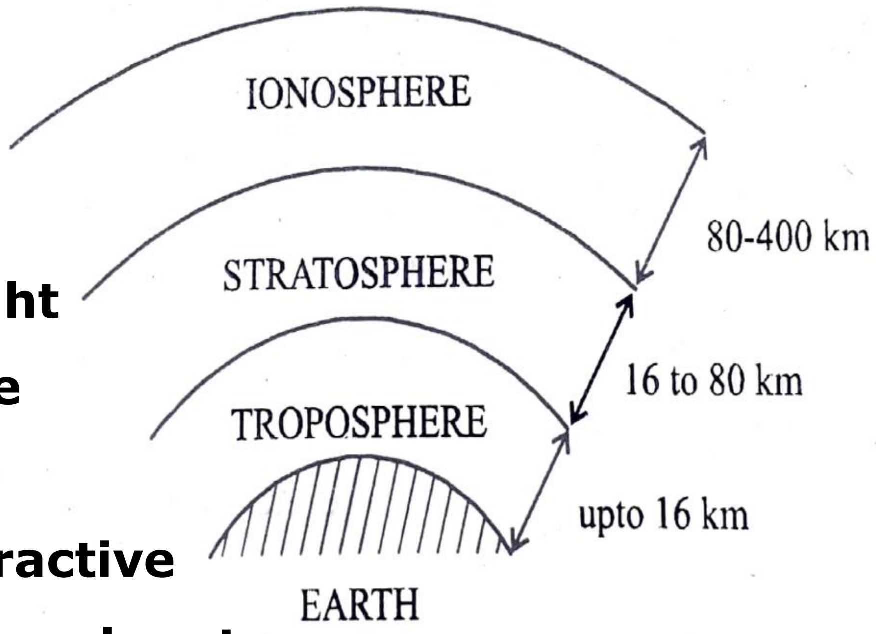
Syllabus

- **Factors involved in propagation of radio waves**
- **Ground wave propagation**
  - **Reflection of waves by the surface of the earth**
- **Space wave propagation**
  - **atmospheric effect in space wave propagation**
- **General picture of the ionosphere and its effect on radio waves**
- **Mechanism by which ionosphere affects radio wave propagation**
- **Refraction and Reflection of sky waves by the ionosphere**
- **Ray path, skip distance and maximum usable frequency**

Radio wave propagation

Wave propagation : study of signal path between two points

- path depends on atmosphere medium under wireless communication
- signal strength depends up on atmosphere conditions, frequency of operation and type of propagation
- atmosphere medium above the earth surface is
- medium ranging up to 80Km is not uniform throughout day and night
- varies abruptly due to temperature variation and wind condition
- Ionosphere is almost uniform (refractive index gradient remains constant) throgh out
- hence used for regular communication



Radio wave propagation contd.

Factors involved in propagation

Following parameters to be considered for satisfactory wave propagation

- **The propagation characteristics**
- **type of propagation concerned**
- **structure and properties of propagation media**

Different ways of propagation

- **Ground wave propagation or surface wave propagation**
- **Sky wave propagation**
- **Space wave propagation**

Radio wave propagation contd.

Factors that affect propagation

- Earth's characteristics in terms of
    - conductivity, permittivity (ability of material to store energy)
    - permeability (ability of material to support the formation of magnetic field)
- Frequency of operation
- polarization of transmitting antenna
- height of the transmitting antenna
- transmitter power
- curvature of the earth
- obstacles between the transmitter and receiver
- electrical characteristics of the atmosphere in tropospheric region
- moisture content in the troposphere

Radio wave propagation contd.

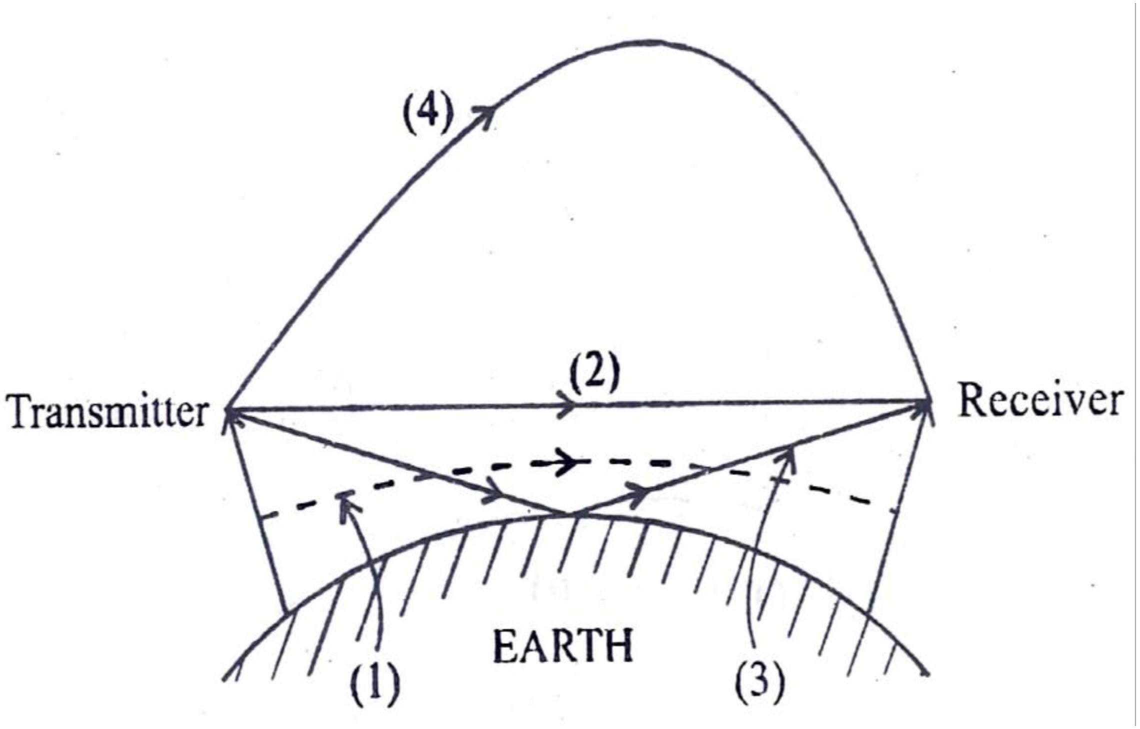
Factors that affect propagation

- characteristics of the ionosphere
- Earth's magnetic field
- refraction index of troposphere and ionosphere
- permittivity of the troposphere and the ionospheric regions
- distance between the transmitter and receiver
- roughness of the earth
- type of earth (hilly terrain, forest, sea water or river water)

Radio wave propagation contd.

Ground (Surface) wave propagation (1)

- **exists when EM wave is radiated close to the surface of the earth**
- **wave is guided by the presence of the ground**
- **low frequency range (up to 300 KHz)**



Radio wave propagation contd.

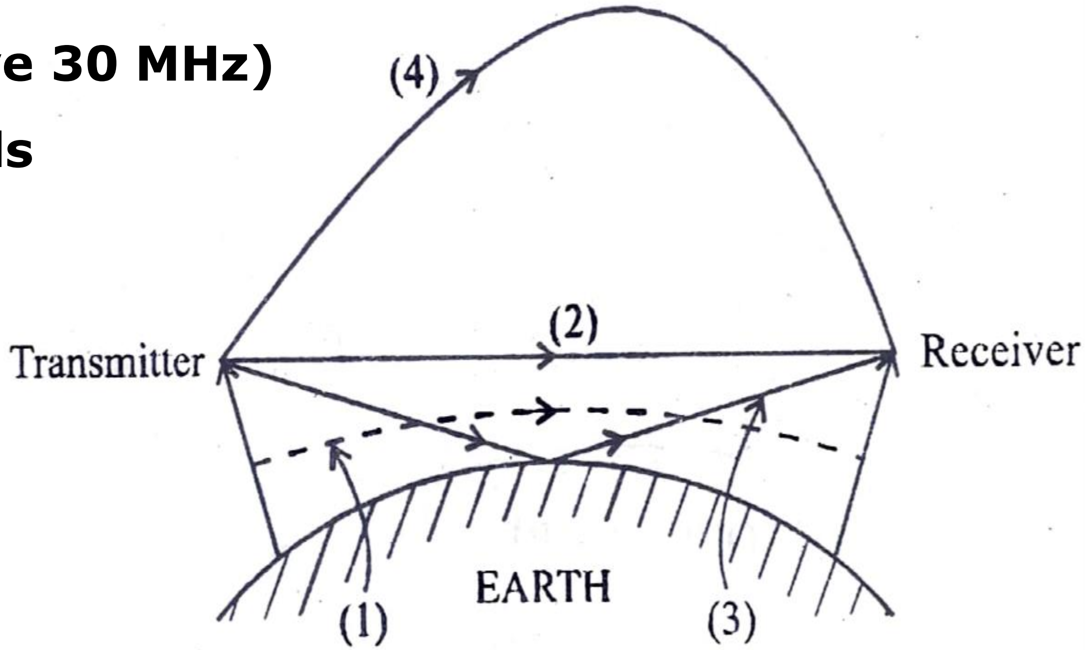
Space wave propagation

- Space wave represents EM wave that travel from transmitter to receiver as line of sight waves

(2) Direct wave with the least path

(3) Ground reflected wave – total space wave includes the direct wave and ground reflected wave

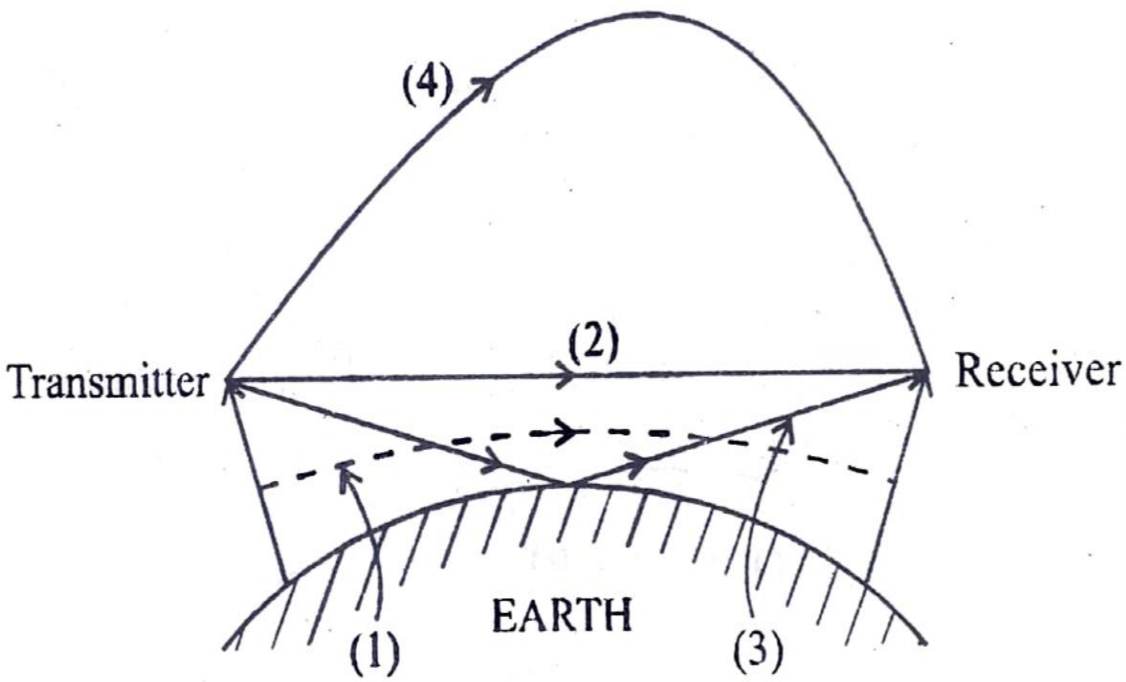
- high frequency range (above 30 MHz)
- Ex. TV, FM and Radar Signals



Radio wave propagation contd.

