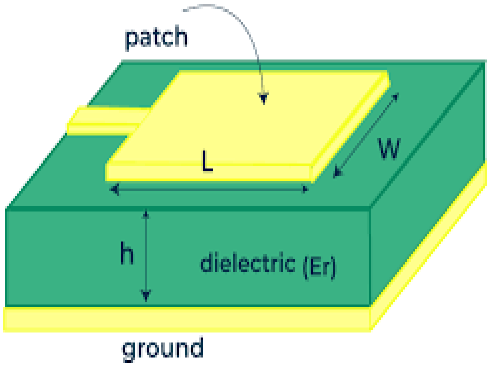
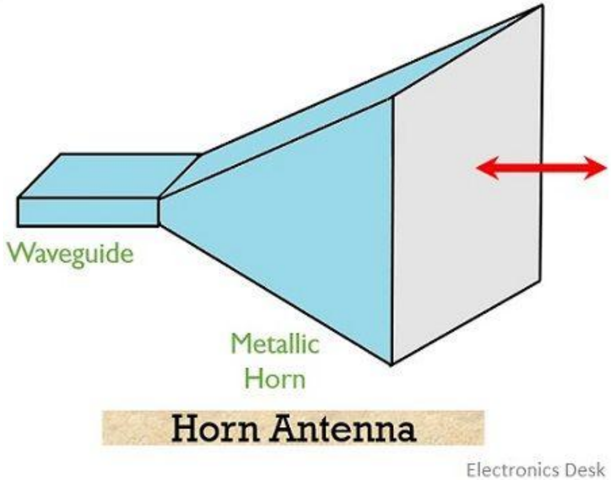
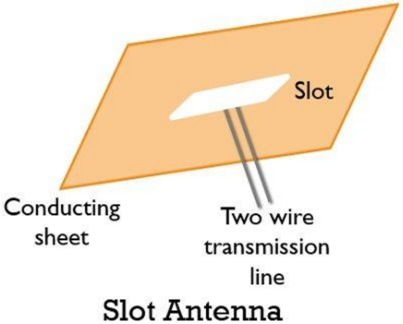
7REC02 Antennas and Propagation

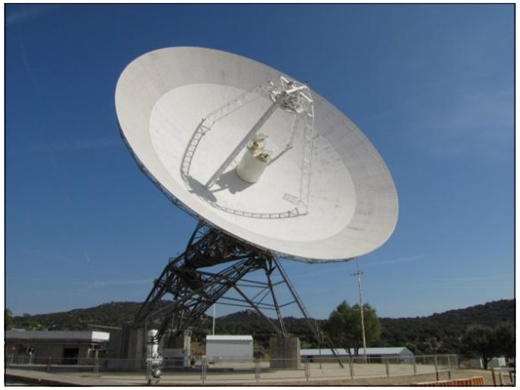


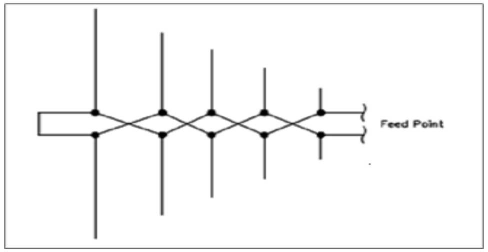
Unit – 4

Practical Antennas







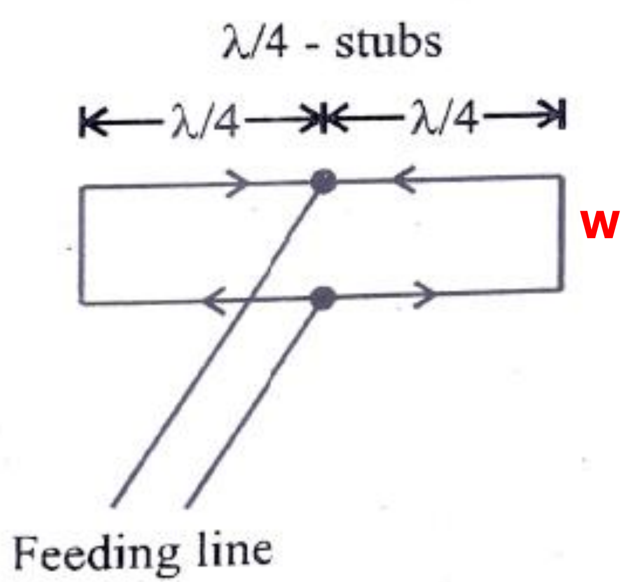


Practical Antennas

- Slot Antenna
- Complementary Antennas
- Horn Antenna
- Patch or Microstrip Antenna
- Log Periodic Antenna
- Reflector type Antenna
- Antennas for Special Applications
    - Terrestrial Mobile Communication
    - Ground Penetrating Radar
    - Embedded Antennas
    - Ultra wide Antenna for digital applications
    - Plasma Antennas
- Introduction to smart antennas

Slot Antenna

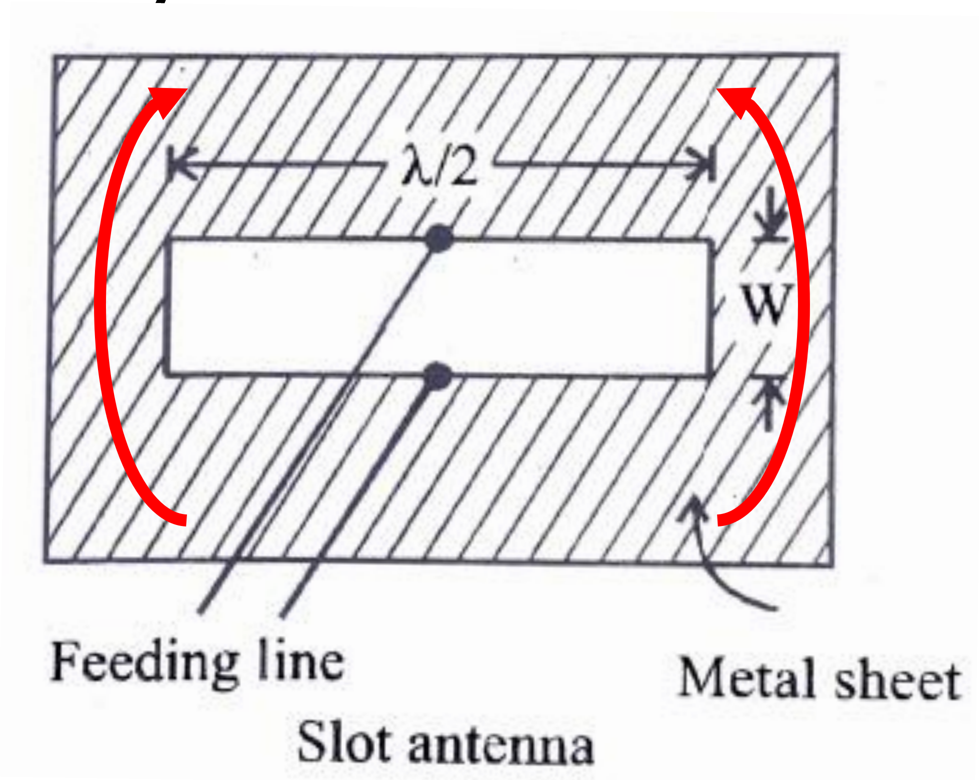
- A slot antenna consists of a metal surface, usually a flat plate, with one or more holes or slots cut out.
- Slot antennas are useful where low profile (small dimension) or flush mountings (inside) are required. Ex. High speed aircrafts
- Consider a system which contains two resonant λ/4 stubs connected to a 2-wire transmission line



- It is an inefficient radiator because
  - long wires are closely placed (W<<λ) and carry currents of opposite phase
  - hence their fields tend to cancel
  - End wires carry currents in the same phase, but they are too short to radiate efficiently
  - Large current is required radiate appreciable power

Slot Antenna contd.

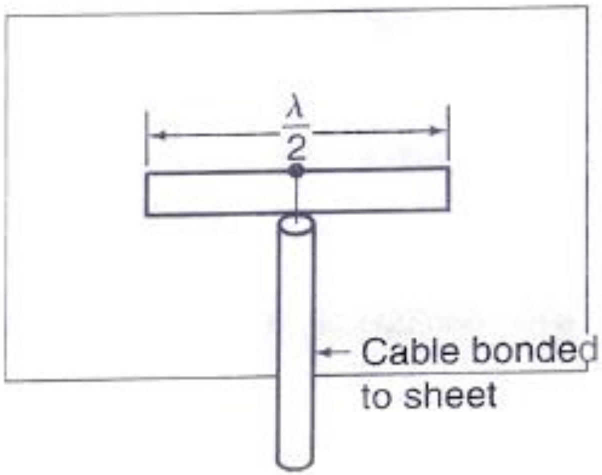
- Instead $\lambda/4$ stubs if $\lambda/2$ slot is cut in a flat metal sheet, the antenna will be very efficient



- although long wires are closely spaced (W<<L) the currents are not confined to the edges of the slot but spread out over the sheet

Slot Antenna contd.

▪ A slot antenna can be conveniently energized by a coaxial transmission line



▪ radiation occurs equally from both sides of the sheet

▪ Outer conductor is bonded to the metal sheet

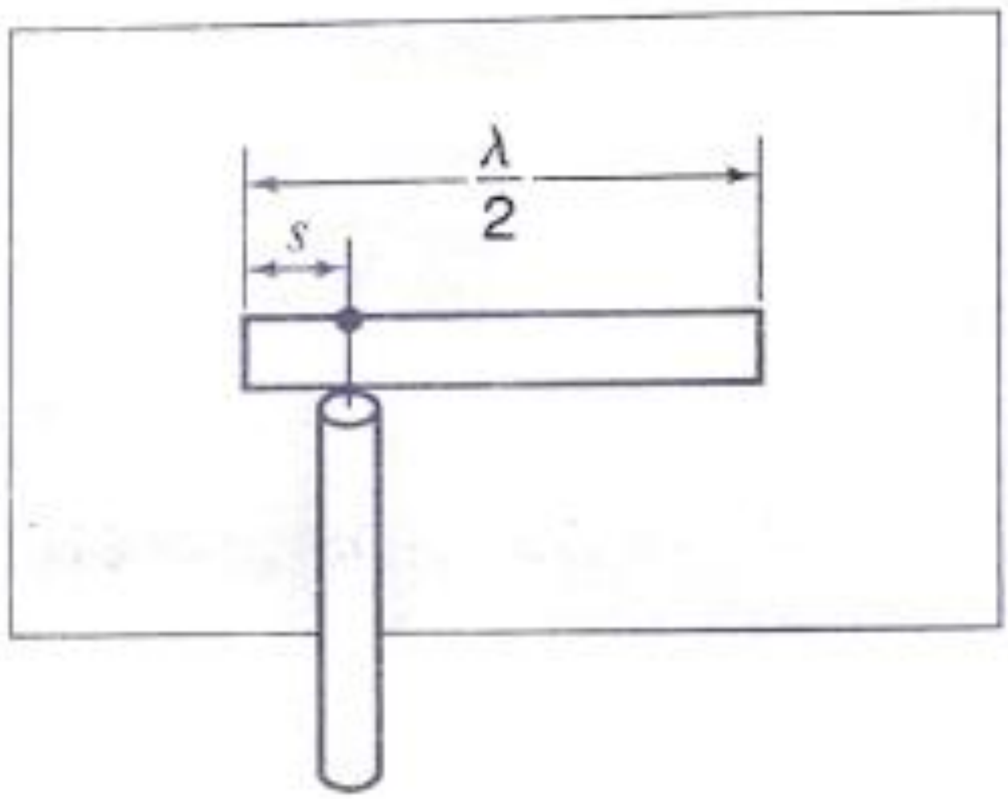
▪ The terminal resistance at the centre of a resonant $\lambda/2$ slot in a large sheet is about 500Ω

▪ Characteristics impedance of coaxial transmission line is usually much less

▪ hence impedance mismatch takes place

Slot Antenna contd.

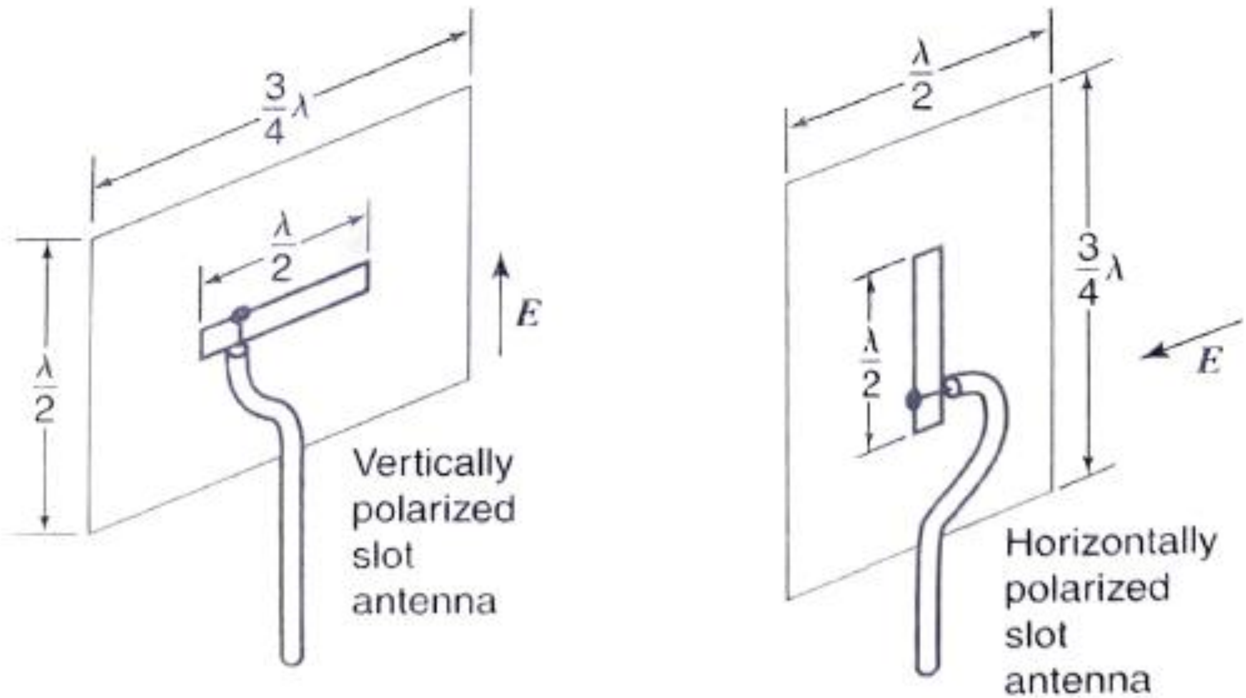
- **An off-centre feed may be used to provide better impedance match**



- **For a 50Ω coaxial cable the distance 's' should be about λ/20**

Slot Antenna contd.