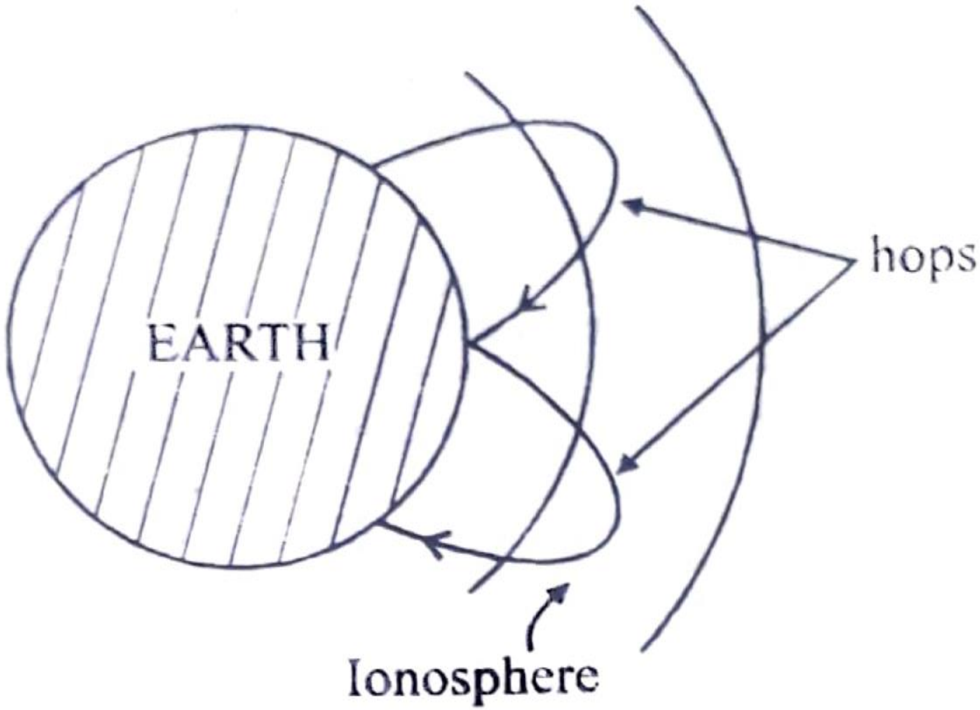
Sky wave propagation

- Represents EM wave that reaches the receiving antenna as a result of reflection by the ionized region (Ionosphere, > 80 KM)
- (4) Sky wave –signal reception due to reflections or refractions through atmosphere medium (300 KHz to 30 MHz)



Radio wave propagation contd.

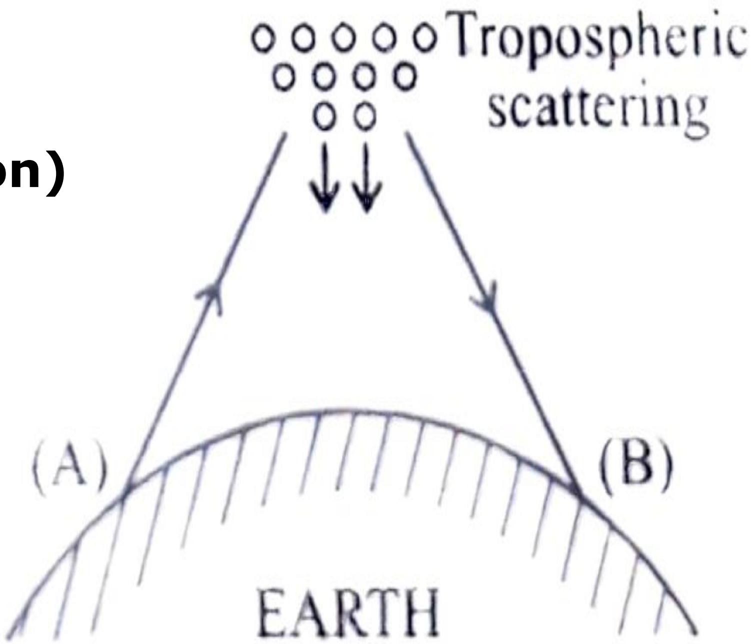
- **Sky wave propagation with multiple hops**
- **no limitations on distance of communication**



Radio wave propagation contd.

- Wave transmitted towards a turbulence (irregular motion of the air) scatters are reflect
- turbulence can be man made or natural, differs in electrical characteristics from the surrounding medium
- from the forward scatter or back reflection a portion of power can be received at point B
- hence a link is established

between 'A' and 'B' (scatter propagation)



Radio wave propagation contd.

Summary

Freq. band	Freq. range	Propagation	Application
1. VLF	3-30 kHz	Ground wave	World Wide Telegraphy
2. LF	30-300 kHz	Ground wave	Navigation, Broadcasting
3. MF	300-3000 kHz	Sky wave	Broadcasting
4. HF	3-30 MHz	Sky wave	Beamed communication systems
5. VHF	30-300 MHz	Space wave (LOS)	TV, Mobile communication
6. UHF	300-3000 MHz	Space wave (LOS)	Radar, Microwave radio
7. SHF	3-30 GHz	Space wave (LOS)	Relay links, Satellite communication

Very low frequency (VLF) :

- **primary mode of propagation ground wave or surface wave**
- **long distance communication is possible as attenuation due to earth's is less at low frequency**

Radio wave propagation contd.

Very low frequency (VLF) :

- low frequency signals can be propagated due to reflections at the bottom edge of ionosphere
- long distance is achieved due to multi reflections between ionosphere and earth surface
- strength of the field reflected depends from the ionosphere depends on diurnal (day to day), seasonal and sun spot cycle variation
- Major drawback of low frequency propagation is the large antenna size

Radio wave propagation contd.

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Low frequency (LF) :

- **characteristics is almost same as that of low frequency range**
- **attenuation due to earth conduction is increased, hence long distance communication depends on sky wave propagation**

Radio wave propagation contd.

Low frequency (LF) :

- attenuation at the lower edge of ionosphere increases
    - hence sky wave field intensity varies with hour of the day and season of the year
    - long distance communication is limited

Radio wave propagation contd.

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1. VLF	3-30 kHz	Ground wave	World Wide Telegraphy
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Medium frequency (MF) :

- **attenuation due to earth conduction is further increased**
- **Sky wave field intensity is very low during day time, because of high attenuation in the bottom layer of ionosphere**
- **hence used for local broadcasting during day time**

Radio wave propagation contd.

Freq. band	Freq. range	Propagation	Application
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Medium frequency (MF) :

- **Long distance communication is possible in night time due to reduced attenuation at the bottom layer of ionosphere**

Radio wave propagation contd.

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High frequency (HF) (short waves) :

- **Surface wave propagation is not preferred, since primary coverage reduces to a very small distance (as attenuation is very high)**
- **preferably operated under sky wave propagation for long distance communication**

Radio wave propagation contd.

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Very high frequency (VHF) :

- **Sky wave propagation is not used since there is no effect of ionosphere and signal penetrates through ionosphere**
- **Space wave propagation or LOS (line of sight) propagation is used**
- **actual service area is slightly more than the LOS propagation due to refractions in atmosphere medium**
- **LOS prapogation has limited distance due to earth's curvature**

Radio wave propagation contd.

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Ultra high frequency (UHF) :

- **Only mode is sky wave propagation**
- **No ionospheric scatter, troposphere scatter occurs some times**
- **duct propagation is also possible**
- **duct propagation occurs where there is temperature inversion (increase with height instead of decreasing) in the troposphere**

Radio wave propagation contd.

Freq. band	Freq. range	Propagation	Application
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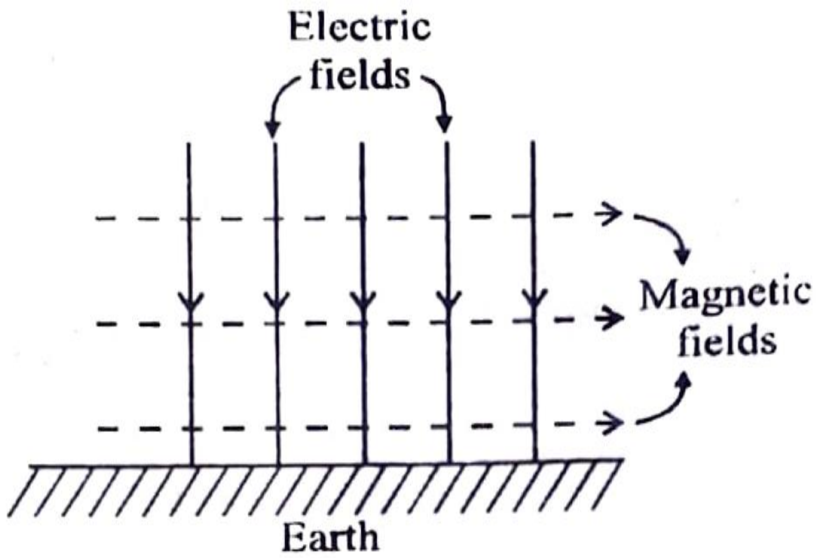
Super high frequency (SHF) (centimeter band):

- **solely by line of sight (LOS), no ground wave and ionospheric reflections**
- **Modern communications technologies, modern radars, DTH services, 5GHz Wi-Fi channel, radio astronomy**
- **mobile networks, TV broadcasting satellites, microwave devices**
- **broadcasting satellites, and amateur radio**

Ground wave propagation

Salient features of ground (surface) wave propagation

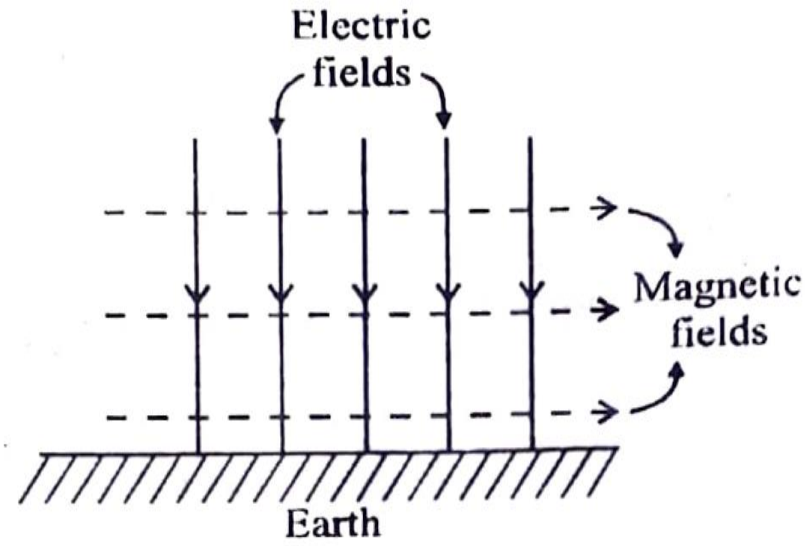
- **Ground wave propagation is by gliding over the surface of earth**
- **It exists for the vertically polarized antenna,**
- **electric field is maintained normal to earth surface to reduce attenuation due to earth's conduction**



- **It exists for the antennas close to the earth surface**
- **It is suitable for VLF, LF and MF (some what) communication**

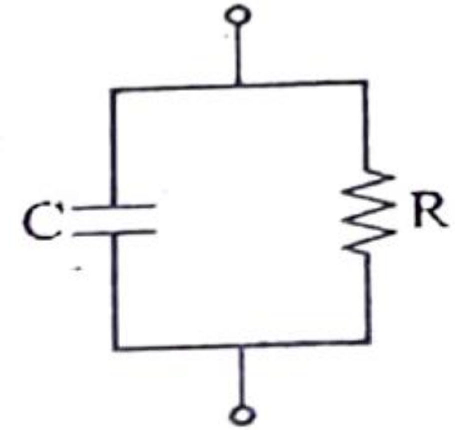
Ground wave propagation contd.

- It can be used even at 15 KHz and up to 2 MHz
- Ground wave requires relatively high power transmitter and not affected by the change in atmospheric conditions
- can be used for radio navigation, ship-to-ship and ship-to-shore communication
- It can be used to communicate between any two points on the globe, if there is sufficient transmitter power
- Horizontal field component is nullified by earth's conduction



Ground wave propagation contd.

- Ground wave induces charges in the earth surface which travel with the wave and so constitute a current
- Earth surface can be represented by a leaky capacitance or capacitance shunted across a resistor



- Earth is characterized by the conductivity σ and dielectric constant ε
- Higher the conductivity, greater is the distance of communication
- Wave can travel over a long distance along sea surface as the conductivity of sea water is more

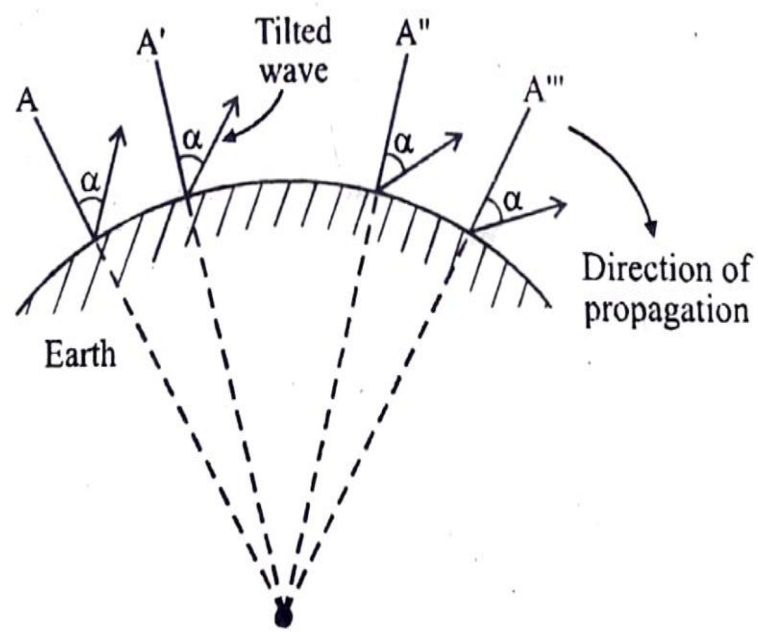
Ground wave propagation contd.

- **A portion of power is wasted as it leaks through the resistance ‘R’**
- **Attenuation of surface wall depends upon frequency, surface irregularities and constants σ and ε**
- **Attenuation increases as the frequency increases and hence surface wave propagation is limited for VLF and LF**
- **Medium frequency can be used up to 2 MHz**
- **Surface wave can be used for local broadcasting**

Ground wave propagation contd.

Surface wave tilting

- Even though the waves are vertically polarized the electric wave will have small forward tilt with respect to earth surface
- tilted wave results a horizontal component which is nullified by earth's conduction and vertical component further proceeds



- Due to continuous tilting, there is continuous attenuation and hence distance of communication is limited
- Maximum range of surface wave propagation depends not only on the frequency, but also on power

Ground wave propagation contd.

- Hence range of transmission can be increased by increasing the power the transmitter in VLF band
- This method is not effective in MF band due to higher wave tilting
- the magnitude of the electric field due to the surface wave can be expressed as

$$E_s = \frac{E_0 A}{d}$$

$E_s \rightarrow Surface\ wave\ field\ strength$

$E_0 \rightarrow Field\ strength\ at\ unit\ distance$

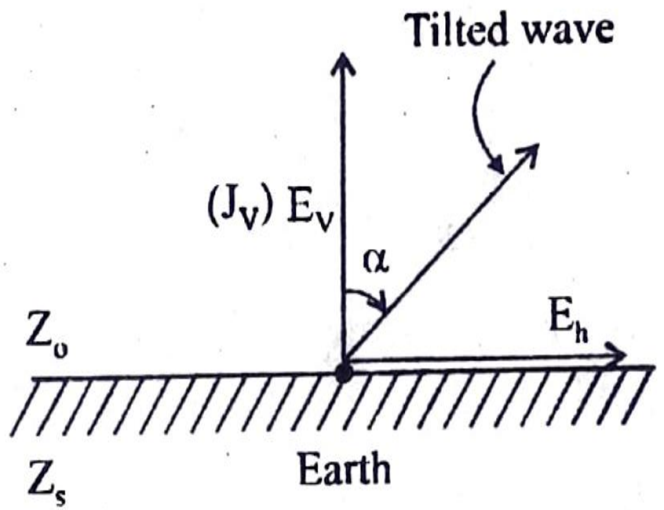
$A \rightarrow Attenuation\ factor$

$d \rightarrow distance$

Ground wave propagation contd.

Tilt angle α

- **Consider a tilted wave tilted by an angle α with respect to its initial orientation**
- **the wave results horizontal component E_h and vertical component E_v**



$$tilt\ angle, \alpha = \frac{E_h}{E_v}$$

Ground wave propagation contd.

- Let Z_s and Z_0 are impedance of earth surface and atmosphere above the earth surface
- J_h and J_v are the current densities due to E_h and E_v

$$\text{Hence} \quad E_h = J_h \times Z_s \quad and \quad E_v = J_v \times Z_0$$

- the surface impedance of the earth is given by

$$Z_s = \sqrt{\frac{\omega\mu}{\sqrt{\sigma^2 + \omega^2\epsilon^2}}} \angle \frac{1}{2} \tan^{-1}\frac{\sigma}{\omega\epsilon}$$

- the ration of the horizontal to vertical field is given by

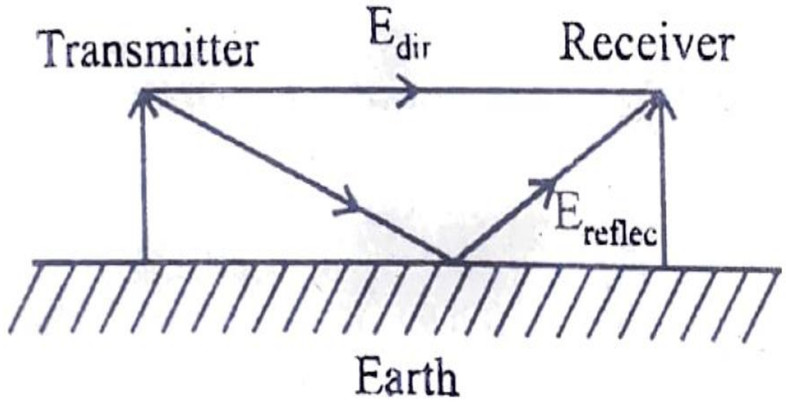
$$\frac{E_h}{E_v} = \frac{Z_s}{Z_0} \qquad Assuming\ J_h = J_v$$

- Substituting for Z_s and $Z_0 = 1/120\pi$

$$\frac{E_h}{E_v} = \frac{1}{120\pi}\sqrt{\frac{\omega\mu}{\sqrt{\sigma^2 + \omega^2\epsilon^2}}} \angle \frac{1}{2} \tan^{-1}\frac{\sigma}{\omega\epsilon}$$

Space wave propagation

- Propagation is achieved by means of space wave travelling between elevated transmitting and receiving antenna
- the wave can be received directly from the transmitter and after reflection from earth's surface

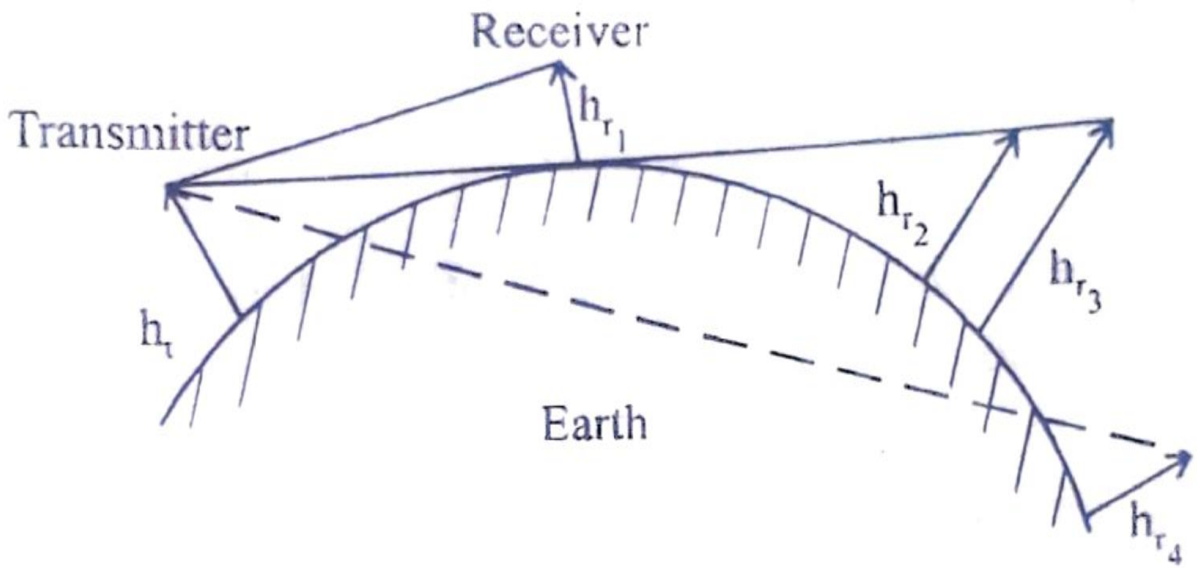


$$E_{space} = E_{dir} + E_{reflection}$$

- for frequencies VHF and above
  - ground wave propagation not preferred – more attenuation due to wave tilt
  - sky wave is not preferred – wave passes through atmosphere and no reflection

Space wave propagation contd.

- line of sight propagation is preferred with elevated antenna
- distance of communication is limited by the earth's curvature

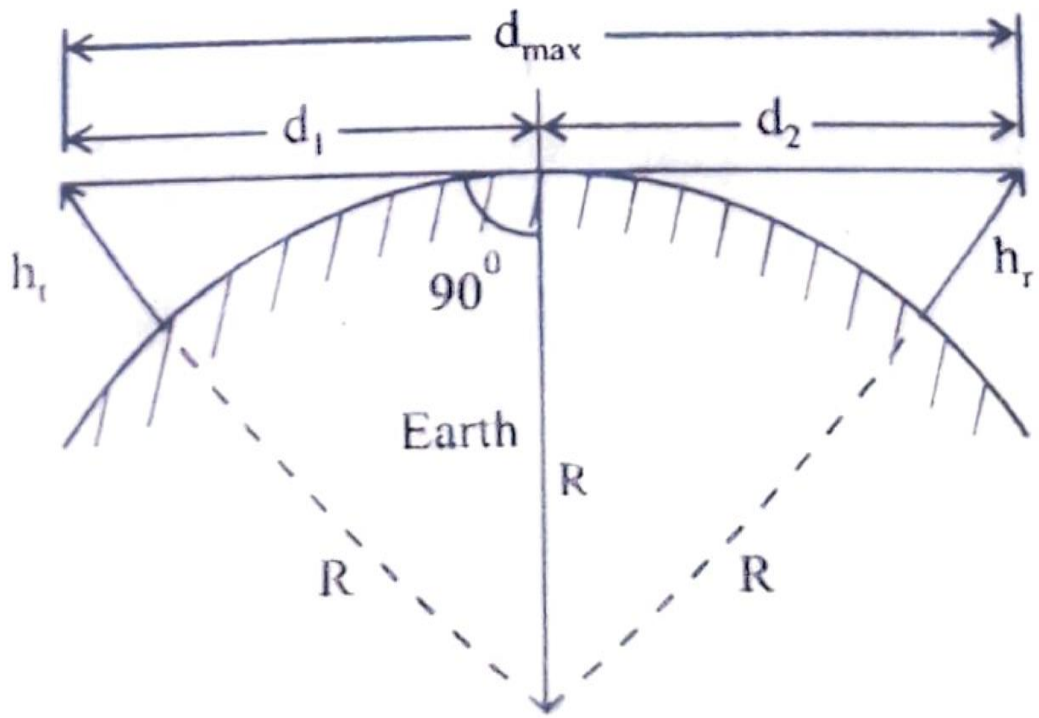


- consider a transmitter mounted at a height h_t
  - h_{r1} can receive both direct and reflected wave
  - h_{r2} and h_{r3} can receive only direct wave
  - h_{r4} cannot receive any signal (due to earth's curvature)

Space wave propagation contd.

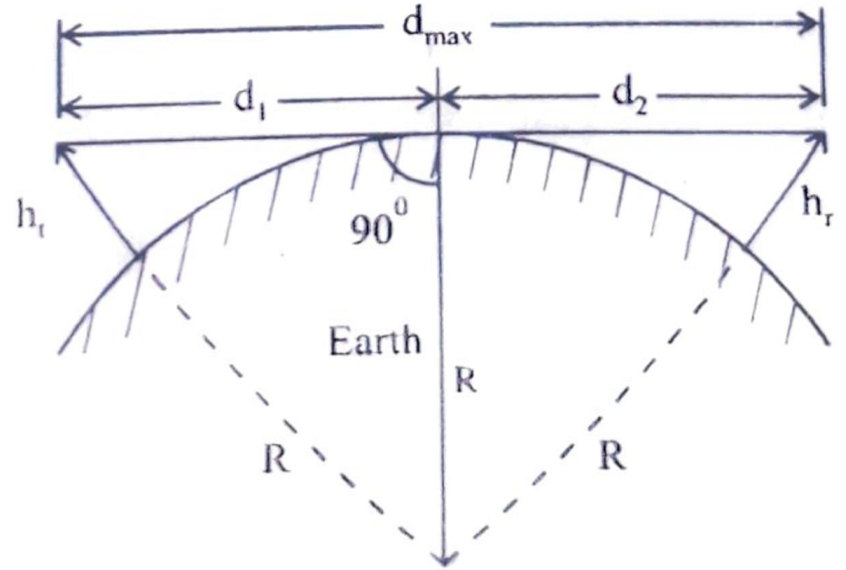
Range or distance of communication

- Consider a spherical earth of radius R



- for a given heights of transmitter (h_t) and receiver (h_r), maximum range is obtained when signal path is tangential

Space wave propagation contd.