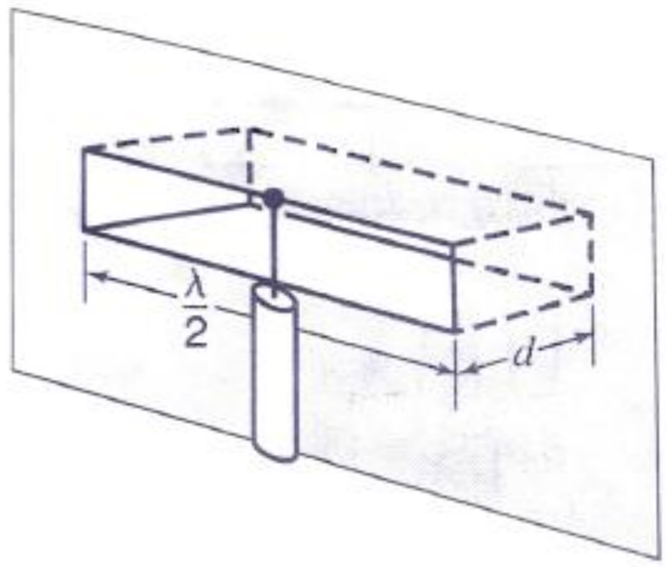
- **Slot antenna fed by a coaxial cable in off-centre manner are**



- **The radiation normal to the sheet with the horizontal slot is vertically polarized**
- **Radiation normal to the sheet with the vertical slot is horizontally polarized**

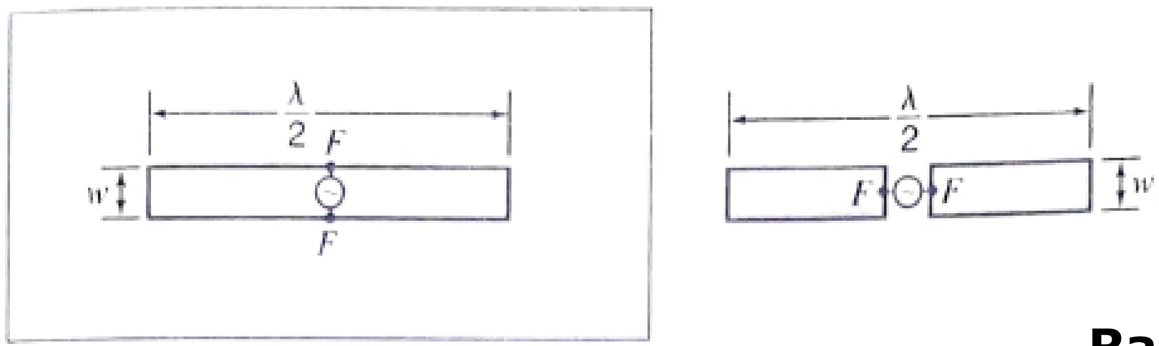
Slot Antenna contd.

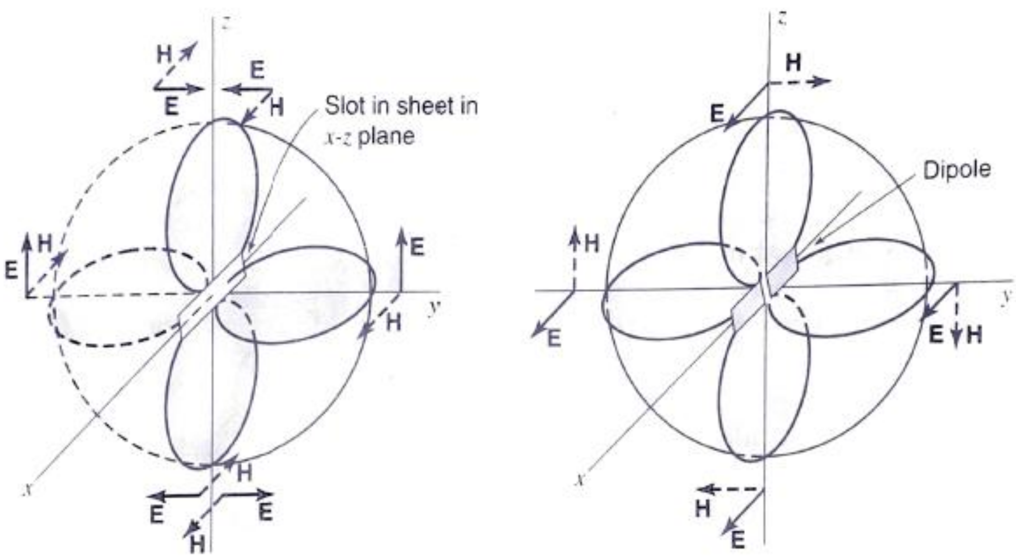
- A flat sheet with a $\lambda/2$ slot radiates equally on both sides of the sheet
- If the sheet is very large (ideally infinite) and boxed, radiation occurs only from one side



Patterns of slot antenna in flat sheet

- Consider a $\lambda/2$ slot antenna and complementary $\lambda/2$ dipole antenna





Radiation patterns are same, except

- Electric and magnetic fields are interchanged
- Component of the electric field of the slot normal to sheet is discontinuous

Babinet’s Principle and Complementary Antennas

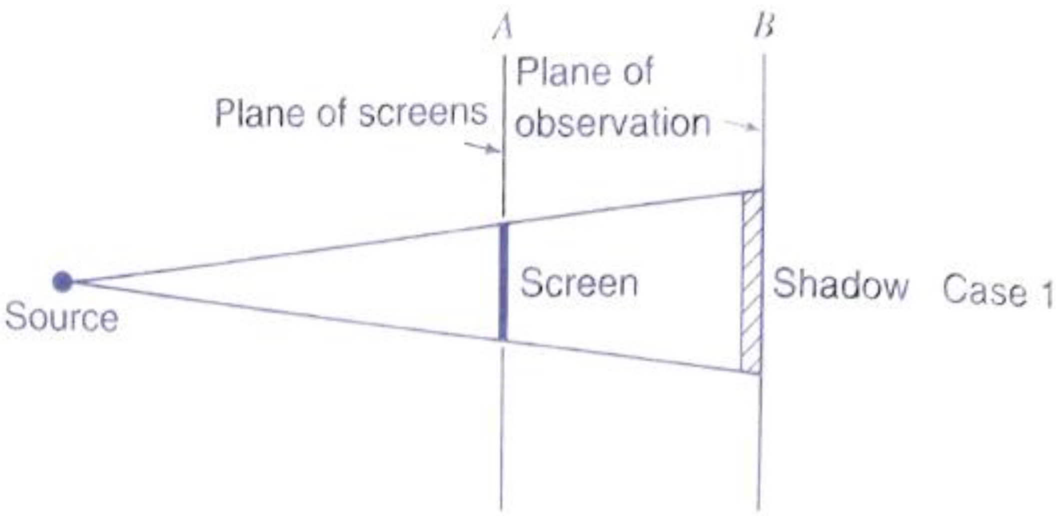
- **Babinet’s principles can be used to reduce the problems of slot antennas**

- **Babinet’s principle states that “The field at any point behind a plane having a screen, if added to the field at the same point when the complementary screen is substituted, is equal to the field when no screen is present (in optics).**

- **Principle is illustrated by considering an example with three cases. Let a source and two imaginary planes, plane of screen A and plane of observation B be arranged as shown**

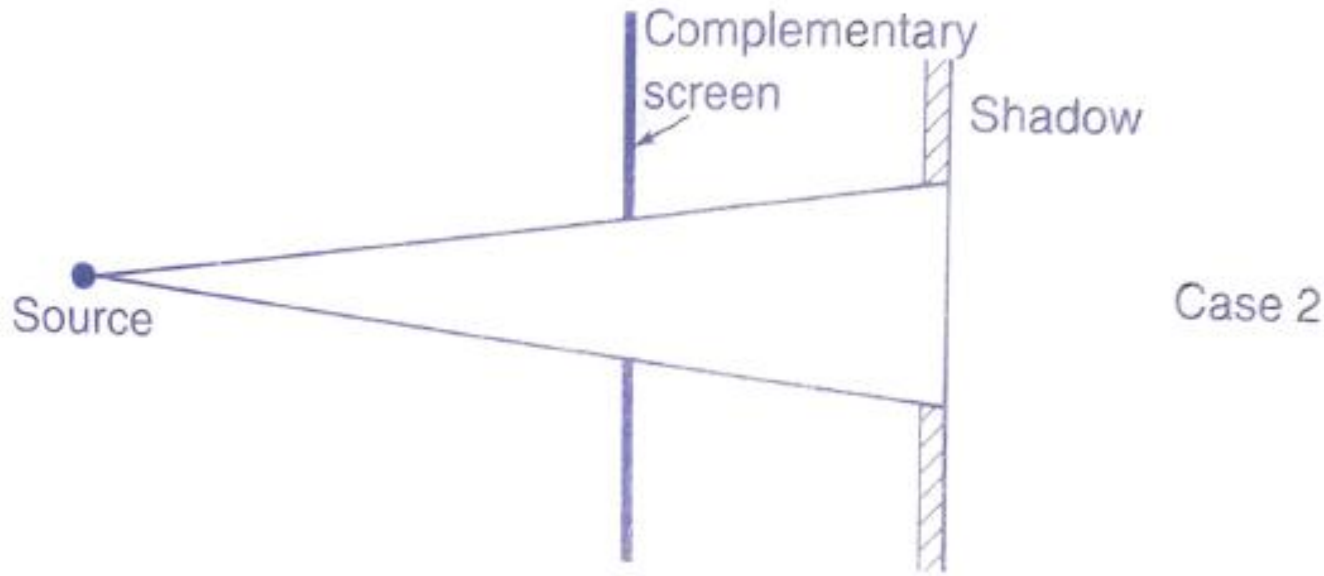
Contd.

- **Case 1: Let a perfectly absorbing screen be placed in Plane A. Then in plane B there is a region of shadow. Let field behind this screen be some function f1 of x, y and z. Thus Fs = f1(x,y,z)**



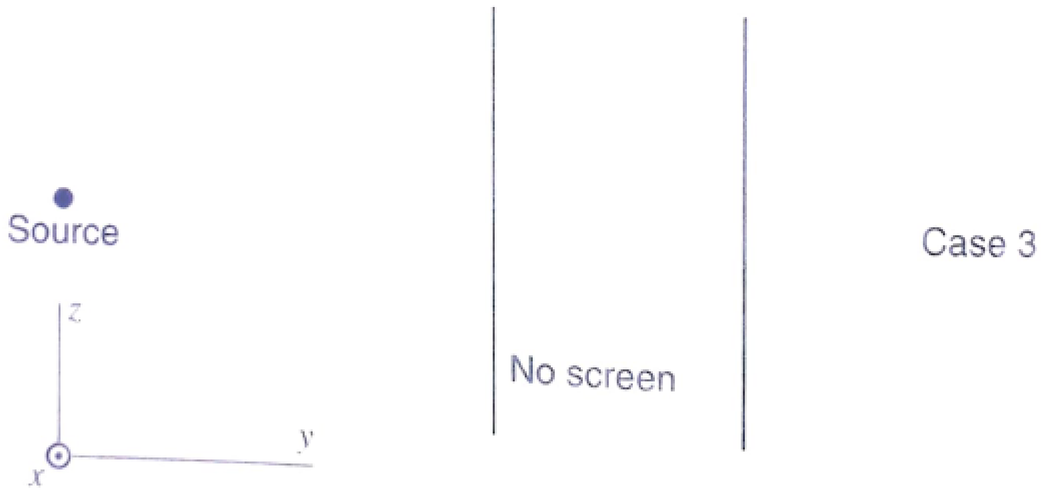
Contd.

- **Case 2: Let the first screen is replaced by its complementary screen and field behind it be given by Fcs = f2(x,y,z)**



Contd.

- **Case 3: With no field present the screen is Fo= f3(x,y,z)**



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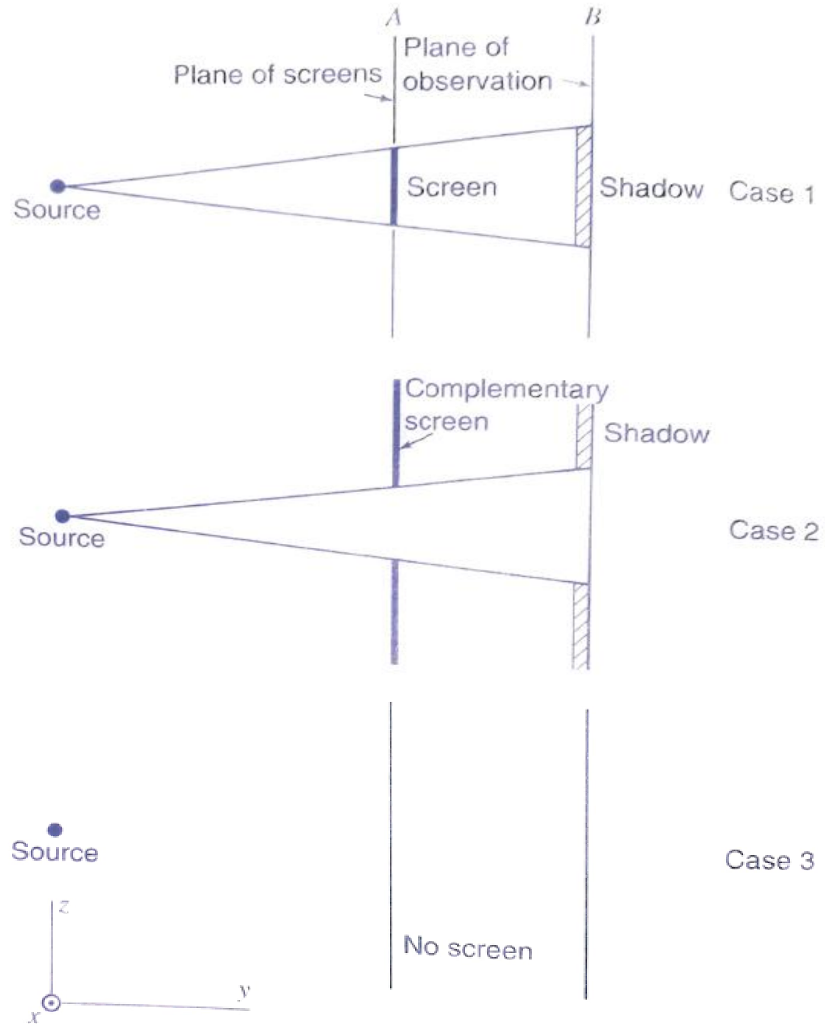


$$Fs + Fcs = Fo$$

Babinet's principle states that

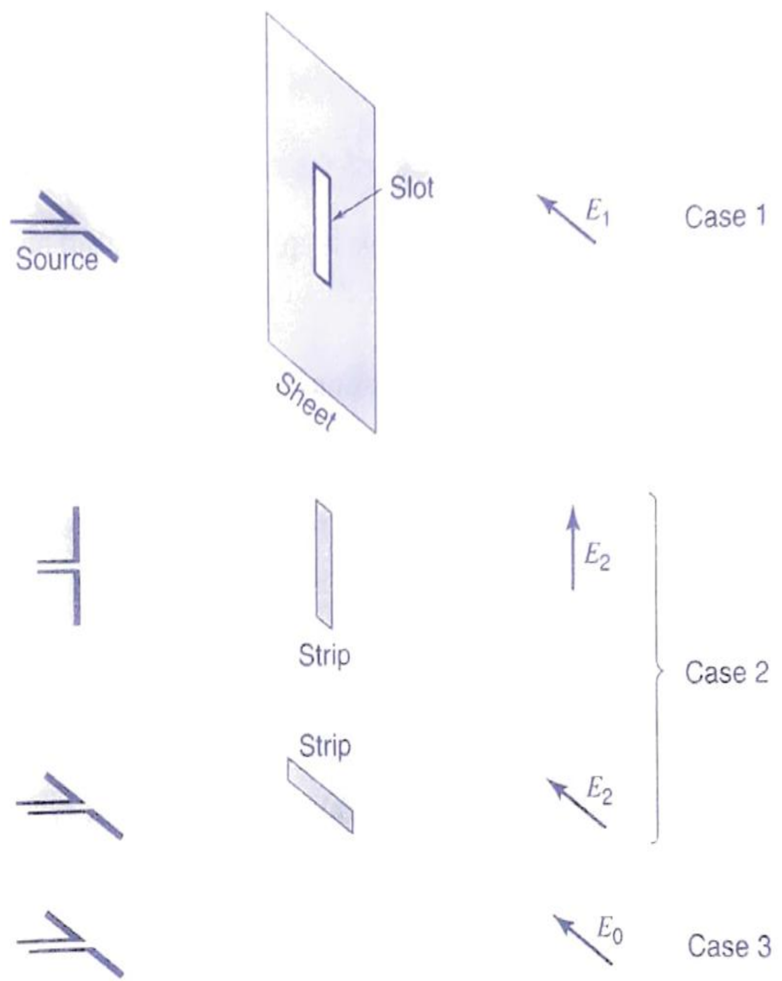
"The field at any point behind a plane having a screen, if added to the field at the same point when the complementary screen is substituted, is equal to the field when no screen is present (in optics).