distance d_{max} can be determined as

$$d_1 = \sqrt{(R+h_t)^2 - R^2} = \sqrt{2Rh_t + {h_t}^2}$$

since earth's radius R is very large

(R ≈ 6350 Km), h_t^2 can be neglected

$$d_1 = \sqrt{2Rh_t}$$

Similarly $d_2 = \sqrt{(R+h_r)^2 - R^2} = \sqrt{2Rh_r + {h_r}^2}$

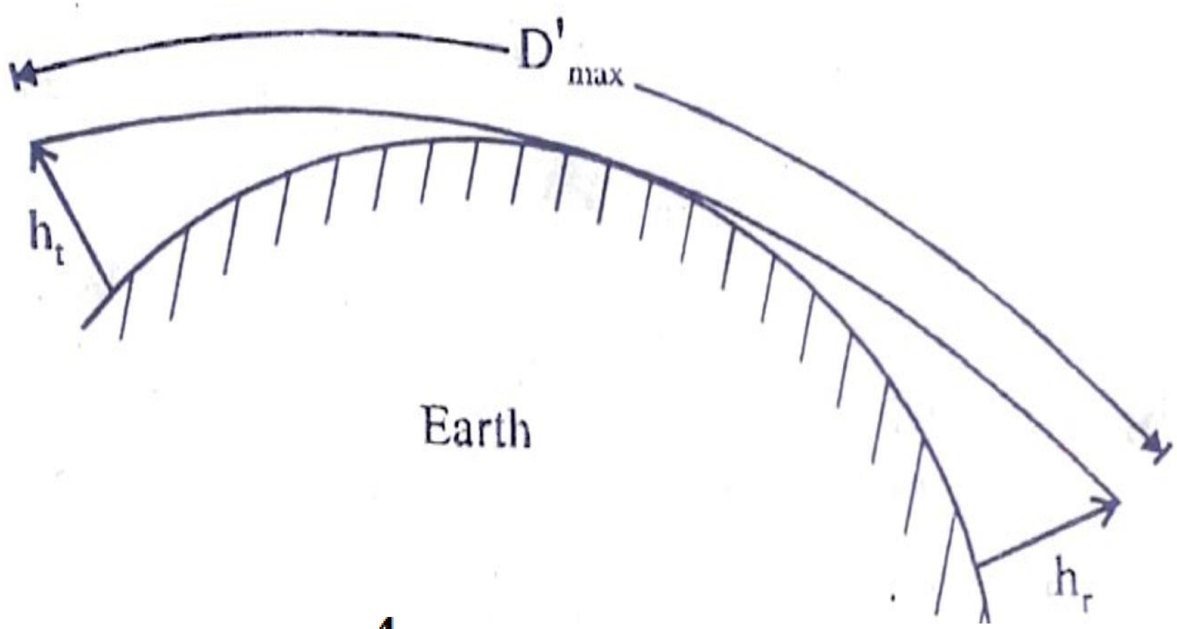
$$d_2 = \sqrt{2Rh_r}$$

$$d_{max} = d_1 + d_2 \qquad d_{max} = \sqrt{2R}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

The range (d_{max}) given is called optical horizon, where signal path is assumed to be in straight line

Space wave propagation contd.

- practically the signal path is curved due to refractions for any higher frequency
- the maximum distance that can be obtained taking into account signal path bending is called radio horizon (D'_{max})
- D'_{max} is more than D_{max}



$$D'_{max} = \sqrt{2R'}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

Where R' is the effective earth's surface, $R' = \frac{4}{3}R$

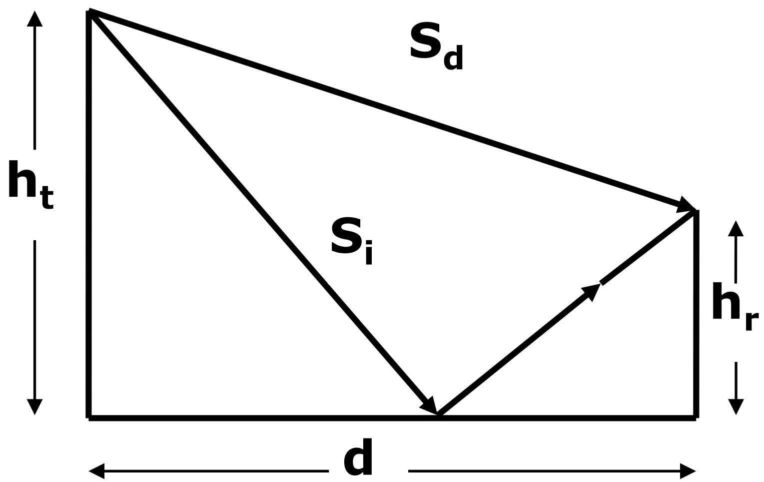
Space wave propagation contd.

Field strength

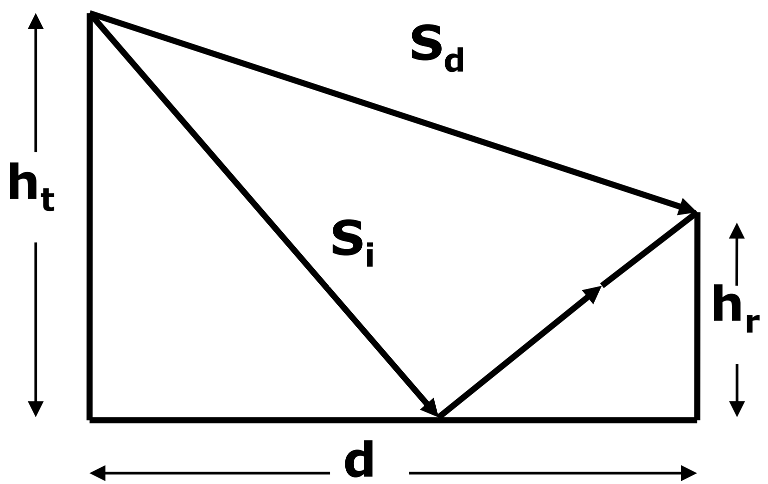
- consider two antennas h_t and h_r separated by d
- earth surface is assumed to be flat
- space wave reaches receiver in two paths, direct wave s_d and reflected wave s_i
- reflected wave travels more distance (has negligible effect on amplitude), phase difference is significant
- if Δs is the path difference,

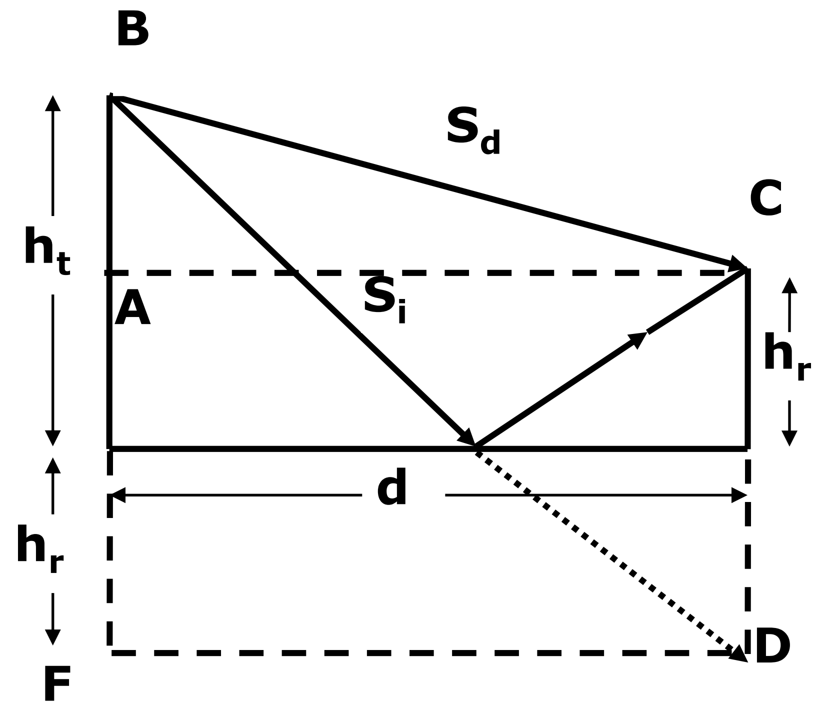
then phase angle difference is

$$\emptyset_s = \frac{2\pi}{\lambda} \Delta s$$



To find the path difference consider the triangle FBD





$$S_i^{\,2} = (h_t + h_r)^2 + d^2$$

From ABC, we have

$$S_d^{\,2} = (h_t - h_r)^2 + d^2$$

from the above equations

$$S_i^{\,2} - S_d^{\,2} = (h_t + h_r)^2 - (h_t - h_r)^2 = 4h_t h_r$$

Space wave propagation contd.

Also

$$S_i^2 - S_d^2 = (S_i + S_d)(S_i - S_d)$$

$$S_i^2 - S_d^2 = (S_i + S_d)\Delta s$$

For most practical purposes

$$S_i = S_d = d$$

$$S_i^2 - S_d^2 = 2d\,\Delta s$$

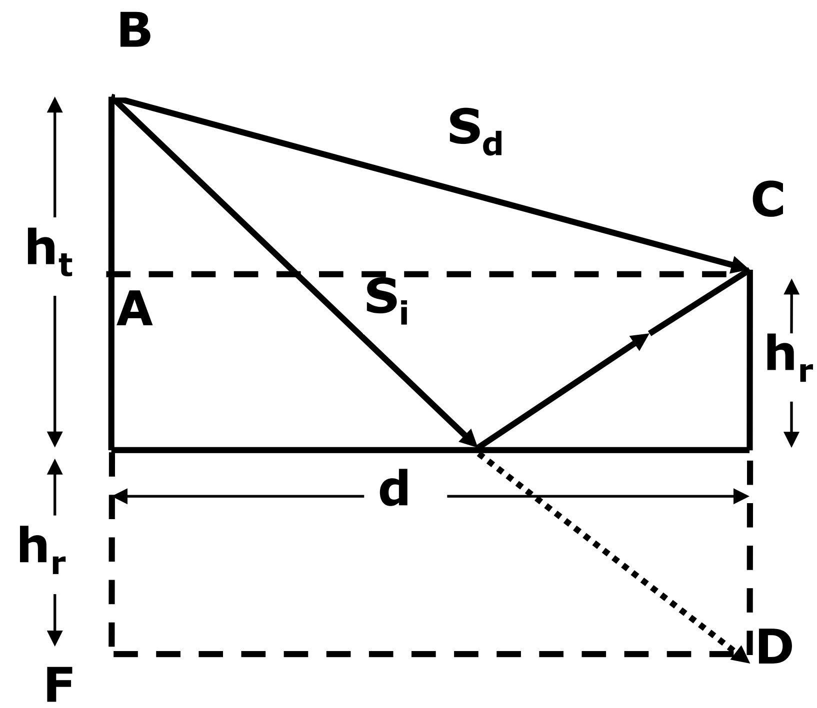
We have

$$S_i^2 - S_d^2 = (h_t + h_r)^2 - (h_t - h_r)^2 = 4h_t h_r$$

$$\text{hence } \; 4h_t h_r = 2d\,\Delta s$$

$$\Delta s = \frac{4h_t h_r}{2d} = \frac{2h_t h_r}{d}$$

$$\text{Therefore } \; \emptyset_s = \frac{2\pi}{\lambda}\,\Delta s = \frac{2\pi}{\lambda}\frac{2h_t h_r}{d} = \frac{4\pi h_t h_r}{\lambda d}$$



Note :

The Phase angle is proportional to height of antennas

Problems

P1. A VHF communication is to be established at 90 MHz with the transmitter power of 35 Watts. Calculate the LOS communication distance, if the height of transmitter and receiver antennas are 40 m and 25 m respectively.

Soln.

$$\text{LOS range (optical range)}, d = \sqrt{2R}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

$$d = \sqrt{2 \times 6350}\left[\sqrt{0.04} + \sqrt{0.025}\right] = 40.36\ Km$$

Problems

P2. A TV transmitter antenna has a height of 169 m and receiver antenna 16m. Calculate the maximum distance through which the TV signal could be received by space wave. What is the radio horizon in this case.

Soln.

$$\text{LOS range (optical range)}, d = \sqrt{2R}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

$$d = \sqrt{2 \times 6350}\left[\sqrt{0.169} + \sqrt{0.016}\right] = 60.58\ Km$$

$$\text{Radio horizon}, D' = \sqrt{2R'}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

$$R' = \frac{4}{3}R$$

$$\text{Radio horizon}, D' = \sqrt{2\,\frac{4}{3} \times 6350}\left[\sqrt{0.169} + \sqrt{0.016}\right]$$

$$D' = 69.95\ Km$$

Problems

P3. Estimate the surface wave tilt in degrees over an earth of 12 m mhos conductivity and relative permittivity 20 at a wavelength 300m.

Soln.

$$\alpha = tan^{-1}\left[\frac{1}{\sqrt{\epsilon_r}(1+x^2)^{1/4}}\right] \qquad x = \frac{\sigma}{\omega\,\epsilon}$$

$$\lambda = 300\ m \qquad f = \frac{C}{\lambda} = \frac{3\times10^8}{300} = 1\,MHz$$

$$x = \frac{\sigma}{\omega\,\epsilon} = \frac{\sigma}{2\pi f\ \epsilon_r\ \epsilon_0}$$

$$x = \frac{12\times10^{-3}}{2\pi\times1\times10^6\times20\times8.854\times10^{-12}} = 10.78$$

$$\alpha = tan^{-1}\left[\frac{1}{\sqrt{20}\,(1+10.78^2)^{1/4}}\right] = 3.88^\circ$$

Problems

P4. A police radio transmitter is operating at 1.69 MHz to provide a ground wave of at least 0.5 mV/m at a distance of 16 Km. If the transmitting antenna used has a power gain of 3 and the ground attenuation factor is 0.15 for the given ground conditions. Find the transmitter power required.

Soln.