The sources may be a point source or distribution of sources. The principle not only applies to plane B but also any point behind screen A

Contd.

- **Babinet's principle is extended to electromagnetic field**
- **In this screen should be perfectly conducting and infinitesimally thin**
- **i.e. if one screen is perfectly conducting the complementary screen is must have infinite permeability**
- **Thus if one screen is a perfect conductor of electricity the complementary screen is a perfect conductor of magnetism**

Contd.



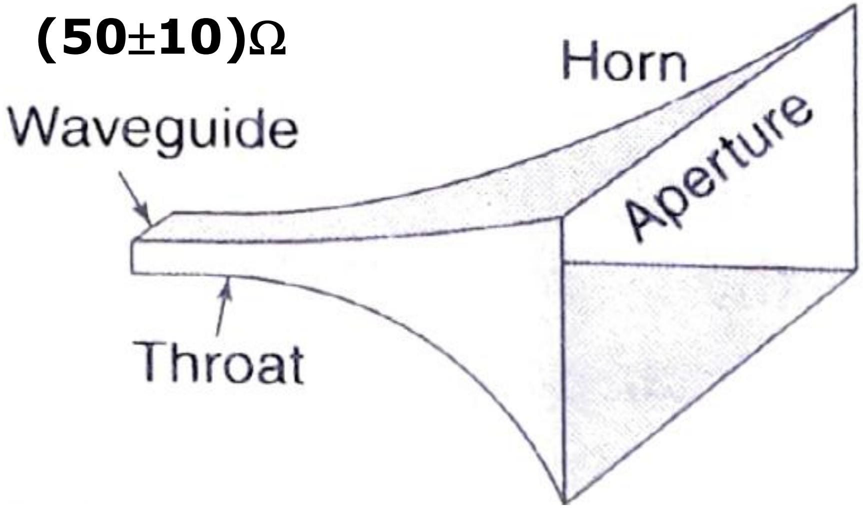
- **Case 1: Dipole is horizontal and screen is perfectly conducting thin sheet with a vertical slot cut. At point P behind the screen the field is E1**
- **Case 2: Complementary screen perfectly conducting thin strip of the same dimensions of the slot. At point P the field is E2**
- **Case 3: No screen is present and the field at point P is Eo**
- **By Babinet's principle**

$$E1 + E2 = Eo \qquad \frac{E1}{Eo} + \frac{E2}{Eo} = 1$$

Horn Antenna

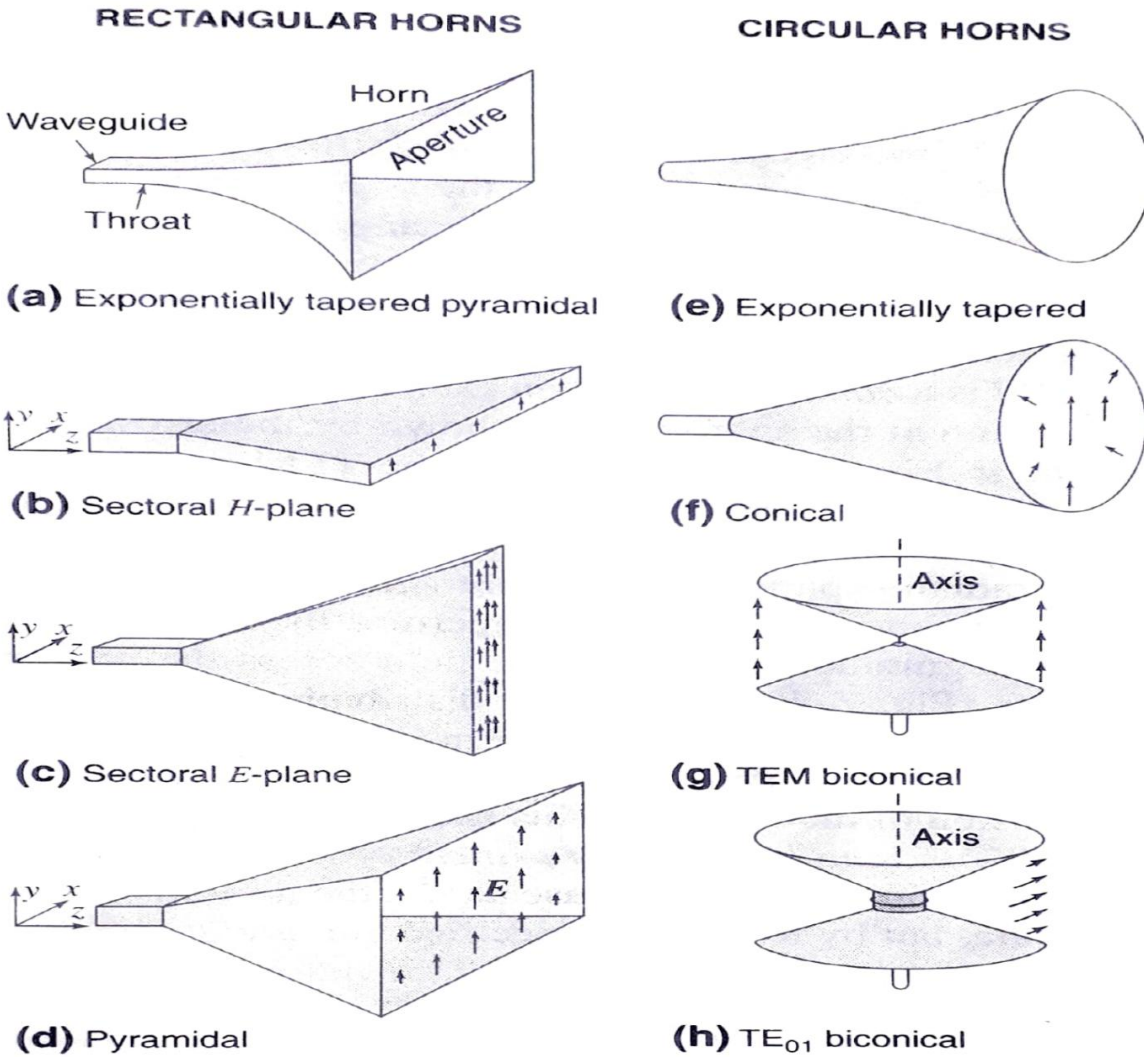
- A Horn antenna is a flared out (opened out) waveguide
  - It improves directivity and impedance matching
- Horn antenna produces
  - Uniform phase front with a larger aperture than that of waveguide, hence greater directivity
- J C Bose constructed a pyramid horn in 1897

(50±10)Ω

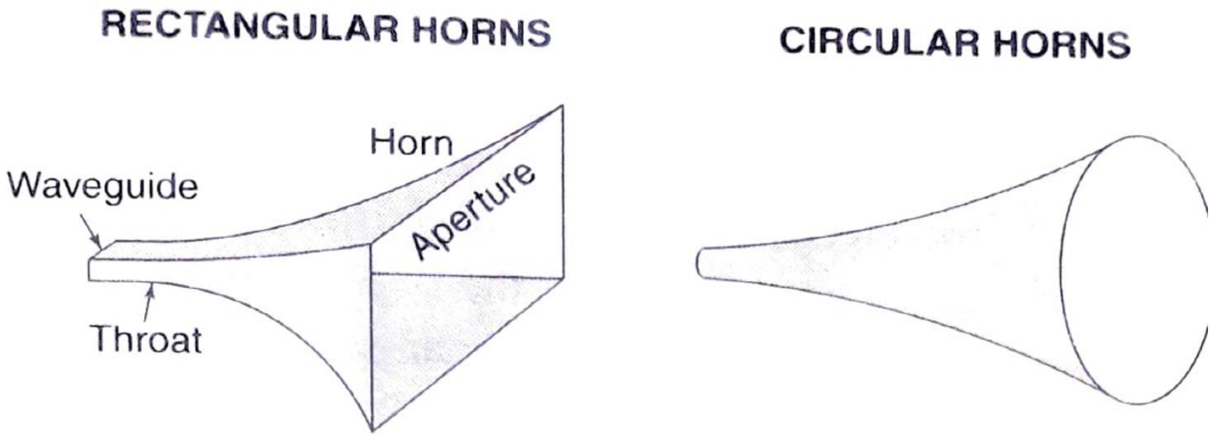


Free space
377Ω

Horn Antenna - Types



Horn Antenna contd.



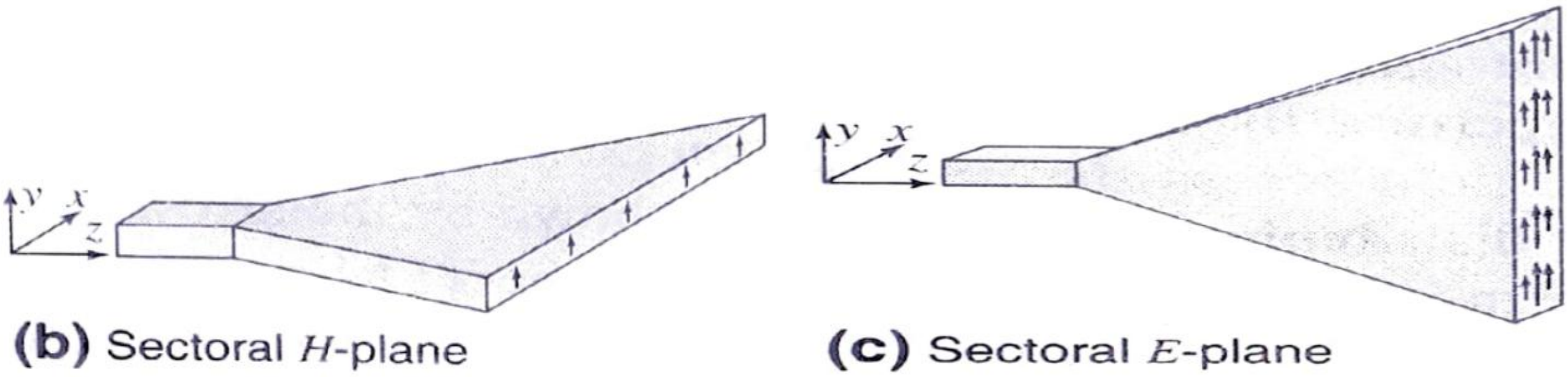
(a) Exponentially tapered pyramidal

(e) Exponentially tapered

- **To minimize reflections of the waveguide, the horn between the waveguide at the throat and the free space at the aperture could be given a gradual exponential taper (transition region)**

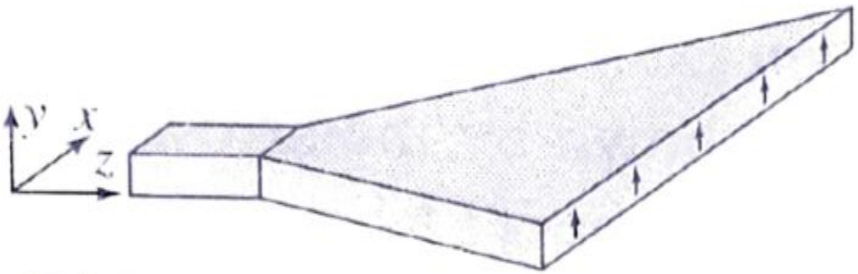
- **The general practice is to make horns with straight flares**

Horn Antenna contd.

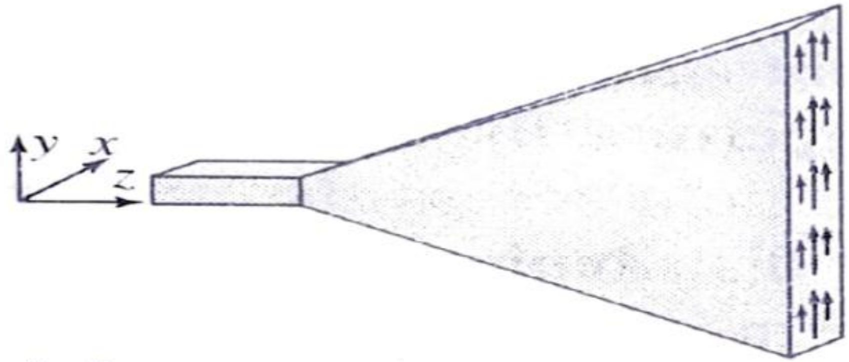


- These are sectoral antenna – rectangular type with flare in only one dimension
- Assuming rectangular waveguide is energized with TE_{10} mode wave electric field (E in the Y direction) [Fig. (b)]
    - horn is flared out in a plane perpendicular to E
    - this is the plane of the magnetic field H
    - Sectoral horn flared in H plane (H-plane sectoral horn)

Horn Antenna contd.