The field magnitude at the unit distance is $E_0 = \frac{\sqrt{30\,P\,G}}{l_1} = \frac{\sqrt{30\,P\,G}}{1}$

$$E_0 = \sqrt{30\,P\,3} = \sqrt{90\,P}$$

The field magnitude of the surface wave is

$$E_{sur} = \frac{E_0 A}{d}$$

$$0.5 \times 10^{-3} = \frac{\sqrt{90\,P} \times 0.15}{16 \times 10^3}$$

$$P = 31.6\,W$$

Problems

P5. A transmitter radiates 100W of power at a frequency of 50 MHz, so that a space wave propagation takes place. The transmitting antenna has gain of 5 and its height is 50m and receiving antenna height is 2 m. It is estimated that a field strength of 100 μV/m is required to give a satisfactory signal at the receiving point. Calculate the distance between transmitter and receiver.

Soln.

The field magnitude of the space wave is $E_{space} = \frac{E_0 4\pi h_t h_r}{\lambda d}$

$$E_0 = \frac{\sqrt{30\,P\,G}}{l_1}$$

When distance between antenna is very large, $l_1 \approx d$

$$E_{space} = \frac{\sqrt{30\,P\,G}\,4\pi h_t h_r}{\lambda d^2}$$

Problems

$$E_{space} = \frac{\sqrt{30\ P\ G}4\pi h_t h_r}{\lambda d^2}$$

$$\lambda = \frac{C}{f} = \frac{3 \times 10^8}{50 \times 10^6} = 6m$$

$$100 \times 10^{-6} = \frac{\sqrt{30 \times 100 \times 5}\ \times 4\pi \times 50 \times 2}{6 \times d^2}$$

$$d^2 = 256.5 \times 10^6$$

$$d = 16\ Km$$

Problems

P6. In a VHF mobile radio system, the base station transmitter radiates 100 W at 150 MHz and the antenna is 20 m above ground surface. The transmitting antenna is a λ/2 dipole with a directivity 1.64. Calculate the field strength at a receiving antenna of height 2 m at a distance of 40 Km.

$$E_{space} = \frac{E_0 4\pi h_t h_r}{\lambda d^2}$$

Soln.

$$\lambda = \frac{3 \times 10^8}{150 \times 10^6} = 2\ m$$

$$E_0 = \sqrt{30\ P\ G}$$

$$E_0 = \sqrt{30 \times 100 \times 1.64} = 70,14\ V/m$$

$$\lambda = \frac{C}{f}$$

$$E_{space} = \frac{70.14 \times 4\pi \times 20 \times 2}{2 \times (40 \times 10^3)^2} = 11\ \mu V/m$$

Problems

P7. If a transmitting aerial is located at the top of a tower 200m above the surface of the earth. Determine the maximum distance at which an aircraft flying at an altitude 3000 m will be able to receive signals from the transmitter. Assume that only LOS propagation is involved. If the transmitting areal has a power gain of 13 dB in the direction of aircraft and the power radiated is 400 W, determine the electric field strength of the signal at the air craft. Assume earth radius as 6350 Km.

Soln.

$$d = \sqrt{2R}\left[\sqrt{h_t} + \sqrt{h_r}\right] = \sqrt{2 \times 6350}\left[\sqrt{200} + \sqrt{3000}\right] = 245.59\ Km$$

$$E_0 = \sqrt{30\ P\ G}$$

Problems

$$G\ in\ dB = 10\ log_{10} G$$

$$13 = 10\ log_{10} G$$

$$G = 19.95$$

$$E_0 = \sqrt{30\ P\ G} = \sqrt{30 \times 400 \times 19.95} = 489.29\ V/m$$

$$E_{space} = \frac{E_0 4\pi h_t h_r}{\lambda d^2} = \frac{489.29 \times 4\pi \times 200 \times 3000}{\lambda \times (245.59 \times 10^3)^2} = \frac{0.061}{\lambda}\ V/m$$

Problems

P8. Estimate the wave tilt in degrees of the surface wave over an earth of 5 m mho conductivity and relative permittivity 10 at 1 MHz.

Soln.

$$x = \frac{\sigma}{\omega\,\epsilon} = \frac{\sigma}{2\pi f\,\epsilon_r\,\epsilon_0}$$

$$x = \frac{5\times10^{-3}}{2\pi\times1\times10^{6}\times10\times8.854\times10^{-12}} = 8.98$$

$$\alpha = tan^{-1}\left[\frac{1}{\sqrt{\epsilon_r}(1+x^2)^{1/4}}\right]$$

$$\alpha = tan^{-1}\left[\frac{1}{\sqrt{10}(1+8.98^2)^{1/4}}\right] = 6^{\circ}$$

Problems

P9. LOS communication has to be established to cover an optical distance of 100 Km. Find the height of transmitter if the height of receiver is 100 m. What could be radio horizon?

Soln.

$$100 = \sqrt{2 \times 6350}\left[\sqrt{h_t} + \sqrt{0.1}\right]$$

$$\sqrt{h_t} = \frac{100}{\sqrt{2 \times 6350}} - \sqrt{0.1} = 0.571$$

$$h_t = 326\ m$$

$$D = \sqrt{2\,\frac{4}{3}\,6350}\ \left[\sqrt{0.326} + \sqrt{0.1}\right] = 115.44\ Km$$

Optical range

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

Radio Horizon

$$D = \sqrt{2R'}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

$$R' = \frac{4}{3}R$$

$$R = 6350\ Km$$

Problems

P10. The surface wave tilt is 4° for the earth of relative permittivity of 10 at a wavelength of 300 m. Find the conductivity of the ground surface.

Soln.

$$\alpha = tan^{-1}\left[\frac{1}{\sqrt{\epsilon_r}(1+x^2)^{1/4}}\right]$$

$$tan\,4^\circ = \frac{1}{\sqrt{10}(1+x^2)^{1/4}}$$

$$x = \frac{\sigma}{\omega\,\epsilon}$$

$$\left(1+x^2\right)^{1/4} = \frac{1}{\sqrt{10}\times 0.0699} = 4.524$$

$$\lambda = \frac{C}{f}$$

$$\left(1+x^2\right) = 4.524^4 = 418.88$$

$$x = 20.44$$

Problems

$$\sigma = x\omega\,\epsilon = x2\pi f\,\epsilon_0\epsilon_r$$

$$f = \frac{C}{\lambda} = \frac{3\times 10^8}{300} = 1\,MHz$$

$$\sigma = 20.44\times 2\pi\times 1\times 10^6\times\ 8.854\times 10^{-12}\times 10$$

$$\sigma = 11.37\ m\,mho$$

P11. The transmitter is mounted at a height 100 m and a receiver of height 50 m is mounted at a distance of 50 Km. Find the space wave field strength at the receiving antenna at 150 MHz, if the field strength per unit distance in the directivity of receiving antenna is 60 V/m

Soln.

$$\lambda = \frac{C}{f}$$

$$\lambda = \frac{3 \times 10^8}{150 \times 10^6} = 2\,m$$

$$E_{space} = \frac{E_0 4\pi h_t h_r}{\lambda d}$$

$$E_{space} = \frac{60 \times 4\pi \times 100 \times 50}{2 \times 50 \times 10^3} = 37.69\,V/m$$

Problems

P12. Find the conductivity of the earth surface which results a wave tilt of 5 at 1 MHz with relative permittivity of 15.

Soln.

$$\tan 5^\circ = \frac{1}{\sqrt{15}(1+x^2)^{1/4}}$$

$$\alpha = \tan^{-1}\left[\frac{1}{\sqrt{\epsilon_r}(1+x^2)^{1/4}}\right]$$

$$(1+x^2)^{1/4} = \frac{1}{\sqrt{15}\times 0.0874} = 2.954$$

$$x = \frac{\sigma}{\omega\,\epsilon}$$

$$(1+x^2) = 2.954^4 = 76.145$$

$$x = 8.668$$

$$\sigma = 8.668\times 2\pi\times 1\times 10^6\times\ 8.854\times 10^{-12}\times 15$$

$$\sigma = 7.23\ m\ mho$$

Ionospheric Propagation

Propagation through Ionosphere

- wave transmitted towards ionosphere can be received back on earth surface due to the combination of reflections and refractions
- this wave received through upper part of atmosphere is called sky wave (mode of communication ionospheric propagation)
- long distance communication can be achieved using sky wave
- medium is said to be ionosphere as it consists of maximum ion density
- ionization takes place in atmosphere medium utilizing external energy (mostly solar energy)
- Important ionizing agents are UV radiations, α, β rays, cosmic rays and meteors

Ionospheric Propagation contd.

Structure of ionosphere

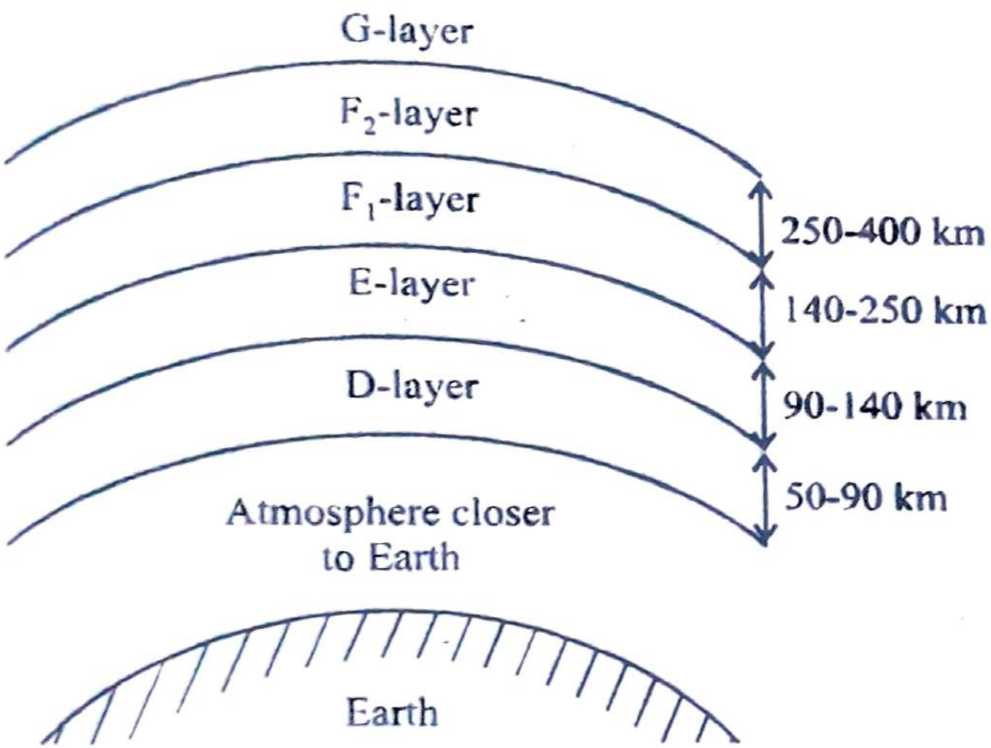
- The ions, electrons and atoms move at random and frequently collide with each other and process of recombination continues
- ionized molecules does not remain ionized indefinitely
- in lower part of atmosphere, collisions are more frequent and hence air molecules do not remain ionized for a longer time
- Below 50 Km the ionization is relatively small and sun's radiation intensity is relatively reduced
- above 400 Km, density of molecules itself is very low
- between 50 and 400 Km ionization is maximum, which helps for sky wave propagation

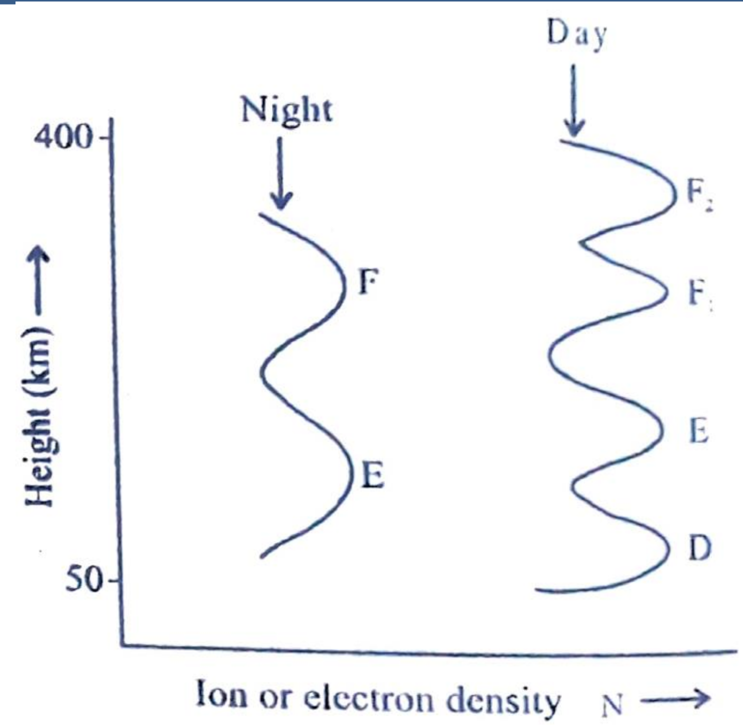
Ionospheric Propagation contd.