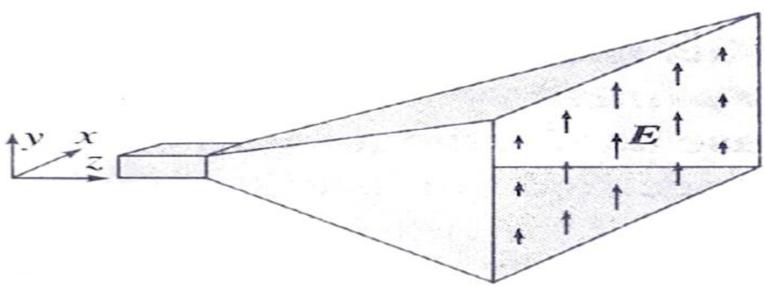


(b) Sectoral H-plane



(c) Sectoral E-plane

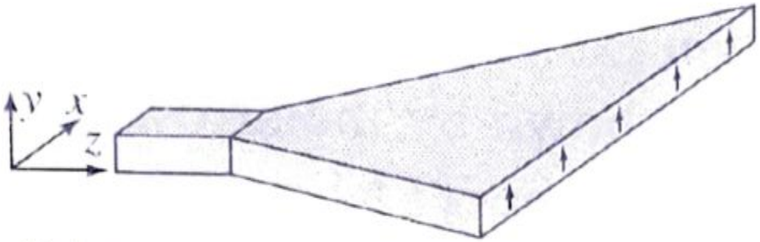
- If horn is flared out in a plane of the electric field E [Fig. (c)]
- Sectoral horn flared in E plane (E-plane sectoral horn)
- Rectangular antenna with flare on both sides is called pyramidal horn



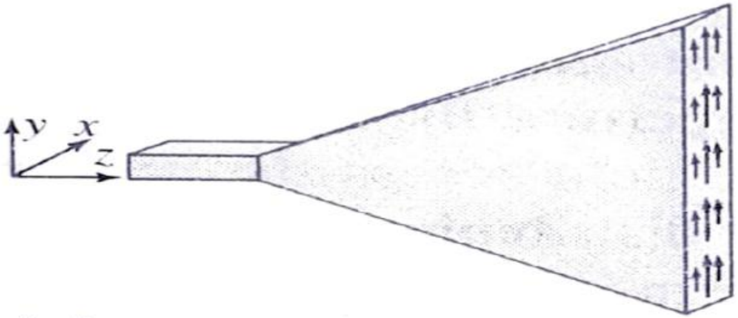
(d) Pyramidal

Horn Antenna contd.

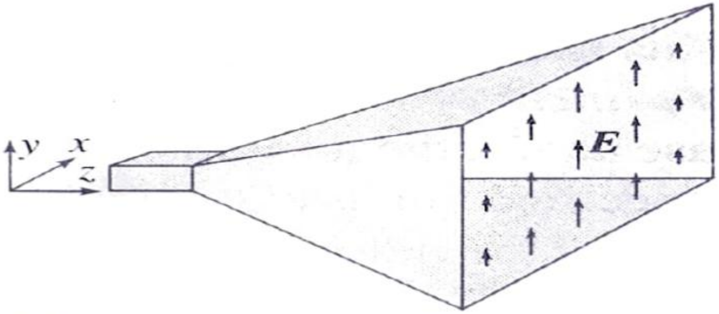
- with TE_{10} wave (electric field perpendicular to direction of propagation) in the waveguide the magnitude of electric field is uniform in the y-direction and zero in the x-direction



(b) Sectoral *H*-plane



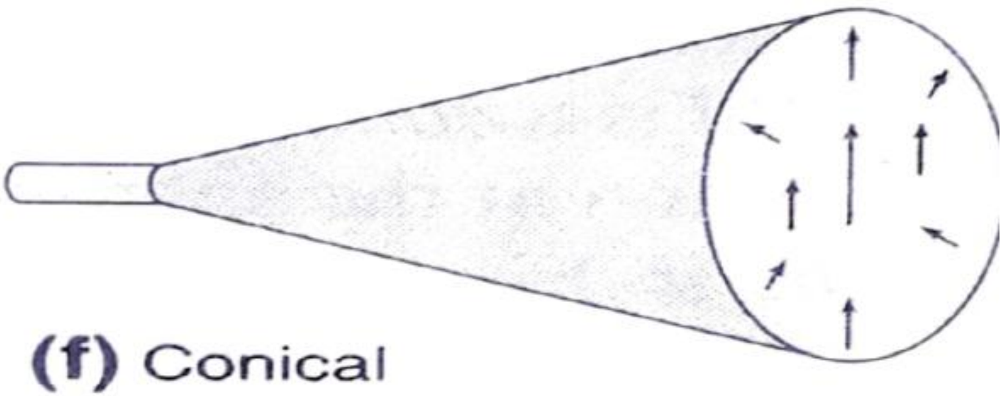
(c) Sectoral *E*-plane



(d) Pyramidal

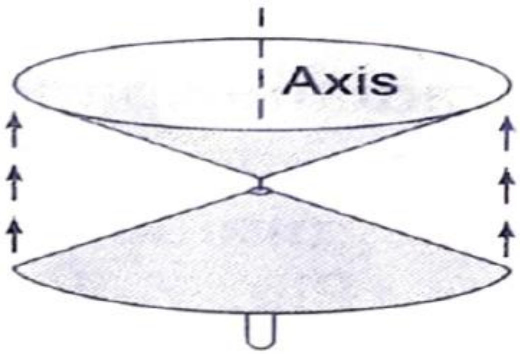
- arrow indicates the direction of E and length gives approximate magnitude of E

Horn Antenna contd.

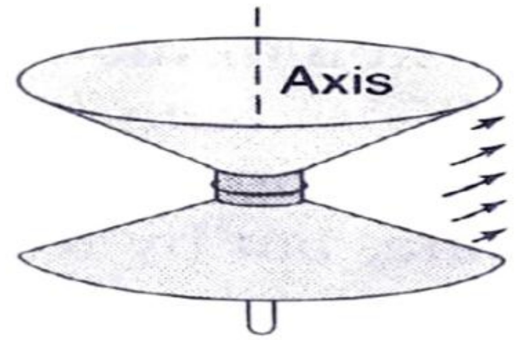


- The horn is conical type
- excited with circular guide in TE_{11} mode
  - TE_{11} → electric field and magnetic field are perpendicular to direction of propagation

Horn Antenna contd.



(g) TEM biconical

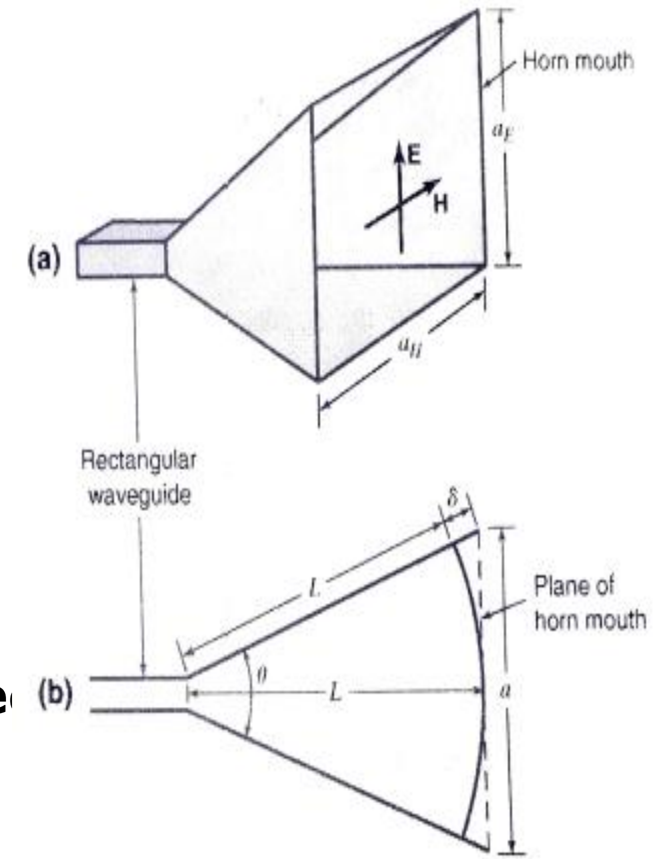


(h) TE_{01} biconical

- horns are biconical type
- excited in the TEM (transverse electromagnetic) mode by the vertical radiator [Fig. (g)]
    - electric and magnetic fields are restricted to perpendicular to the direction of propagation
- excited with TE_{01}mode by a small horizontal loop antenna
- these horns are non directional in the horizontal plane

Horn Antenna contd.

- Neglecting the edge effects, the radiation pattern of the horn antenna can be determined
    - if the aperture dimensions and field distribution (aperture distribution) are known
- if the flare angle is too great, the phase distribution over the mouth will be non uniform, resulting in
    - decreased directivity and increased beam width
    - minor lobes are likely to appear
- if the flare angle is too small, results in small aperture area and directivity is reduce



Horn Antenna contd.

$$Cos\frac{\theta}{2} = \frac{L}{L+\delta}$$

$$Sin\frac{\theta}{2} = \frac{a}{2(L+\delta)}$$

$$tan\frac{\theta}{2} = \frac{a}{2L}$$

$\theta \rightarrow flare\ angle\ in\ degrees$

$\theta_E \rightarrow for\ E-plane$

$\theta_H \rightarrow for\ H-plane$

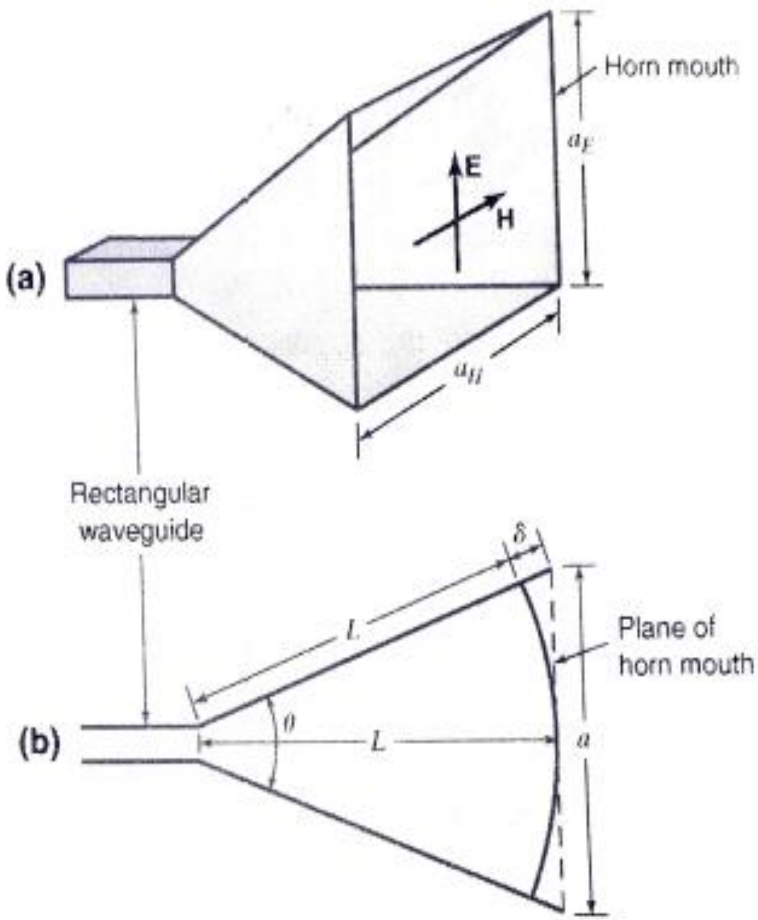
$a \rightarrow aperture\ in\ meters$

$a_E \rightarrow for\ E-plane$

$a_H \rightarrow for\ H-plane$

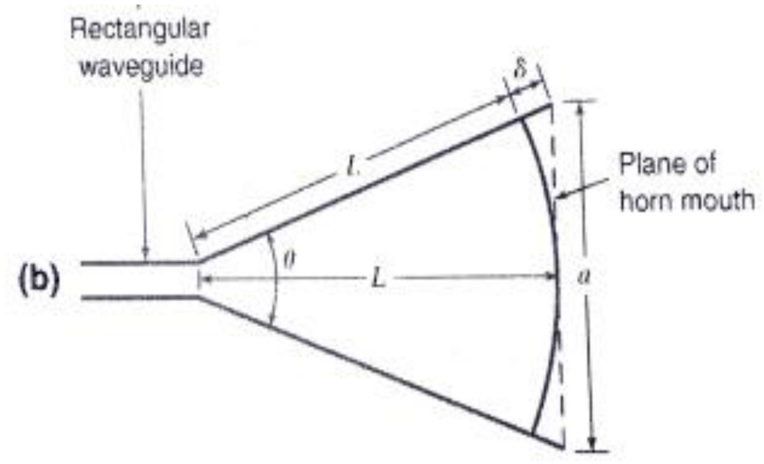
$L \rightarrow Horn\ length\ in\ meters$

$\delta \rightarrow path\ length\ difference\ in\ meters$



Horn Antenna contd.

From the geometry we have that



$$(L+\delta)^2 = L^2 + \left(\frac{a}{2}\right)^2$$

$$L^2 + 2L\delta + \delta^2 = L^2 + \frac{a^2}{4}$$

$$2L\delta = \frac{a^2}{4} \qquad since\ \delta \ll L$$

$$L = \frac{a^2}{8\delta}$$

$$\theta = 2\tan^{-1}\frac{a}{2L} = 2\,Cos^{-1}\frac{L}{L+\delta}$$

In the E-plane of horn, δ is usually held to 0.25λ or less

In the H-plane, δ is 0.4λ or greater

$$A_p = a_E\, a_H \quad for\ rectangular\ horn$$

$$D = \frac{7.5\,A_p}{\lambda^2} \qquad D = 10\,Log_{10}\frac{7.5\,A_p}{\lambda^2}\ dB$$

$$A_p = \pi\, r^2 \quad for\ conical\ horn$$

Horn Antenna contd.

- To obtain minimum aperture a long horn with small flare angle is required
- for practical convenience a horn should be as short as possible
- optimum horn should be between these extremes and has the minimum beam width without excessive side lobe levels for given length

$$\delta_0 = \frac{L}{Cos\,\frac{\theta}{2}} - L \rightarrow optimum\,\delta$$

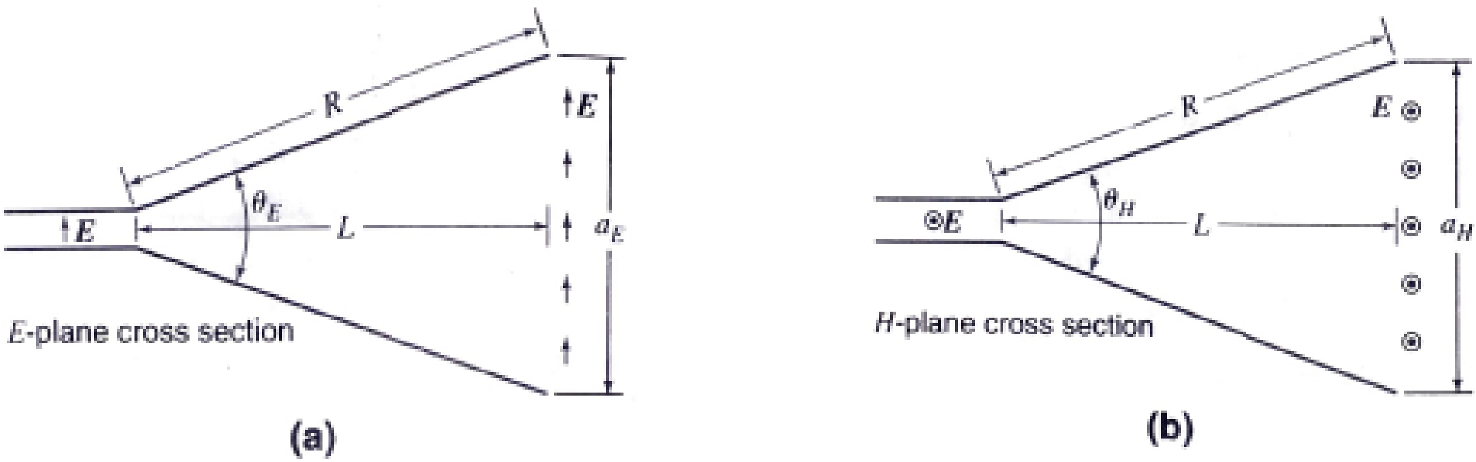
$$L = \frac{\delta_0\,Cos\,\frac{\theta}{2}}{1 - Cos\,\frac{\theta}{2}} \rightarrow optimum\,Length$$

$$Optimum\,E - plane\,rectangular\,horn, HPBW = \frac{56}{a_{E\lambda}} \qquad BWFN = \frac{115}{a_{E\lambda}}$$

$$Optimum\,H - plane\,rectangular\,horn, HPBW = \frac{67}{a_{H\lambda}} \qquad BWFN = \frac{175}{a_{H\lambda}}$$

Rectangular Horn Antenna

- If aperture in both planes of a rectangular horn exceeds 1λ, the pattern in one plane will be independent of aperture in the other plane

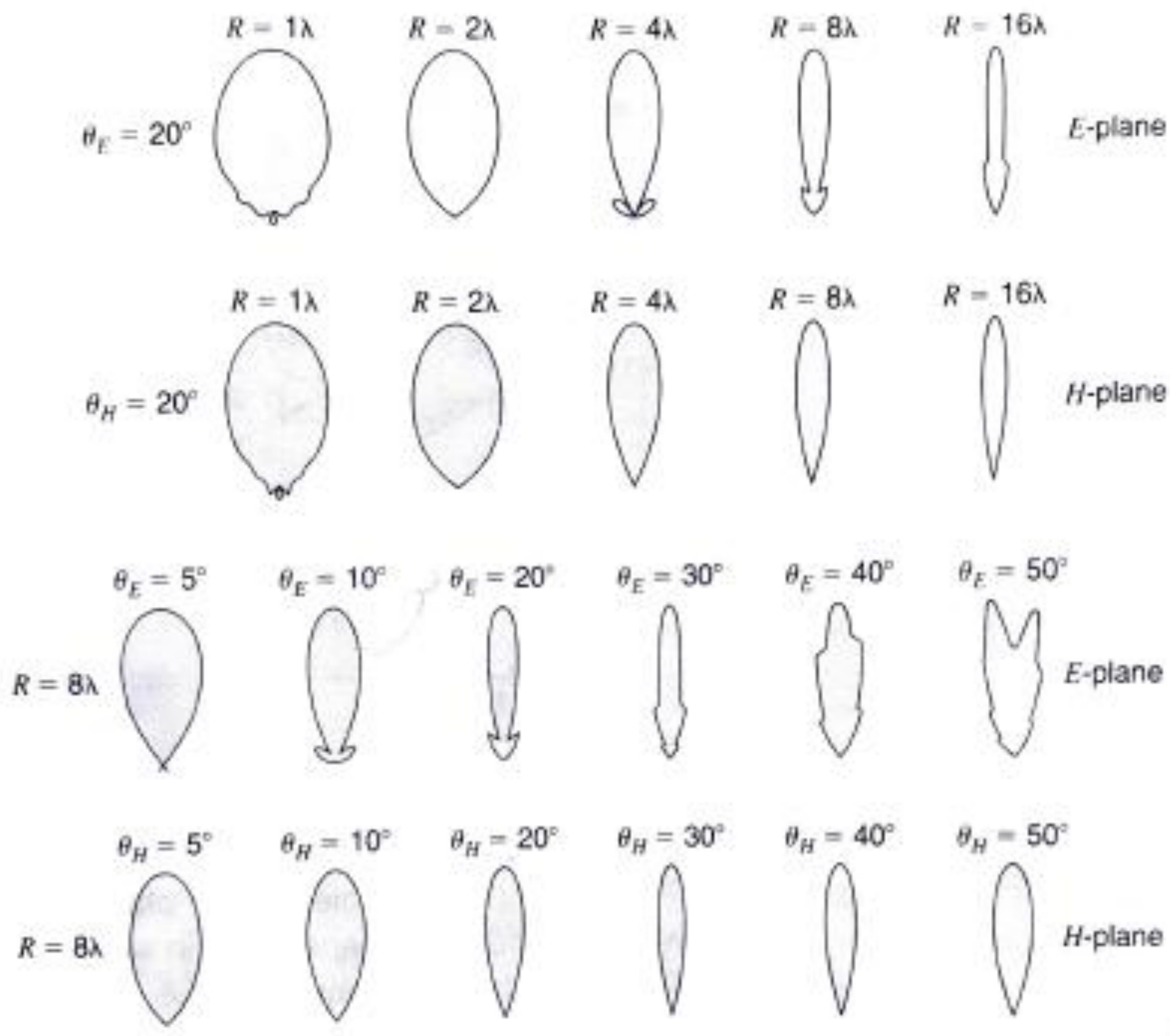


- The measured E and H plane field patterns of rectangular horn as a function of flare angle and horn length for $a_E > 1\lambda$ and $a_H > 1\lambda$ is

Rectangular Horn Antenna contd.

Has minor lobes

No minor lobes



splits

No split

Problems

P1. Determine the length L, H-plane aperture and flare angle θE and θH of a pyramidal horn for which E-plane aperture aE = 10λ. The horn is fed by a rectangular waveguide with TE10 mode. Let δ is 0.2λ in the E-plane and 0.375λ in the H-plane. Also, find the half power beam widths and directivity.

Soln.

$$L = \frac{a^2}{8\delta} = \frac{(10\lambda)^2}{8 \times 0.2\lambda} = 62.5\lambda$$

$$Flare\ angle\ in\ E - plane$$

$$\theta_E = 2\ tan^{-1}\frac{a}{2L} = 2tan^{-1}\frac{10\lambda}{2 \times 62.5\lambda} = 9.1^\circ$$

$$Flare\ angle\ in\ H - plane,$$

$$\theta_H = 2\ Cos^{-1}\frac{L}{L + \delta} = 2Cos^{-1}\frac{62.5\lambda}{62.5 + 0.375\lambda} = 12.52^\circ$$

$$L = \frac{a^2}{8\delta}$$

$$\theta_E = 2\ tan^{-1}\frac{a}{2L}$$

$$\theta_H = 2\ Cos^{-1}\frac{L}{L + \delta}$$

$$HPBW\ (E - plane) = \frac{56}{a_{E\lambda}}$$

$$HPBW\ (H - plane) = \frac{67}{a_{H\lambda}}$$

$$D = 10\ Log_{10}\frac{7.5\ A_p}{\lambda^2}\ dB$$

Problems

$$\theta_H = 2\,tan^{-1}\frac{a_H}{2L}$$

$$L = \frac{a^2}{8\delta}$$

$$\frac{\theta_H}{2} = tan^{-1}\frac{a_H}{2L}$$

$$\theta_E = 2\,tan^{-1}\frac{a}{2L}$$

$$tan\frac{\theta_H}{2} = \frac{a_H}{2L}$$

$$\theta_H = 2\,Cos^{-1}\frac{L}{L+\delta}$$

$$a_H = 2Ltan\frac{\theta_H}{2} = 2\times 62.5\lambda\,tan\left(\frac{12.52}{2}\right) = 13.7\lambda$$

$$HPBW\,(E-plane) = \frac{56}{a_{E\lambda}}$$

$$HPBW\,(E-plane) = \frac{56}{a_{E\lambda}} = \frac{56}{10} = 5.6^\circ$$

$$HPBW\,(H-plane) = \frac{67}{a_{H\lambda}}$$

$$HPBW\,(H-plane) = \frac{67}{a_{H\lambda}} = \frac{67}{13.7} = 4.9^\circ$$

$$D = 10\,Log_{10}\frac{7.5\,A_p}{\lambda^2}\,dB$$

$$D = 10\,Log_{10}\frac{7.5\ \times 10\lambda\times 13.7\lambda}{\lambda^2} = 30.1\,dB$$

Problems

P2. Calculate the power gain of an optimum horn antenna whose one side of square aperture is 10λ.

Soln.

$$A = a^2$$

$$A = a^2 = (10\lambda)^2 = 100\lambda^2$$

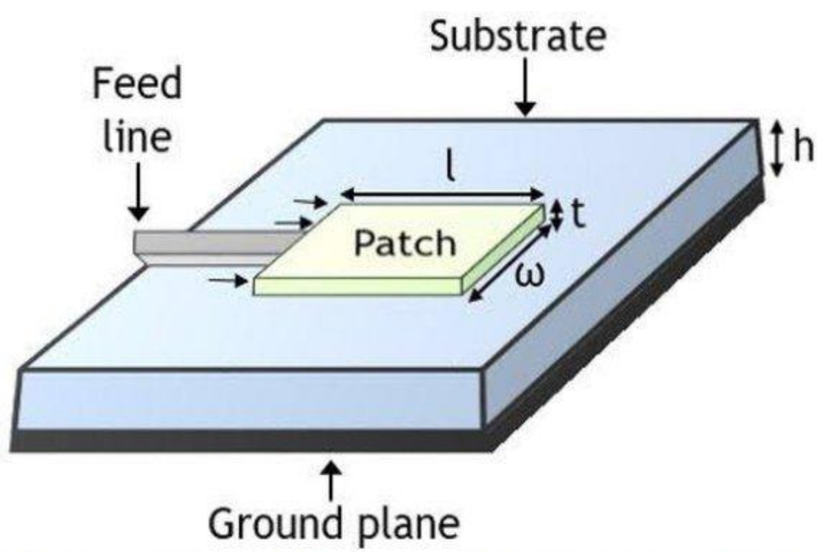
$$Gain = 4.5\frac{A}{\lambda^2}$$

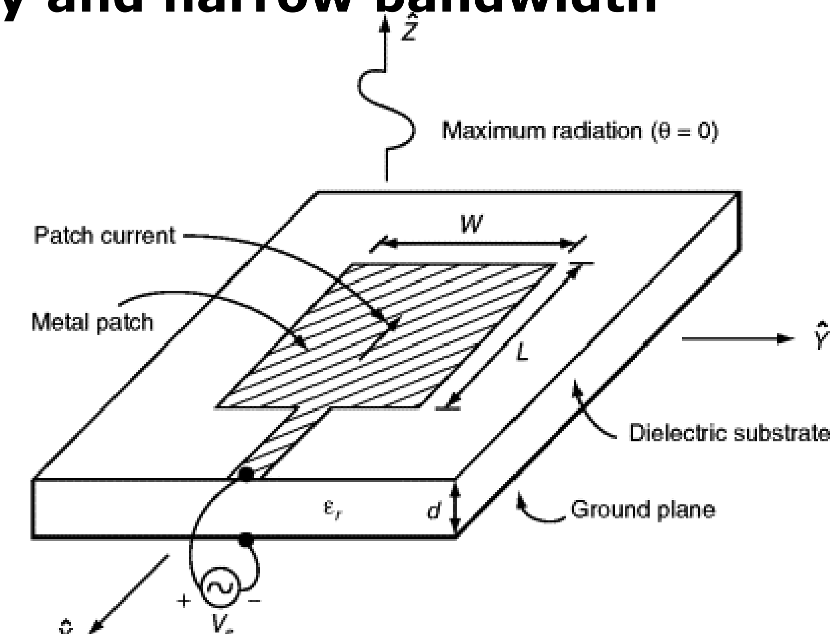
$$Gain = 4.5\frac{A}{\lambda^2} = 450$$

$$Gain\ in\ dB = 10\ Log_{10}450 = 26.53\ dB$$

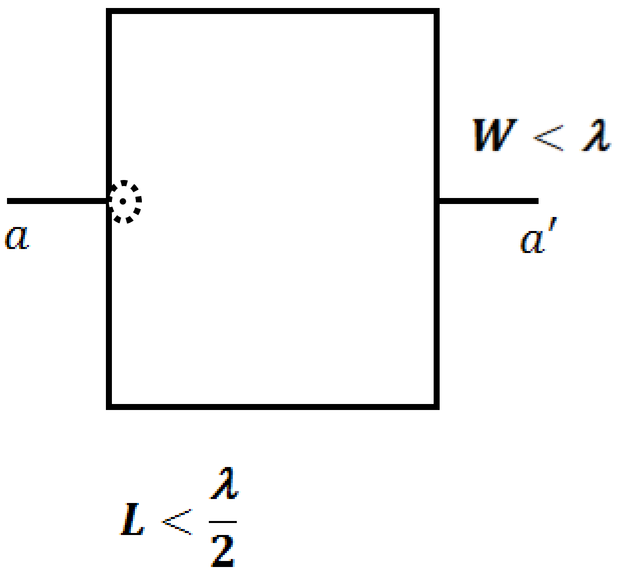
Patch or Microstrip Antenna

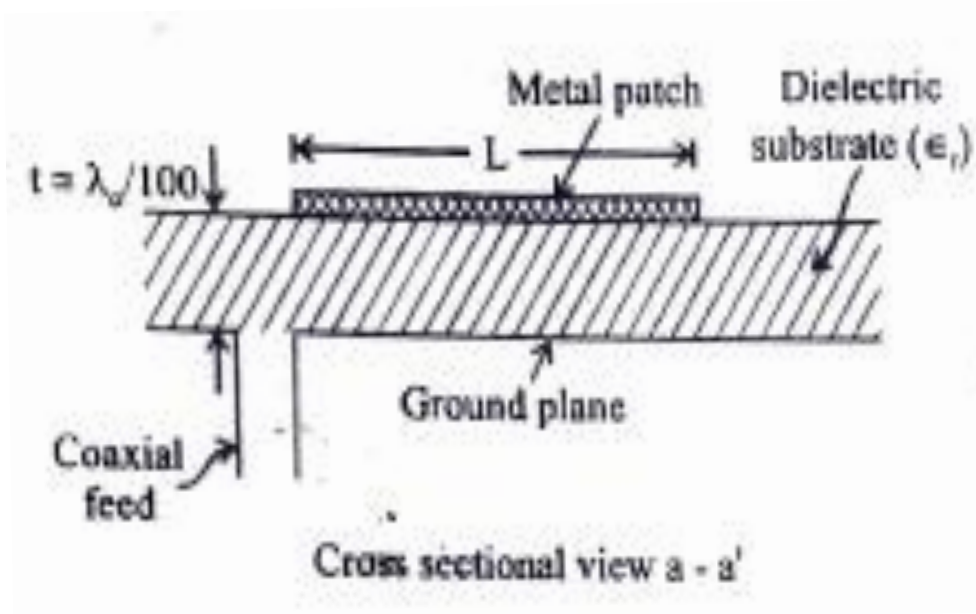
- Popular for low profile and frequencies above 100 MHz (λ_0 < 3m)
- Rectangular or square metal patch on a thin layer of dielectric substrate on a ground plane
- Patches may be photoetched for low cost mass production
- It can be fabricated on printed circuit board (PCB)
- Installation is very easy – low size, weight and cost
- Drawbacks : less radiation efficiency and narrow bandwidth



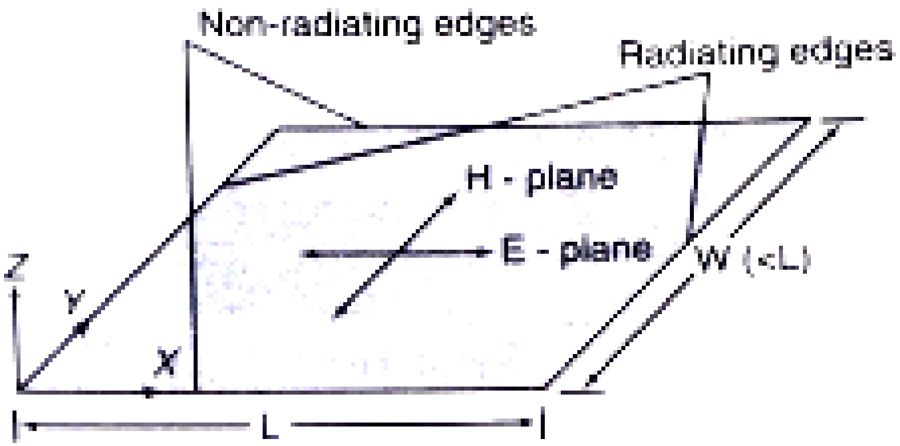


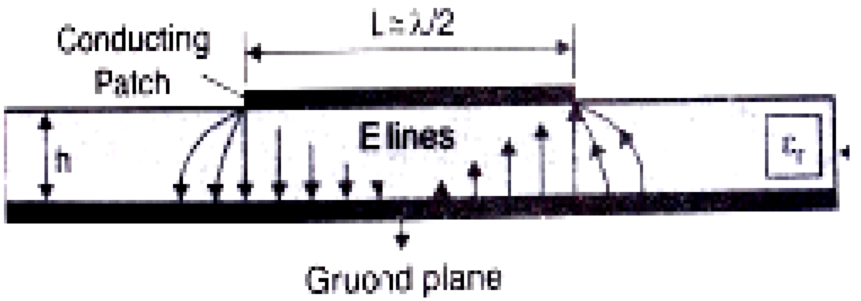
Typical dimensions of patch





Patch or Microstrip Antenna contd.