Chapman's theory can be used to show the different layers of maximum ion density layers within ionosphere

- **molecular density (number of molecules existing per unit volume) reduces as the height above earth surface increases**
- **rate of ionization increases as the height above the earth surface increases , since sun's radiation intensity increases**
  - **rate of ionization : number of splitting related to with respect to the number of existing molecules per unit volume**
- **different molecules occupy different heights above the earth surface based on upon their molecular weight and average velocity**
- **based on these factors there are layers of maximum ion densities occupying different heights above the earth surface**

Ionospheric Propagation contd.





- During night time principal layers are E and F. total ionosphere width is less during night
- during day F layers splits into F1 and F2, D layer is much predominant, total ionosphere width is more

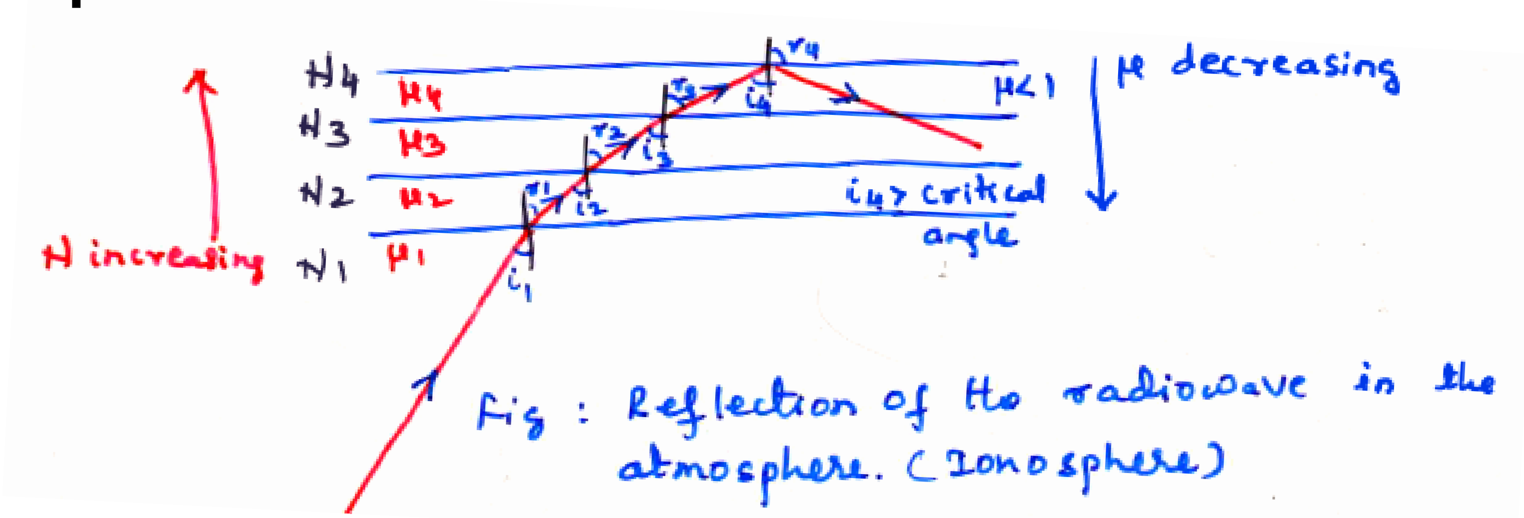
Ionospheric Propagation contd.

Characteristics of different layers of ionosphere

Sl. No.	Layer	Height (km)	Density ions/cm^3	Critical freq.	Virtual height (km)	Contents
1.	D	60-90	10^{14} to 10^{16}	100 kHz	70-80	Oxygen
2.	E (normal)	90-140	5×10^3 to 4.5×10^5	3-5 MHz	110-120	Sodium
3.	E (sporadic)	90-130	–	–	–	–
4.	F_1	140-250	2×10^5 to 4.5×10^5	5-7 MHz	225	Oxygen and Nitrogen
5.	F_2	250-400	2×10^5 to 2×10^6	5-12 MHz	300-400	– ” –
6.	G	Above 400	–	–	–	–

Wave propagation in ionosphere

- **Ionosphere : dielectric with variable refractive index**

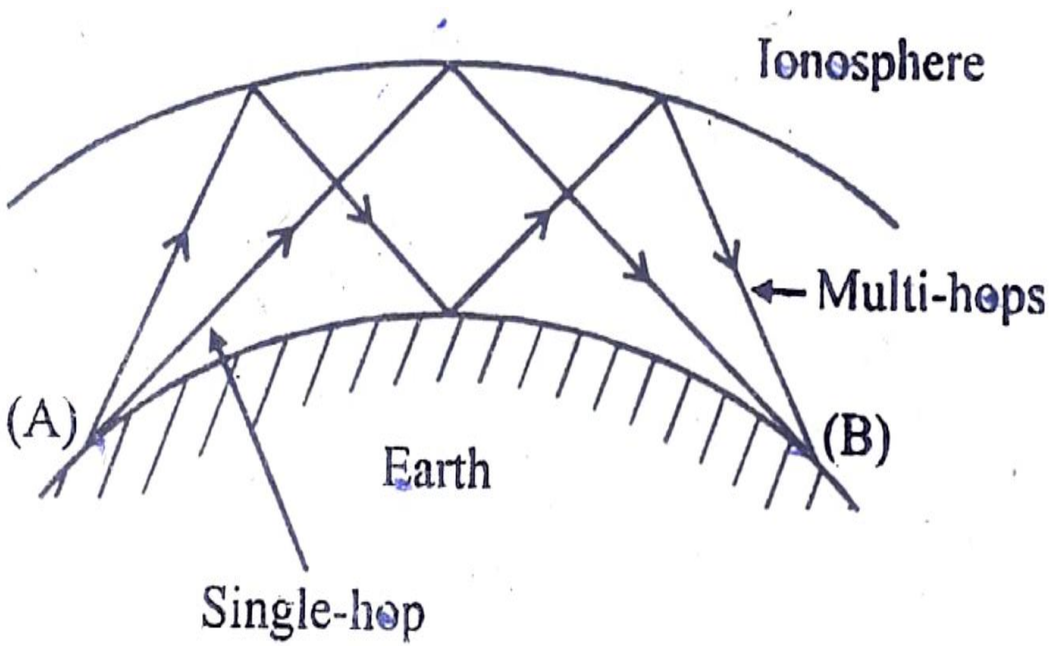


- **for simplicity the ionosphere can be divided into number of thin strips of constant electron density**
- **increase in electron density with increasing height, decreases the refractive index, hence incident ray will bend**
- **once the incident angle becomes greater than critical angle total internal reflection will occur and the wave is received back**

Ionospheric Propagation contd.

Sky wave propagation (ionospheric propagation)

- can be used for long distance communication (1000 Km and above)
- the signal transmitted towards ionosphere can be obtained back due to single hop or multi-hop reflection at the ionosphere



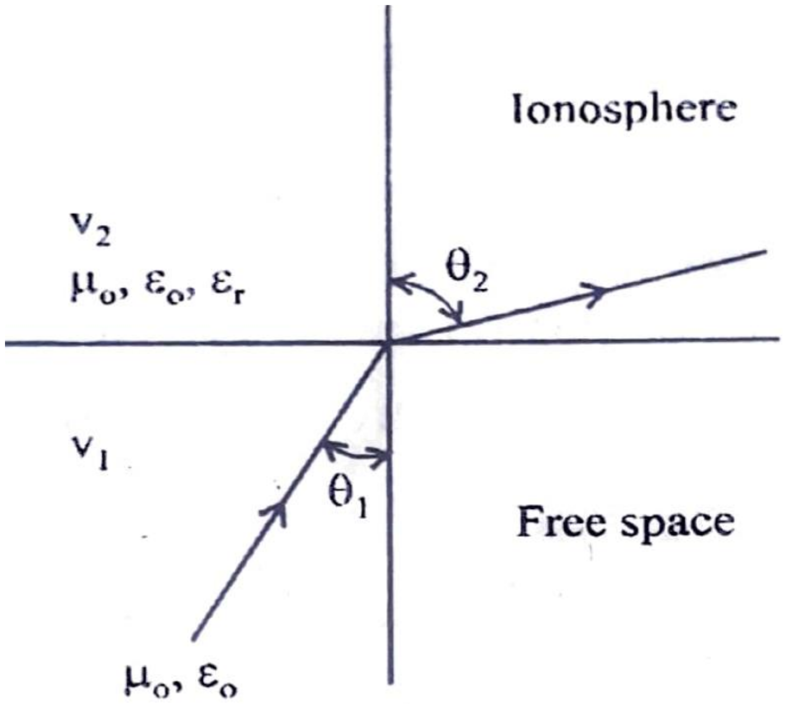
Ionospheric Propagation contd.

- at suitable frequency the sky wave propagation can be used to cover any distance round the earth
- efficient long distance communication is performed in the frequency range 10 to 30 MHz
- radio waves of 2 MHz will be reflected from the ionosphere
- but in day time the lower frequency 2 to 10 MHz are highly attenuated
- at the receiving point more than one wave is received under different paths
- the total wave will have amplitude and phase variations depending upon the phase difference between the waves

Rafractive index (a)

- refractive index of ionosphere with respect to free space is given by

$$a = \frac{Sin\ \theta_1}{Sin\ \theta_2}$$



In terms of velocities

$$a = \frac{V_1}{V_2} = \frac{\sqrt{\mu_0 \epsilon_0 \epsilon_r}}{\sqrt{\mu_0 \epsilon_0}}$$

Hence $a = \dfrac{Sin\ \theta_1}{Sin\ \theta_2} = \sqrt{\epsilon_r}$

The relative permittivity of ionosphere is $\epsilon_r = 1 - \dfrac{81\ N}{f^2}$

N → ion density, f → operating frequency

Ionospheric Propagation contd.

hence

$$a = \frac{Sin\ \theta_1}{Sin\ \theta_2} = \sqrt{\epsilon_r} = \sqrt{1 - \frac{81\ N}{f^2}}$$

assuming that there is total internal reflection at N_{max}

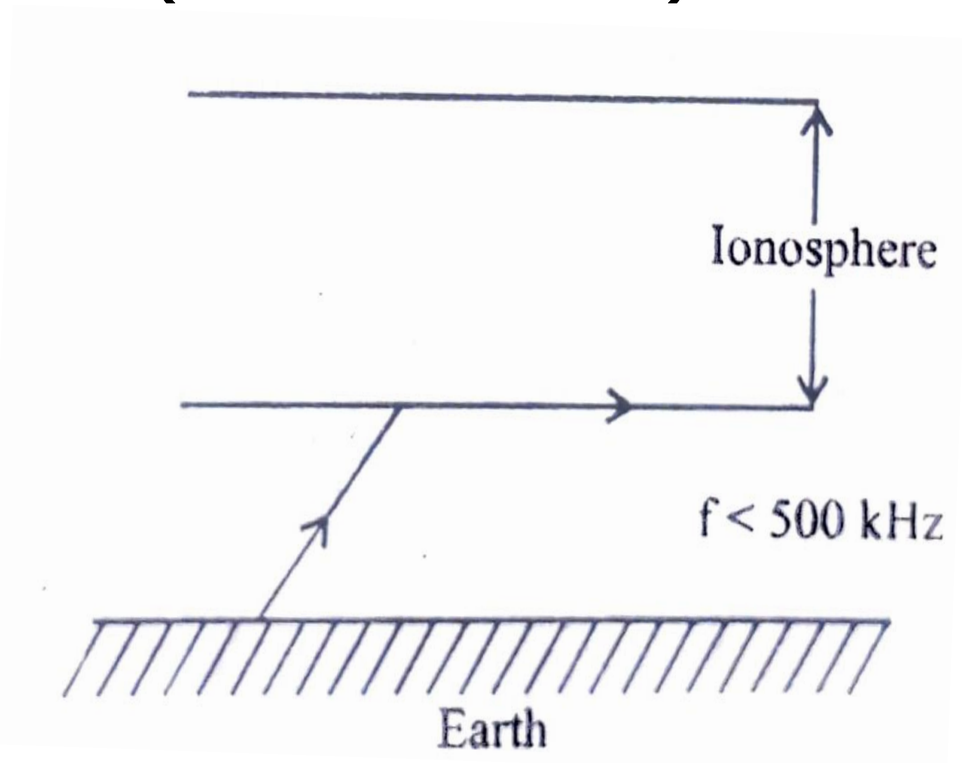
$$\theta_2 = 90^{\circ}\ at\ N = N_{max}$$

then

$$a = Sin\ \theta_1 = \sqrt{1 - \frac{81\ N_{max}}{f^2}}$$

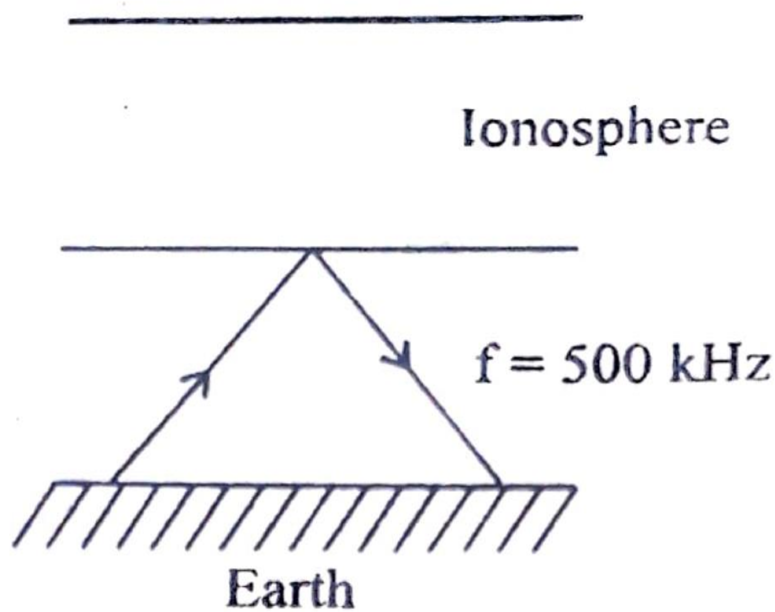
Use of ionosphere for different frequencies