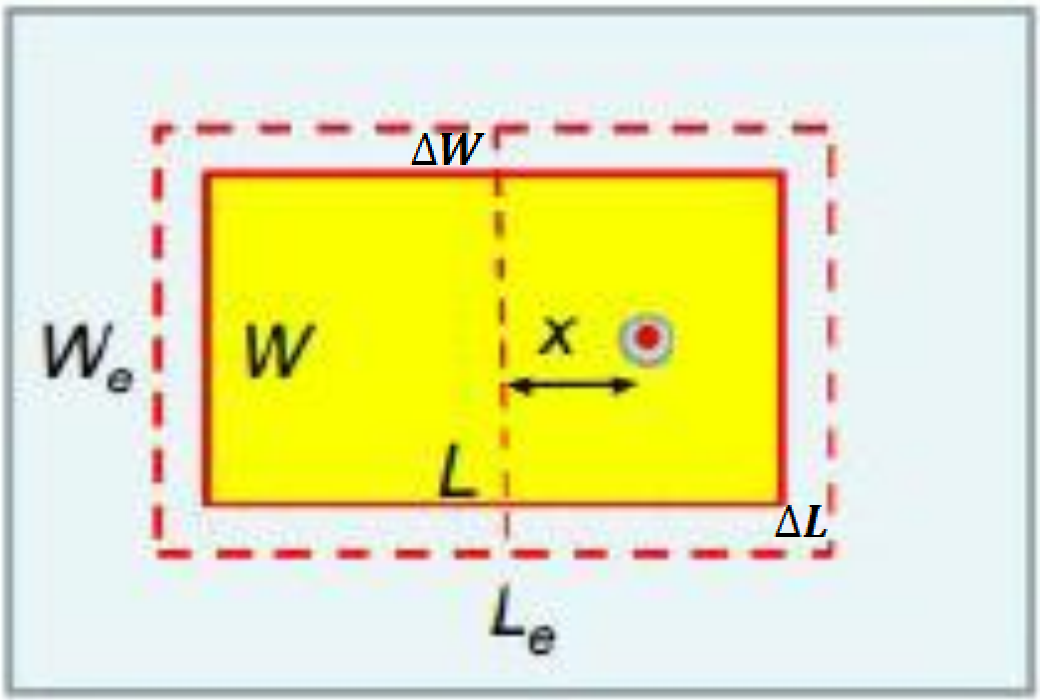




- **Radiation - only on left and right sides of L, not in other sides**
- **Horizontal components of the electric field at the left and right edges are in the same direction**
    - **giving in phase linearly polarized radiation with maximum broadside to the path**
- **if L=λ/2, patch acts like resonant λ/2 parallel plate transmission line**

Patch or Microstrip Antenna contd.

Design



$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{10h}{W}\right]^{-1/2}$$

$$L_e = L + 2\,\Delta L = \frac{\lambda_0}{2\sqrt{\epsilon_e}} = \frac{C}{2f_0\sqrt{\epsilon_e}}$$

$$L_e = L + 2\,\Delta L$$

$$W_e = W + 2\,\Delta W$$

$$\Delta L = \frac{h}{\sqrt{\epsilon_e}}$$

$$f_0 = \frac{C}{2\sqrt{\epsilon_e}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{1/2}$$

m and n are orthogonal modes of excitation

$m = 1$ and $n = 0$ for TM_{10} mode

$$W = \frac{C}{2f_0\sqrt{\frac{\epsilon_r + 1}{2}}}$$

Since BW and $G \,\alpha\, W$

W can be suitable selected

P1. Design a rectangular microstrip antenna (RMSA) for WiFi application (2.4 to 2.483GHz). Choose substrate with ε_r=2.32, h=0.16cm.

$$W = \frac{C}{2f_0\sqrt{\frac{\epsilon_r + 1}{2}}}$$

Soln.

$$f_0 = \frac{(2.4 + 2.483) \times 10^9}{2} = 2.4415 \times 10^9 Hz$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{10h}{W}\right]^{-1/2}$$

$$W = \frac{3 \times 10^{10}}{2 \times 2.4415 \times 10^9 \times \sqrt{\frac{2.32 + 1}{2}}} = 4.77\ cm$$

$$L_e = \frac{C}{2f_0\sqrt{\epsilon_e}}$$

$$\epsilon_e = \frac{2.32 + 1}{2} + \frac{2.32 - 1}{2}\left[1 + \frac{10 \times 0.16}{4.77}\right]^{-1/2} = 2.23$$

$$\Delta L = \frac{h}{\sqrt{\epsilon_e}}$$

$$L_e = \frac{3 \times 10^{10}}{2 \times 2.4415 \times 10^9 \times \sqrt{2.23}} = 4.11\ cm$$

Problems

$$W = \frac{C}{2f_0\sqrt{\frac{\epsilon_r + 1}{2}}}$$

$$\Delta L = \frac{0.16}{\sqrt{2.23}} = 0.107\ cm$$

$$L = L_e - 2\,\Delta L = 4.11 - 2 \times 0.107 = 3.896\ cm$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{10h}{W}\right]^{-1/2}$$

$$L_e = \frac{C}{2f_0\sqrt{\epsilon_e}}$$

$$\Delta L = \frac{h}{\sqrt{\epsilon_e}}$$

Frequency Independent Antenna

- **Antenna for which impedance and radiation characteristics are independent of frequency (wide band antenna)**
- **How to achieve?**
  - **Antenna should expand or contract in proportion to the frequency**
  - **If antenna structure is not mechanically adjustable, the size of the radiating region should be proportional to the frequency**
- **Frequency independent antenna**
  - **will have fixed shape and size, operates for wide frequency**
  - **relatively constant impedance, gain, pattern and polarization**
- **Example : Log Periodic Dipole Antenna (LPDA)**
- **Rumsey's Principle : The impedance and pattern properties of an antenna are frequency independent if the antenna shape is specified by the angle.**

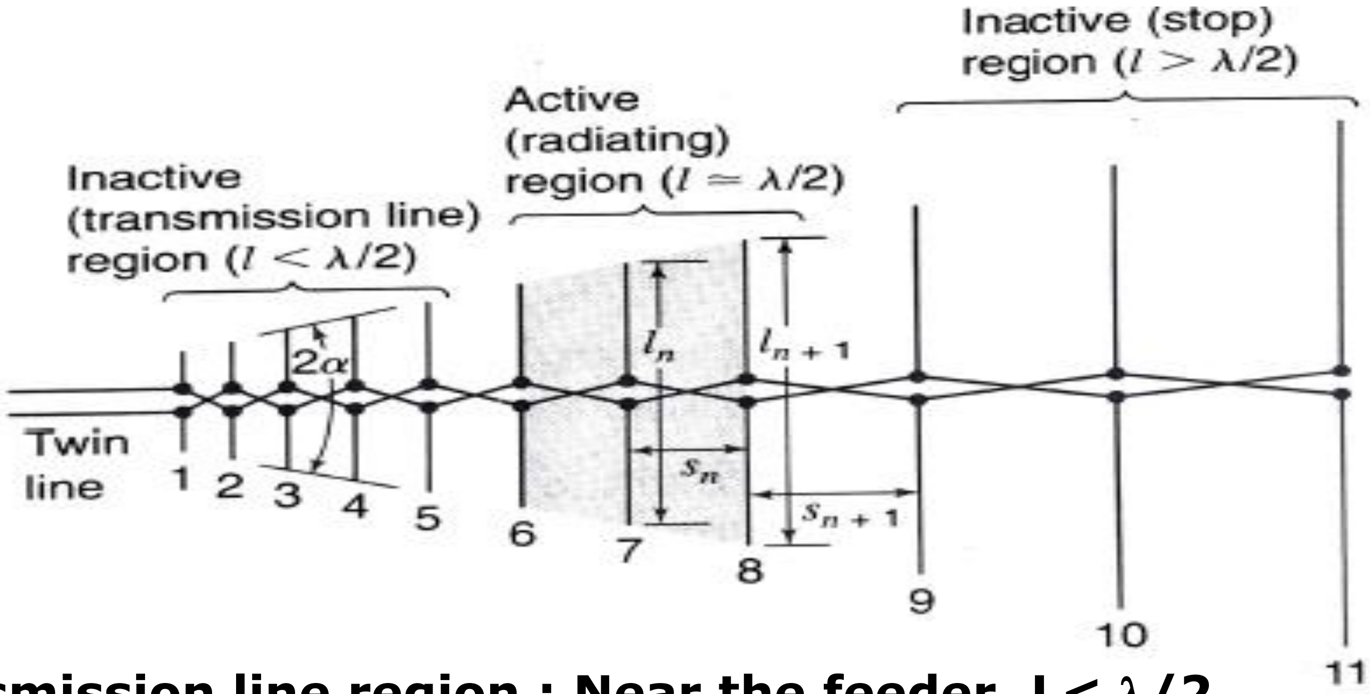
Log Periodic Dipole Antenna (LPDA)

- **LPDA (LPA) : broad band antennas with bandwidth of 10:1 (100:1 is also achievable)**
- **broad band characteristics : (both impedance and pattern)**
- **Radiation : Unidirectional or bidirectional with moderate gain**
- **Log Periodic : Geometry of the antenna structure is chosen that the electrical properties repeat periodically with logarithm of the frequency.**
- **Frequency independence is achieved when the variation of the properties over one period is small**

Construction

- **Basic geometry structure which is repeated with the changing size of the structure**
- **size of the structure changes with equal repetition by a constant scale factor, such that it expands or contract**

Log Periodic Dipole Antenna (LPDA) contd.



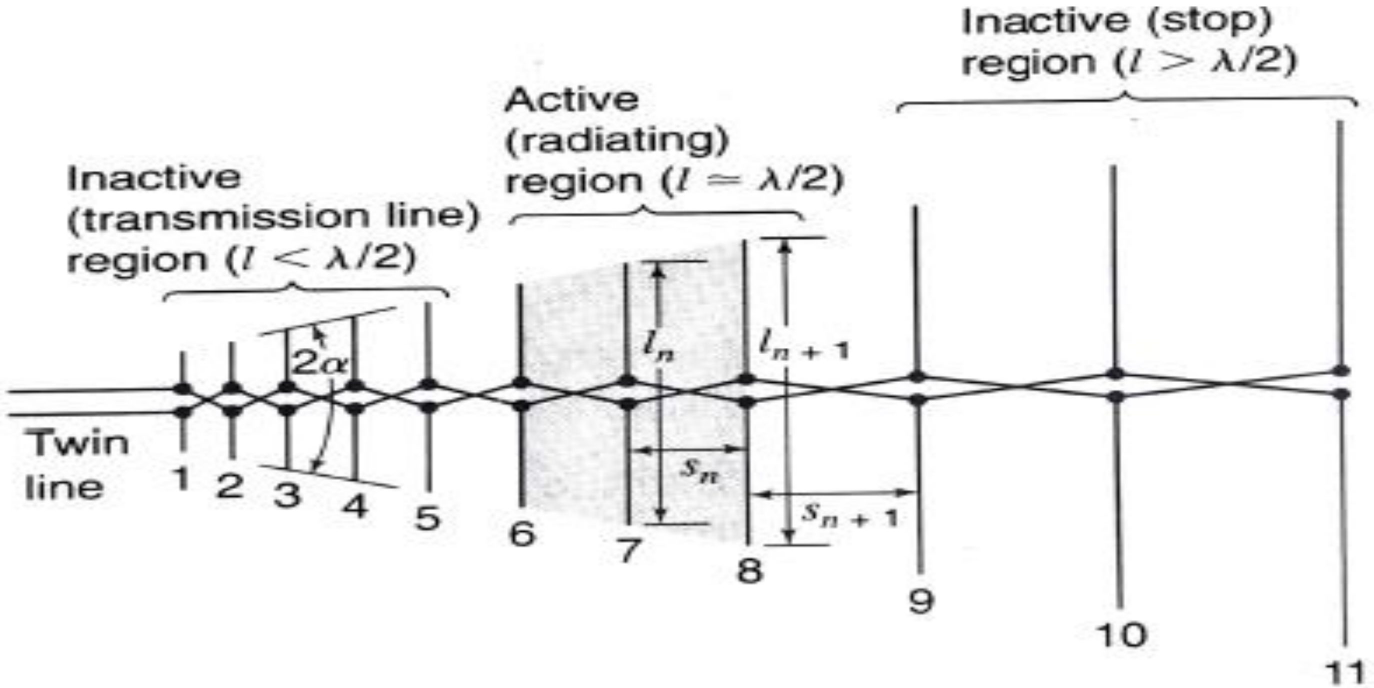
(1) Transmission line region : Near the feeder, L< $\lambda/2$

- **element impedance is large capacitive**
- **element current is small, radiation is small**

(2) Active region : L= $\lambda/2$, E-plane radiation is maximum

- **element impedance has appreciable resistance component**
- **element current is large, in phase with voltage, strong radiation**

Log Periodic Dipole Antenna (LPDA) contd.

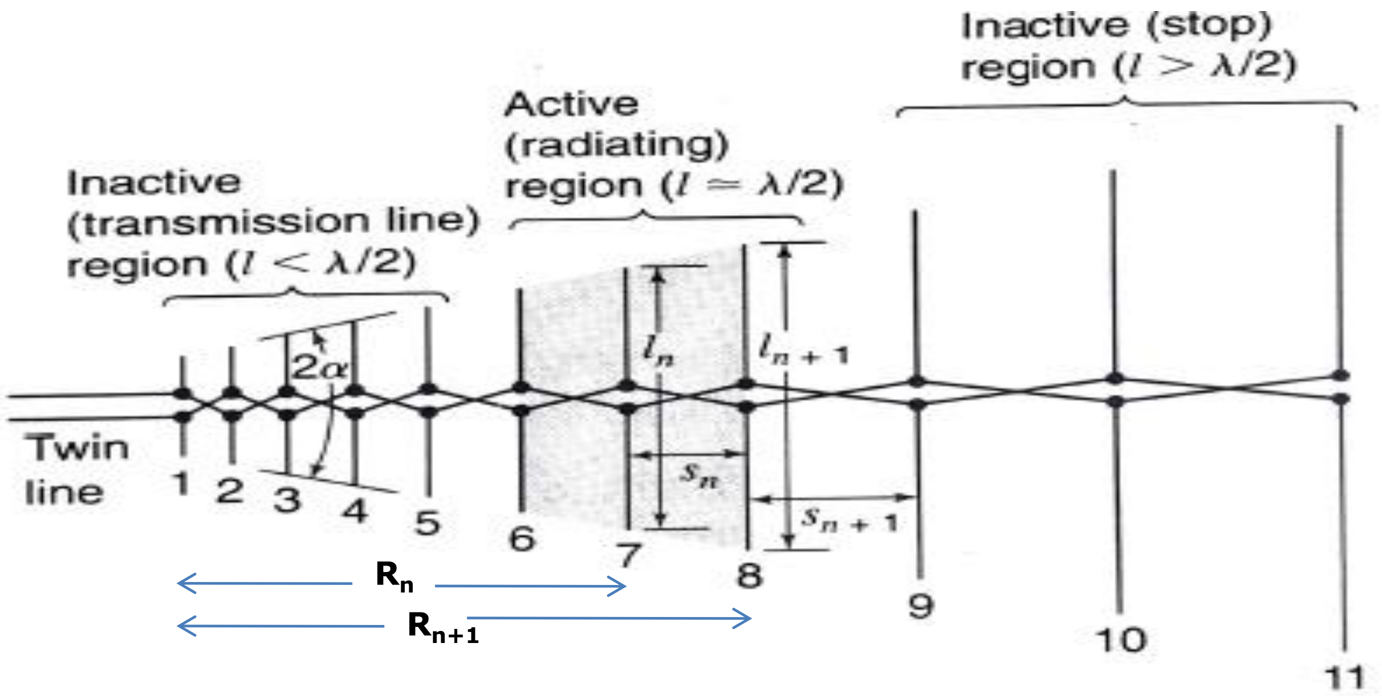


(3) Reflective region (Inactive region) : L> λ/2

- **element impedance becomes large inductive**
- **element current is very small and lags the voltage**

- **When wavelength increases : Radiation zone moves to the right**
- **When wavelength decreases : Radiation zone moves to the left**
- **At any given frequency : fraction of the antenna is used**

Log Periodic Dipole Antenna (LPDA) contd.



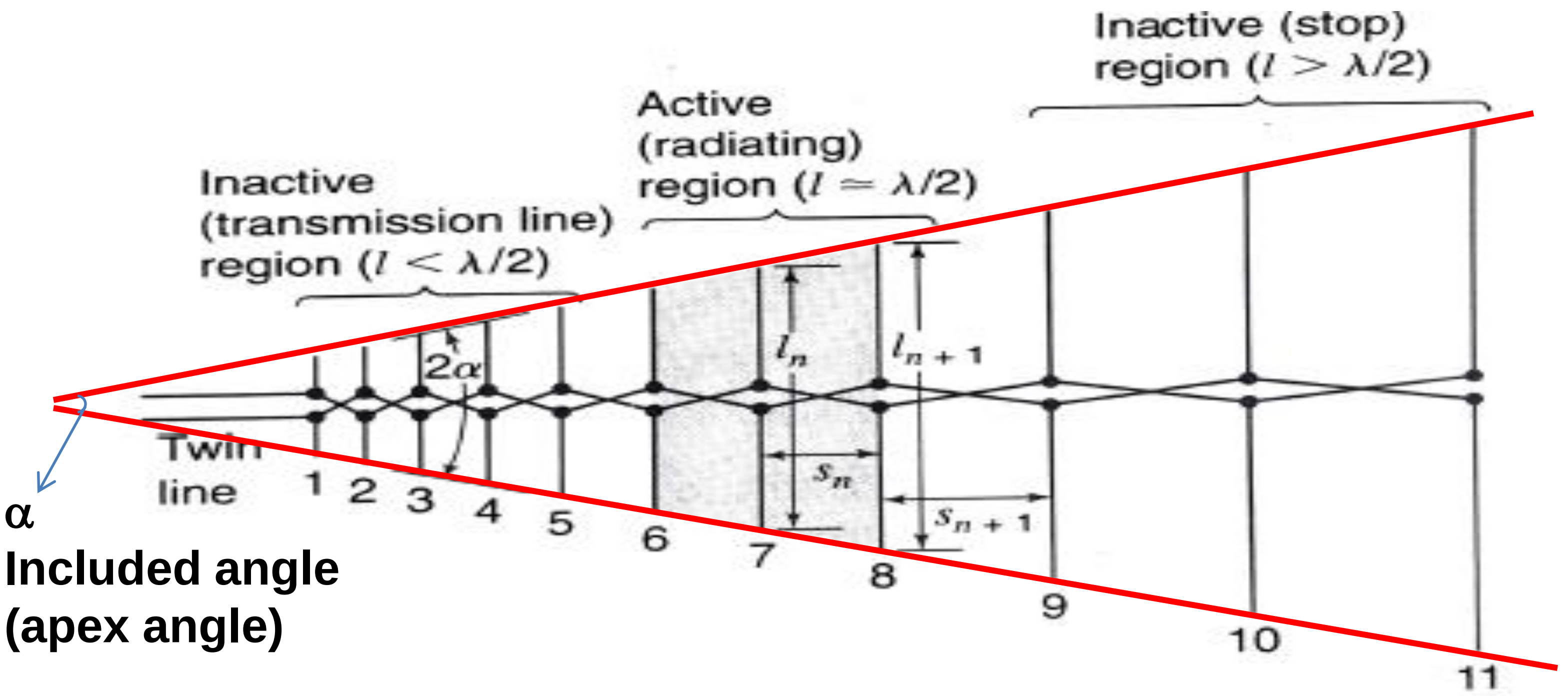
Relation between Length (L), distance from origin (R) is

$$\frac{R_1}{R_2} = \frac{R_2}{R_3} = \ldots \ldots \ldots = \frac{R_n}{R_{n+1}} = \tau = \frac{L_1}{L_2} = \frac{L_2}{L_3} = \ldots \ldots \ldots = \frac{L_n}{L_{n+1}}$$

$\tau \rightarrow$ design ratio or scale factor or periodicity factor

$$\tau = \frac{R_n}{R_{n+1}} = \frac{L_n}{L_{n+1}} \quad (\tau < 1) \quad or \quad \frac{S_{n+1}}{S_n} = \frac{L_{n+1}}{L_n} = \frac{1}{\tau} = K \quad (K > 1)$$

Log Periodic Dipole Antenna (LPDA) contd.



- **S → spacing between two adjacent elements**
- **The condition defined by τ and K yield the dipole to the along two straight lines of an angle α**
- **Typically α = 30° and τ = 0.7**
- **resonant frequency,** $f_r = \frac{C}{\lambda} = \frac{C}{2L}$ **when L=λ/2 (depends on size)**

Log Periodic Dipole Antenna (LPDA) contd.

Characteristics of LPDA

- Array is excited from
  - shorter length side or high frequency side for one active region LPDA to achieve maximum directivity
  - centre for two active region LPDA to achieve maximum directivity
- Though large number of different structures of LPDA is possible all are not frequency independent
- broad band characteristics can be achieved in LPDAs with small variation in the periodicity property
- Radiation pattern can be of unidirectional or bi directional depending up on log periodic structure
  - unidirectional – radiation in backward (shorter elements) direction is considerable (forward direction-negligible)

Log Periodic Dipole Antenna (LPDA) contd.

  - bidirectional – maximum radiation in the broadside direction (normal to the surface of antenna)
- transmission line (inactive) region → proper characteristic impedance with negligible radiation
- Active region → magnitude and phasing of the current should be proper
  - for strong radiation in backward direction
  - negligible radiation in forward direction
- Inactive (stop) region → rapid decay of current is required for antenna to be frequency independent (structure should be truncated)

Log Periodic Dipole Antenna (LPDA) contd.

Applications

- for High frequency communications, where multiband steerable and fixed antenna are required
- TV reception where single antenna can receive all channels
- for all round monitoring (covers all frequency bands)

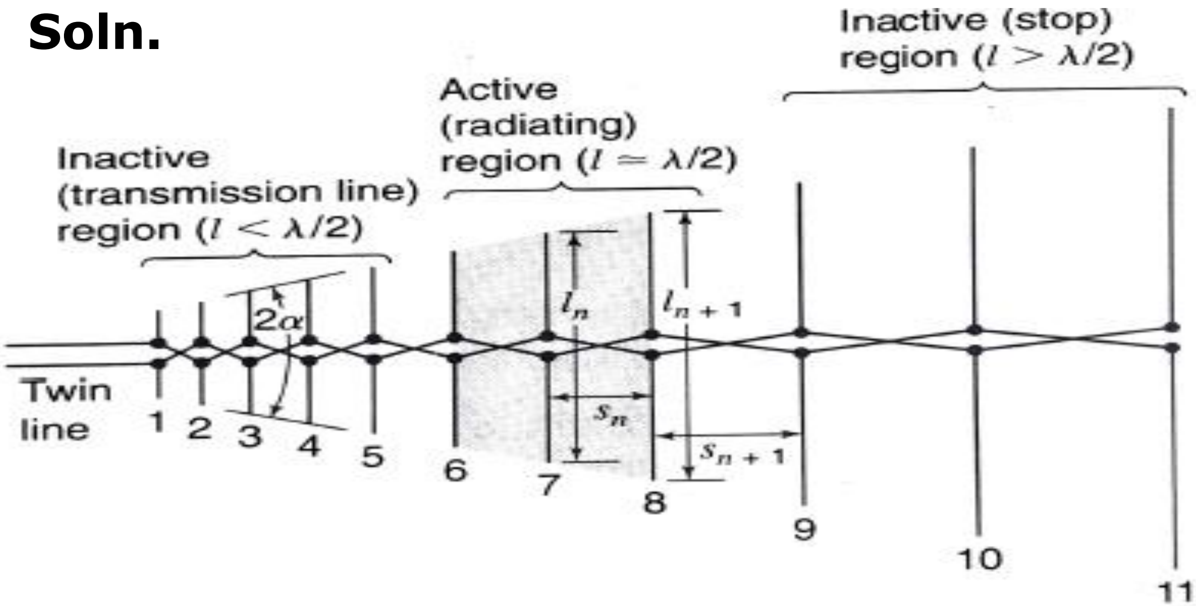
Drawbacks

- less gain (compared to Yagi antenna of same size)
- quite expensive
- mounting platform must be strong to hold large elements
- large number of elements for low frequency

P1. Design a 54 MHz to 216 MHz log periodic dipole antenna for the following data

Desired Gain = 6.5 dB, Design factor (τ) = 0.822 and σ = 0.149.

Soln.



$$\alpha = 2\tan^{-1}\frac{1-\tau}{4\sigma}$$

$$\sigma = \frac{S_n}{2L_n}$$

$$L_n = \frac{\lambda_L}{2} \qquad \lambda_L = \frac{C}{f_L}$$

$$L_1 = \frac{\lambda_H}{2} \qquad \lambda_H = \frac{C}{f_H}$$

$f_L \rightarrow lowest\ frequency\ of\ operation$

$f_H \rightarrow Highet\ frequency\ of\ operation$

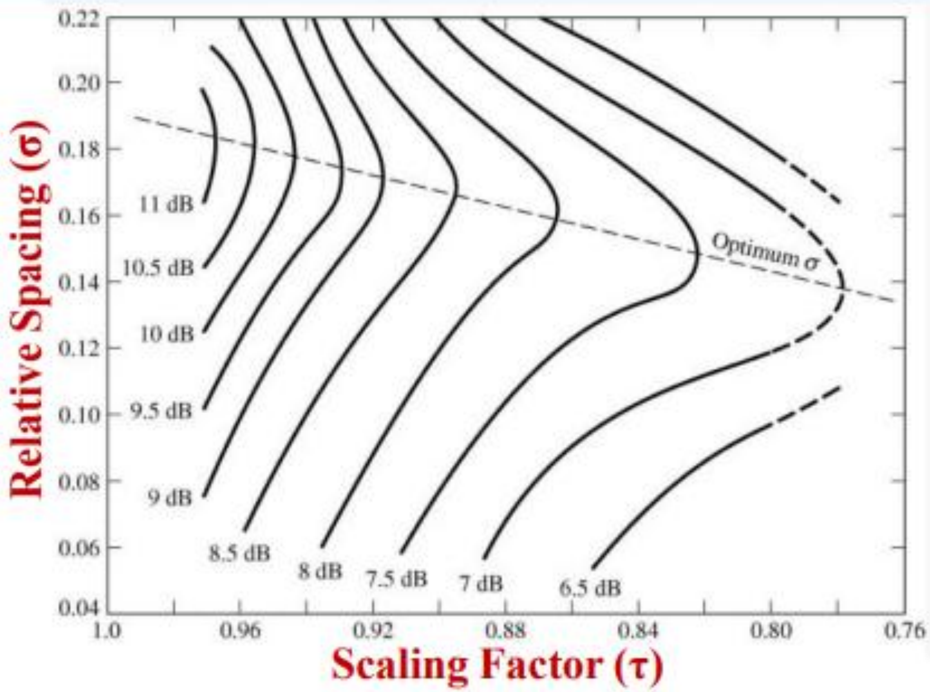
Problems

P1. Design a 54 MHz to 216 MHz log periodic dipole antenna for the following data

Desired Gain = 6.5 dB, Design factor (τ) = 0.822 and σ = 0.149.

Soln.

Design Curve for LPDA for given Directivity



For Gain

6.5 dB + 1dB loss = 7.5dB $\tau = 0.822$ $\sigma = 0.149$

Problems

P1. Design a 54 MHz to 216 MHz log periodic dipole antenna for the following data

Desired Gain = 6.5 dB, Design factor (τ) = 0.822 and σ = 0.149.