VLF (less than 500 KHz)



No reflection, travels along bottom edge of ionosphere

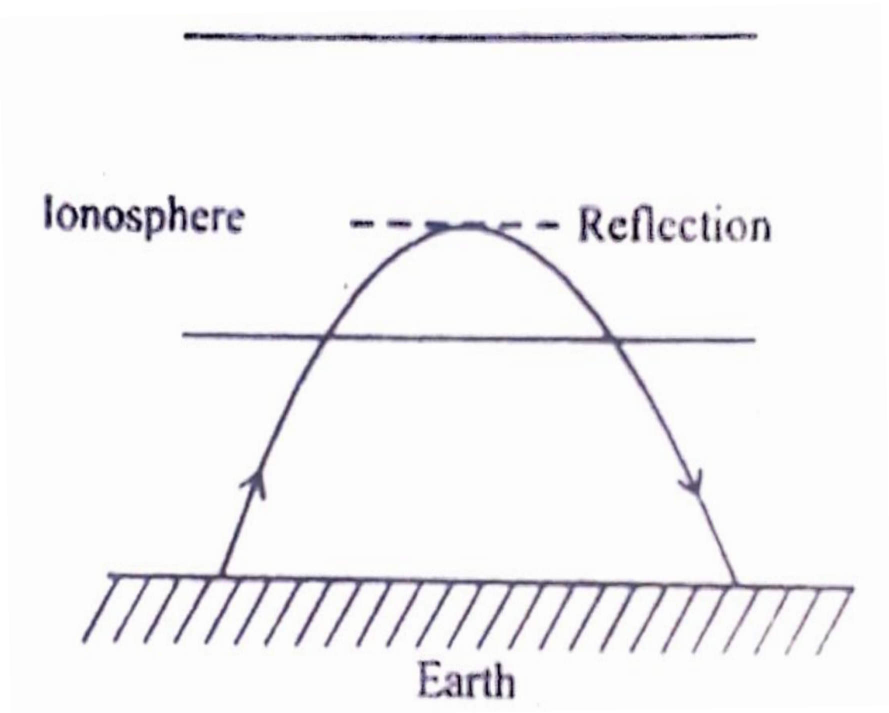
above 500 KHZ



Reflects back from ionosphere

Ionospheric Propagation contd.

MF (500 KHz to 2 MHz)

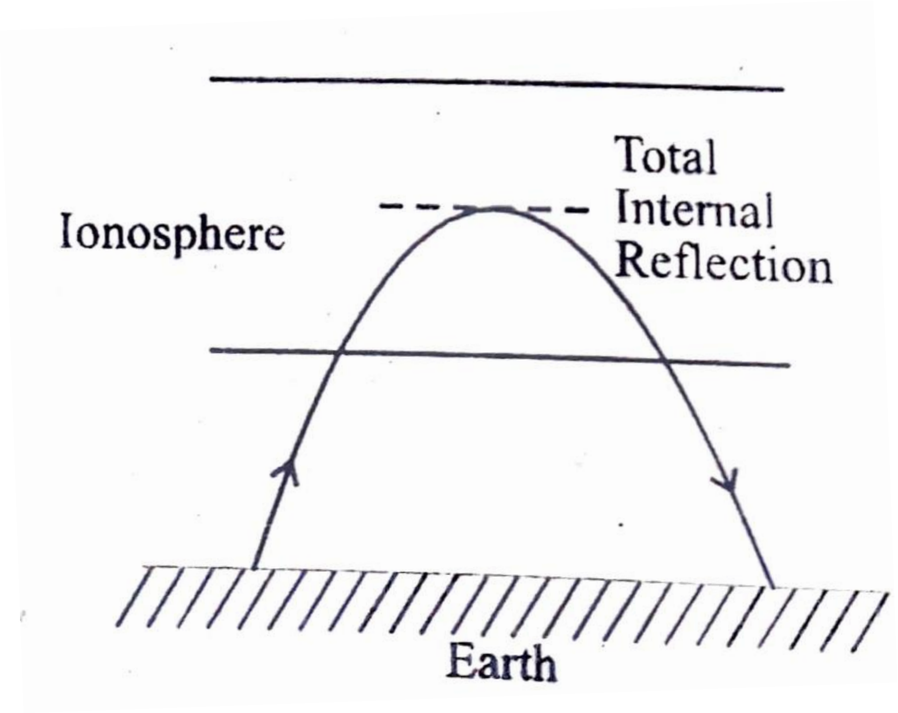


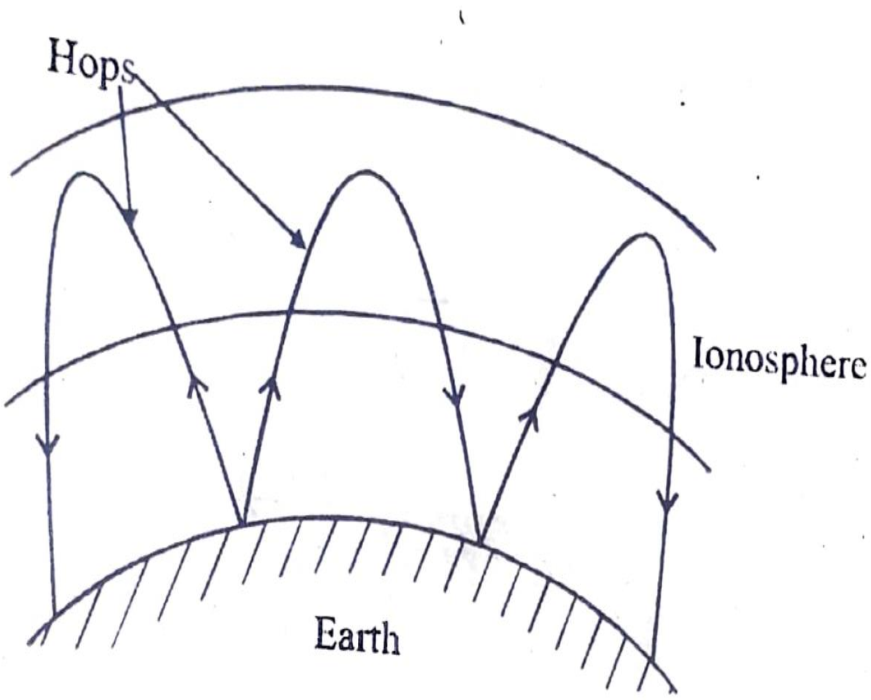
enters ionosphere, undergoes irregular refraction and received back.

Received power is less and distance covered is limited

Ionospheric Propagation contd.

HF (2 MHz to 30 MHz)

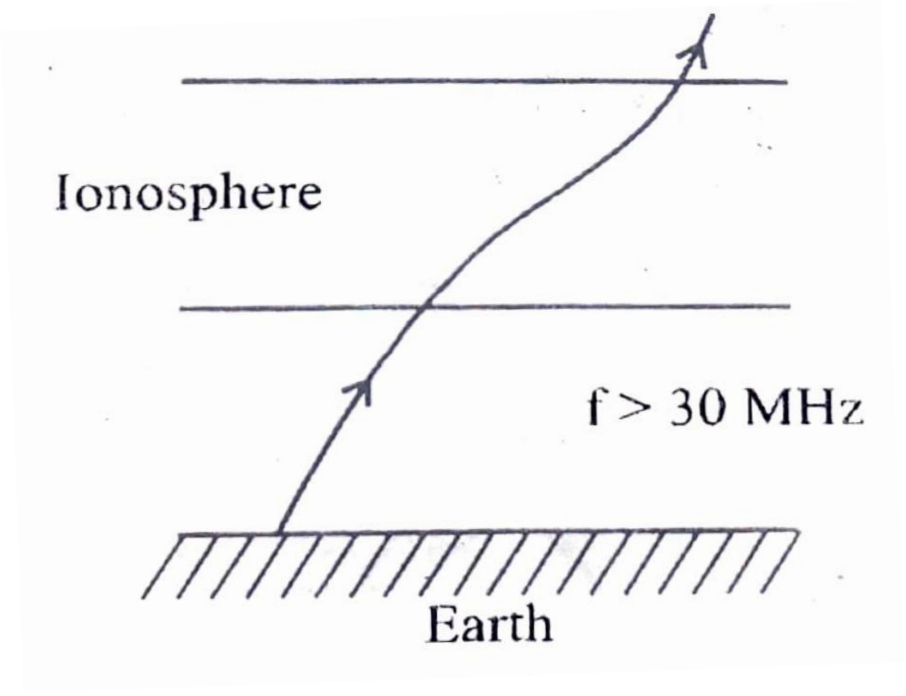




Wave undergoes total internal reflection, received power is large, no limitation on distance of communication due to multiple hops

Ionospheric Propagation contd.

VHF (above 30 MHz)



Wave cannot be received back on earth surface using ionosphere as there is no effect of the ionosphere

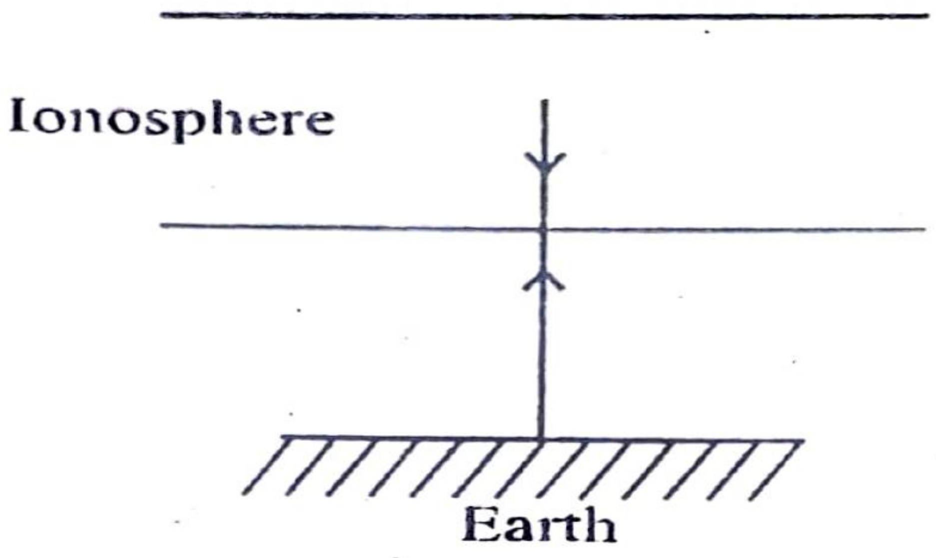
Ionospheric propagation is possible for frequencies ranging between 500 KHz and 30 MHz

Ionospheric Propagation contd.

Simple definitions

Critical Frequency

- **Maximum frequency at which the signal can be received back on earth surface using ionosphere feeding the wave vertically upwards**
- **critical frequency differs for different layers**



Ionospheric Propagation contd.

We know that

$$a = Sin\,\theta_1 = \sqrt{1 - \frac{81\,N_{max}}{f^2}}$$

$$(Sin\,\theta_1)^2 = 1 - \frac{81\,N_{max}}{f^2}$$

$$\frac{81\,N_{max}}{f^2} = 1 - (Sin\,\theta_1)^2$$

$$\frac{81\,N_{max}}{f^2} = Cos^2\,\theta_1$$

$$\frac{81\,N_{max}}{Cos^2\,\theta_1} = f^2 \qquad f = \frac{9\sqrt{N_{max}}}{Cos\,\theta_1}$$

$$f = \frac{9\sqrt{N_{max}}}{Cos\,\theta_1}$$

when power fed is vertically upwards, the angle of incidence with respect to normal is 0°

Hence critical frequency is obtained at θ = 0° as

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

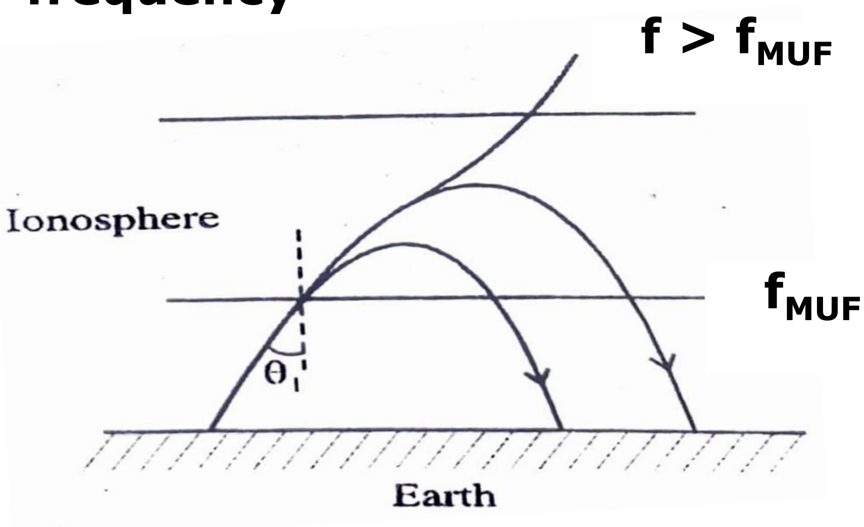
f_c is in MHz when the density N_{max} is in ions or electrons/m^3

If frequency is more than f_c, the wave penetrates through ionosphere

Ionospheric Propagation contd.

Maximum usable frequency (MUF)

- The maximum frequency up to which the wave can be received back on earth surface using ionosphere depends upon the angle of incidence θ_1
- this frequency for a given angle θ_1 is called maximum usable frequency



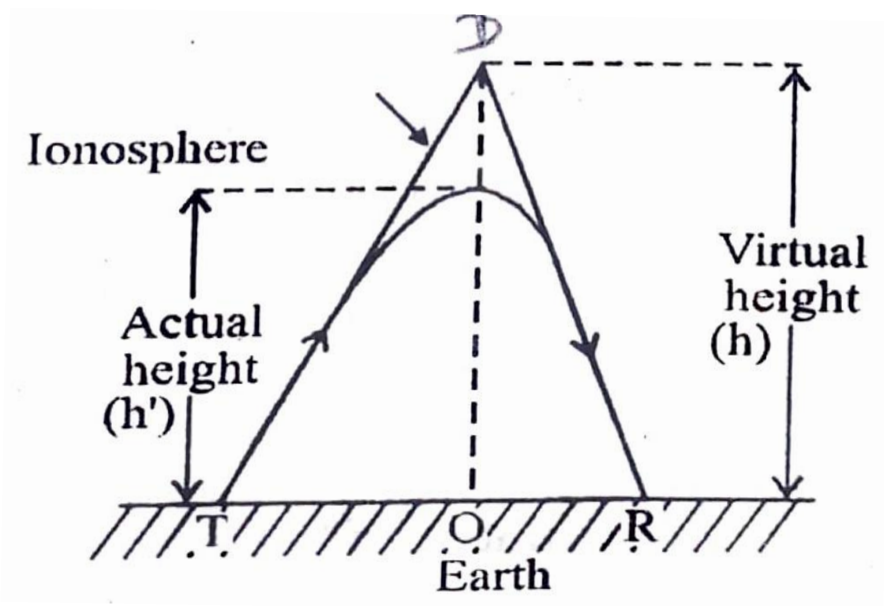
- MUF increases as θ_1 increases
- If frequency is above MUF, wave penetrates through ionosphere
- MUF ranges between 8 MHz to 35 MHz

$$f_{MUF} = \frac{9\sqrt{N_{max}}}{Cos\ \theta_1}$$

$$\text{Or}\quad Cos\ \theta_1 = \frac{f_c}{f_{MUF}}$$

Virtual Height

- The actual path of the wave in the ionized layer is a curve and is due to the refraction of the wave

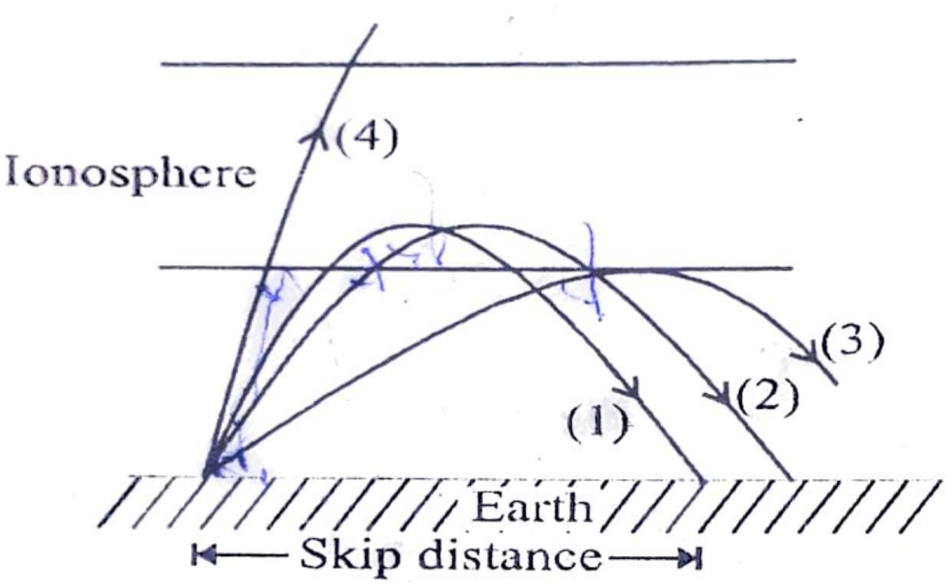


- The actual or true height (h’) of the ionosphere is layer is obtained from the actual signal path
- approximate height can be obtained considering straight paths TD and DR
- This approximate height DO is called virtual height (h)

Ionospheric Propagation contd.

Skip distance

- The distance from the transmitter to receiver at which the ray returns to ground reduces as the angle of incidence θ_1 reduces
- the minimum distance that is measured from the transmitter to receiver at which the signal cannot be received using ionosphere for a given angle of incidence is called skip distance
- skip distance reduces as the angle of incidence reduces



Problems

P13. Calculate the critical frequency for reflection at vertical incidence if the maximum electron density is 1.24 X $10^6/cm^3$.

Soln.

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

$$N_{max} = 1.24 \times 10^6/cm^3 = 1.24 \times 10^{12}/m^3$$

$$f_c = 9\sqrt{1.24 \times 10^{12}} = 10.02\ MHz$$

Problems

P14. A HF radio link is established for a range of 2000 km. If the reflection region of the ionosphere is at a height of 200 Km and has a critical frequency of 6 MHz, calculate MUF.

Soln.

$$D = 2H\sqrt{\left(\frac{f_{MUF}}{f_c}\right)^2 - 1}$$

$$f_{MUF} = f_c\sqrt{\left(\frac{D}{2H}\right)^2 + 1}$$

$$f_{MUF} = 6\sqrt{\left(\frac{2000}{2 \times 200}\right)^2 + 1} = 30.594\ MHz$$

Problems

P15. The ion density for an ionospheric layer is 1.15 X10⁶/cm³. Find the critical frequency of that layer.

Soln.

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

$$N_{max} = 1.15 \times 10^6/cm^3 = 1.15 \times 10^{12}/m^3$$

$$f_c = 9\sqrt{1.15 \times 10^{12}} = 9.65\ MHz$$

Problems

P16. The critical frequency for F1 layer ranges between 5 to 7 MHz. Find its maximum electron density.

Soln.

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

$$7 \times 10^6 = 9\sqrt{N_{max}}$$

$$N_{max} = \left(\frac{7 \times 10^6}{9}\right)^2 = 6.04 \times 10^{11}\ electron\,s/m^3$$

Problems

P17. A distance of 1500 Km is to be covered along earth's surface using a communication link. If the reflection region of ionosphere has f_c = 6 MHz and f_{MUF} = 7.5 MHz, calculate the height of the region

$$D = 2H\sqrt{\left(\frac{f_{MUF}}{f_c}\right)^2 - 1}$$

Soln.

$$1500 = 2H\sqrt{\left(\frac{7.5}{6}\right)^2 - 1}$$

$$H = 1000\ Km$$

Problems

P18. At what frequency a wave must propagate for the D region to have an index of refraction 0.5. Given N_{max} = 500X10^6 electrons/cc for D region.

Soln.

$$\epsilon_r = 1 - \frac{81\, N_{max}}{f^2}$$

$$\mu = \sqrt{1 - \frac{81\, N_{max}}{f^2}} \quad since\ \mu_r = 1$$

$$N_{max} = 500 \times 10^6/cm^3 = 500 \times 10^{12}/m^3$$

$$0.5 = \sqrt{1 - \frac{81 \times 500 \times 10^{12}}{f^2}}$$

$$f = 232.38\ MHz$$

Problems

P19. The electron density in the F layer in the ionosphere is $2X10^6/m^3$. Find the dielectric constant of the layer if the frequency of the EM wave is 40 MHz.

Soln.

$$\epsilon_r = 1 - \frac{81\, N_{max}}{f^2}$$

$$\epsilon_r = 1 - \frac{81 \times 2 \times 10^6}{(40 \times 10^6)^2} = 0.99$$

$$\epsilon = \epsilon_0 \epsilon_r = 8.854 \times 10^{-12} \times 0.999$$

$$\epsilon = 8.85399 \times 10^{-12} F/m$$

Problems

P20. What is the critical frequency for the F1, F2 and E layers for which the maximum ionic densities are 2.5 X 10^6, 3.5 X 10^6, 1.5 X 10^6/cm^3 respectively.

Soln.

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

For F1 layer

$$N_{max} = 2.5 \times 10^6/cm^3 = 2.5 \times 10^{12}/m^3$$

$$f_c = 9\sqrt{2.5 \times 10^{12}} = 14.23\ MHz$$

For F2 layer

$$N_{max} = 3.5 \times 10^6/cm^3 = 3.5 \times 10^{12}/m^3$$

$$f_c = 9\sqrt{3.5 \times 10^{12}} = 16.84\ MHz$$

For E layer

$$N_{max} = 1.5 \times 10^6/cm^3 = 1.5 \times 10^{12}/m^3$$

$$f_c = 9\sqrt{1.5 \times 10^{12}} = 11.02\ MHz$$

Problems

P21. The observed critical frequency of E and F layers at Udupi at a particular time are 3 MHz and 9 MHz respectively. Calculate the maximum electron concentration of the layers.

Soln.

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

$$N_{max} = \frac{f_c^{\,2}}{81}$$

For E layer

$$N_{max} = \frac{(3 \times 10^6)^2}{81} = 0.11 \times 10^{11}\ electrons/m^3$$

For F layer

$$N_{max} = \frac{(9 \times 10^6)^2}{81} = 1 \times 10^{12}\ electrons/m^3$$

Problems

P22. Two points on earth are 1000 Km apart and are to communicate by means of HF, given that this is to single hop transmitter and the critical frequency is 7 MHz. Calculate MUF if the height of ionization layer is 200 Km.

Soln.

$$f_{MUF} = f_c \sqrt{\left(\frac{D}{2H}\right)^2 + 1}$$

$$f_{MUF} = 7 \sqrt{\left(\frac{1000}{2 \times 200}\right)^2 + 1} = 18.25\ MHz$$

Problems

P23. A high frequency radio link has to be established between two points at a distance of 2000 Km on earth's surface. Considering the ionospheric height to be 250 Km and critical frequency 5 MHz, calculate the MUF for he given path.

Soln.

$$f_{MUF} = f_c \sqrt{\left(\frac{D}{2H}\right)^2 + 1}$$

$$f_{MUF} = 5 \sqrt{\left(\frac{2000}{2 \times 250}\right)^2 + 1} = 20.62\ MHz$$

Problems

P24. Determine the change in electron density of E layer when the critical frequency changes from 3 to 1.5 MHz between mid day and sun set.

Soln.

$$f_{c1} = 3 \times 10^6 = 9\sqrt{N_{max1}} \qquad f_{c2} = 1.5 \times 10^6 = 9\sqrt{N_{max2}}$$

$$f_{c1} - f_{c2} = 1.5 \times 10^6 = 9\left(\sqrt{N_{max1}} - \sqrt{N_{max2}}\right) \dots\dots\dots\dots (1)$$

$$f_{c1} + f_{c2} = 4.5 \times 10^6 = 9\left(\sqrt{N_{max1}} + \sqrt{N_{max2}}\right) \dots\dots\dots\dots (2)$$

(1)+(2) $6 \times 10^6 = 18\sqrt{N_{max1}}$

$$N_{max1} = 1.11 \times 10^{11}\ electrons\ /\ m^3$$

(2)-(1)

$$3 \times 10^6 = 18\sqrt{N_{max2}}$$

$$N_{max2} = 2.77 \times 10^{10}\ electrons\ /\ m^3$$

$$Change\ in\ electron\ density\ from\ 2.77 \times 10^{10}\ to\ 1.11 \times 10^{11}\ electrons\ /\ m^3$$