Soln.

$$\alpha = 2\,tan^{-1}\frac{1-\tau}{4\sigma}$$

$$\alpha = 2\,tan^{-1}\frac{1-0.822}{4\times 0.149} = 33.3^{\circ}$$

$$L_n = \frac{\lambda_L}{2}$$

$$\lambda_L = \frac{C}{f_L}$$

$$\lambda_L = \frac{3\times 10^8}{54\times 10^6} = 5.55\,m$$

$$L_n = \frac{5.55}{2} = 2.775\,m$$

$$L_1 = \frac{\lambda_H}{2}$$

$$\lambda_H = \frac{C}{f_H}$$

$$\lambda_H = \frac{3\times 10^8}{216\times 10^6} = 1.388\,m$$

$$L_1 = \frac{1.388}{2} = 0.694\,m$$

$$\tau = \frac{R_n}{R_{n+1}} = \frac{L_n}{L_{n+1}} = \frac{S_n}{S_{n+1}}$$

Problems

Design factor (τ) = 0.822 and σ = 0.149.

$$\tau = \frac{R_n}{R_{n+1}} = \frac{L_n}{L_{n+1}} = \frac{S_n}{S_{n+1}}$$

Soln.

$$L_n = \frac{5.55}{2} = 2.775\ m$$

$$L_1 = \frac{1.388}{2} = 0.694\ m$$

Length of other elements to be calculated by scaling the smallest dipole length (0.694 m) until the largest dipole length (2.775 m) is achieved

$$\tau = \frac{L_n}{L_{n+1}} = \frac{L_1}{L_2}$$

$$L_2 = \frac{L_1}{\tau} = \frac{0.694}{0.822} = 0.844\ m$$

$$L_3 = \frac{L_2}{\tau} = \frac{0.844}{0.822} = 1.026\ m$$

Similarly

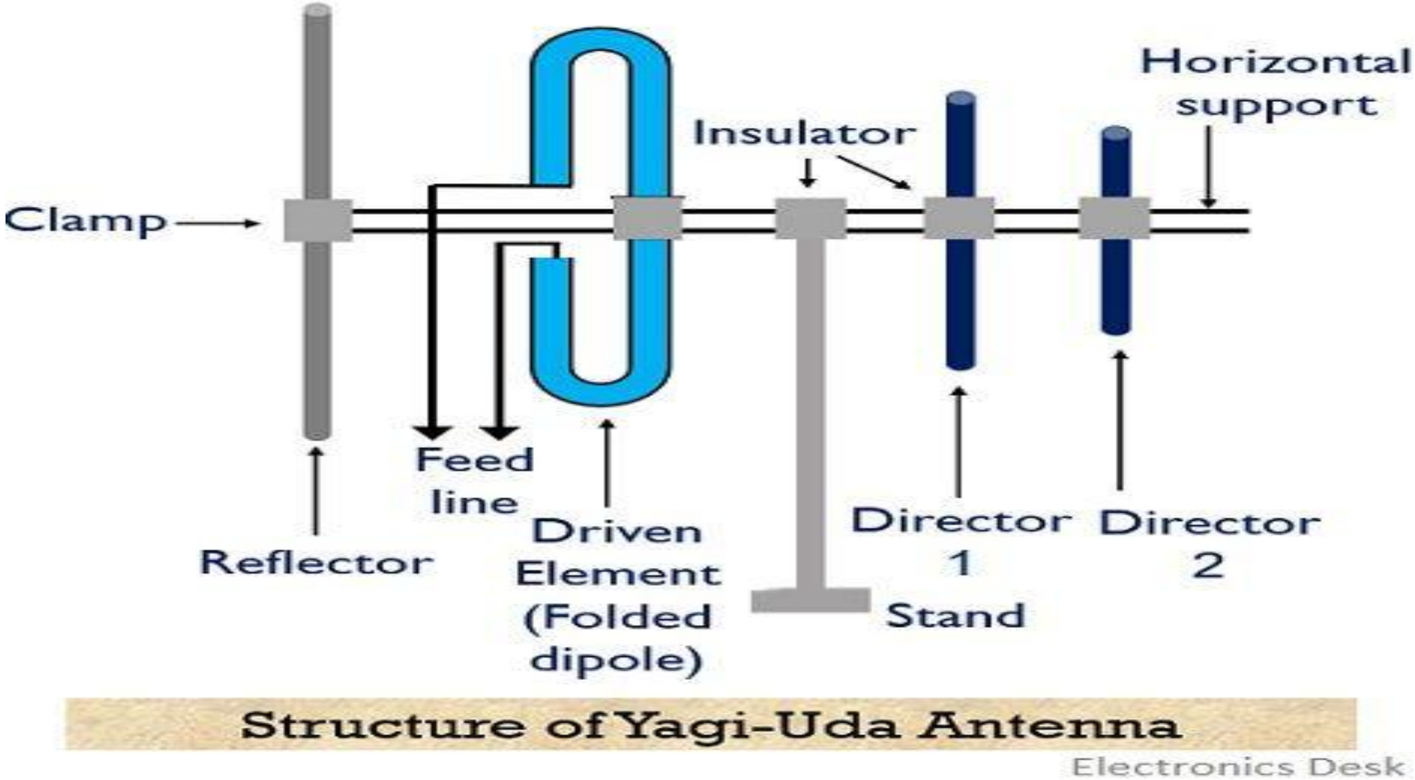
$$L_4 = 1.248\ m \qquad L_7 = 2.245\ m$$

$$L_5 = 1.518\ m \qquad L_8 = 2.731\ m$$

$$L_6 = 1.846\ m \qquad L_9 = 3.322\ m$$

Reflector type Antennas

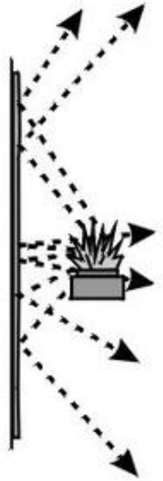
- **Reflector antenna : eliminate backward radiation, increase signal radiation in desired direction**
- **Reflectors are widely used to modify the radiation pattern of a radiating element**
- **Reflector : element that reflects electromagnetic waves**



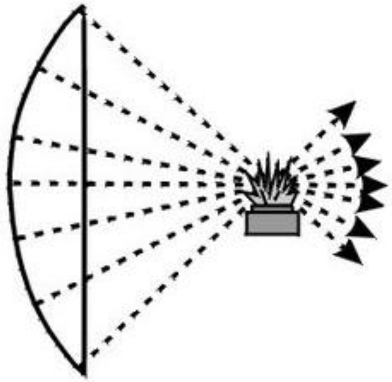
Reflector type Antennas contd.

Types of reflectors

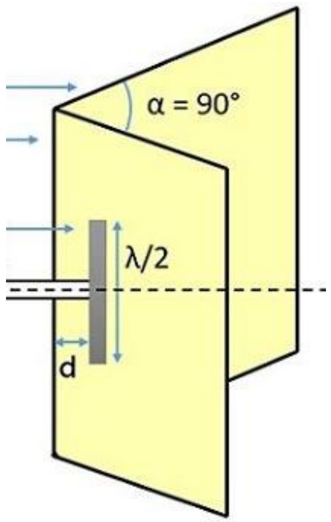
Flat sheet



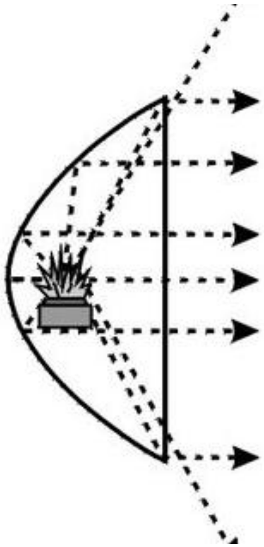
Spherical



Corner

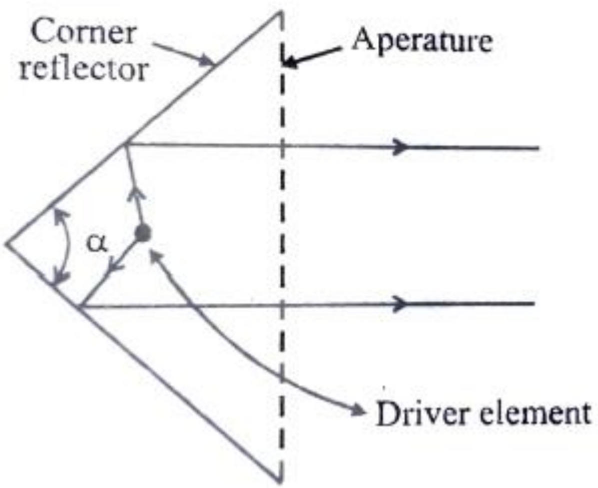


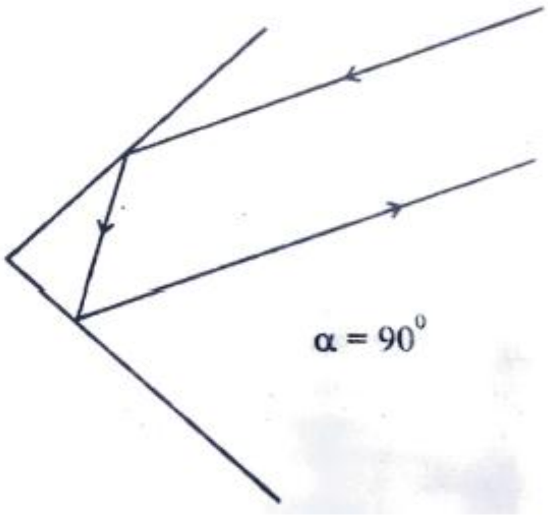
Parabolic



Corner Reflector

- Corner reflector is obtained when a flat metal sheet is folded in the middle to form a 90° square corner
- Corner reflector without the source or driven element is called a passive reflector
- 90° passive reflector can be used to reflect the wave in the same direction

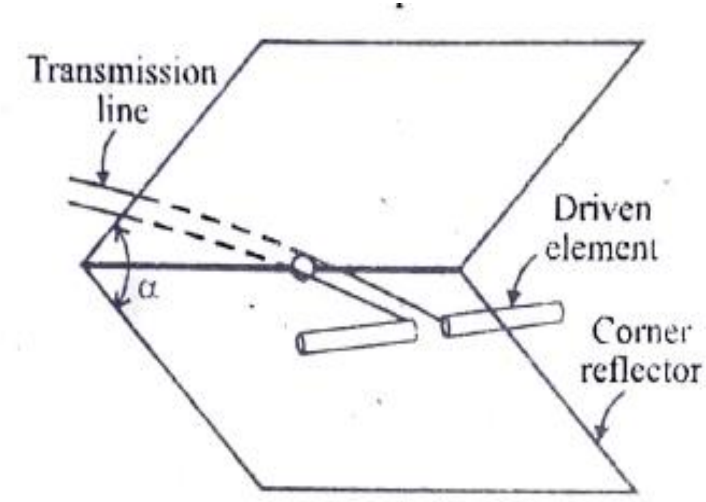




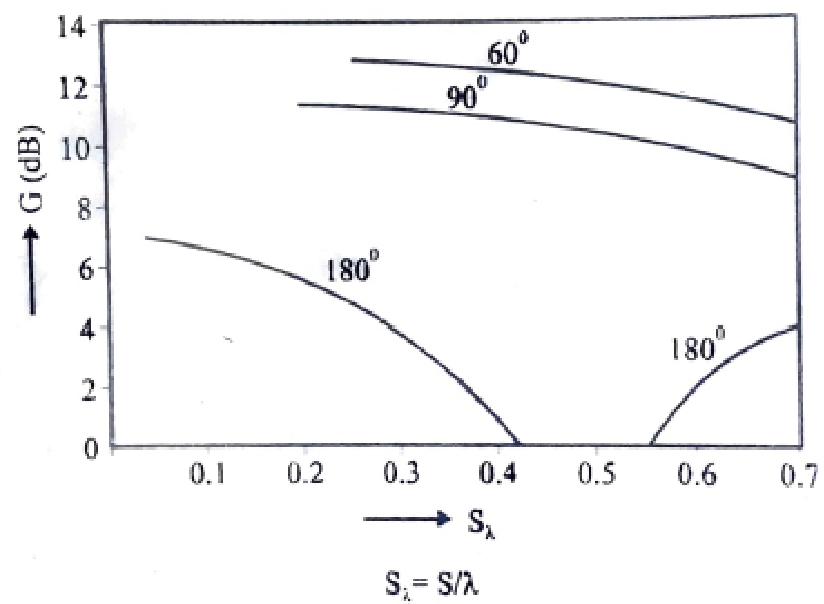
Reflector type Antennas contd.

Corner Reflector Antenna

- Corner reflector with a driven element
- corner angles of 90˚, 60˚, 45˚ and 30˚ are most commonly used, above 90˚ is occasional



- gain depends on corner angle α and distance between corner and driven element 'S'
- gain is maximum for α = 60˚ least for α = 180˚



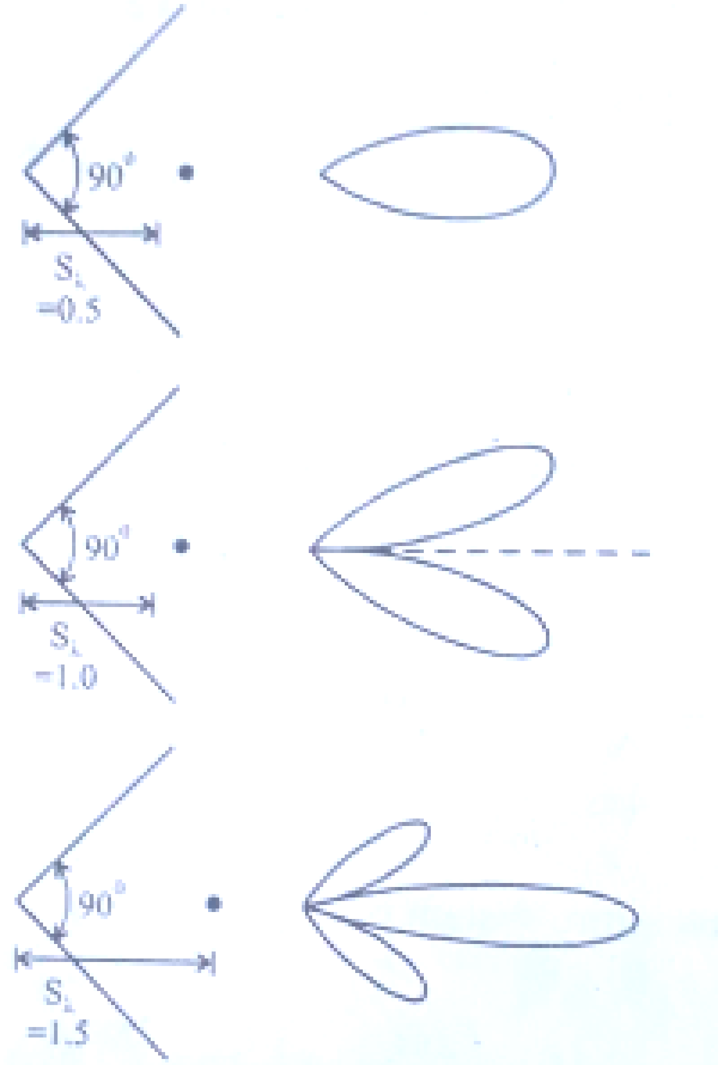
Field Pattern

- pattern is function of the spacing 'S' for a fixed value of α

- $S\lambda$ = 1.0 → two lobed pattern
- $S\lambda$ = 1.5 → gain is large,
  (12.7 dB for $\lambda/2$ dipole)

- no side lobes for $S\lambda$ ranging from 0.25 to 0.7, for $\alpha = 90^\circ$

- no side lobes for $S\lambda$ ranging from 0.1 to 0.3, for $\alpha = 180^\circ$



Reflector type Antennas (Dish Antenna) contd.

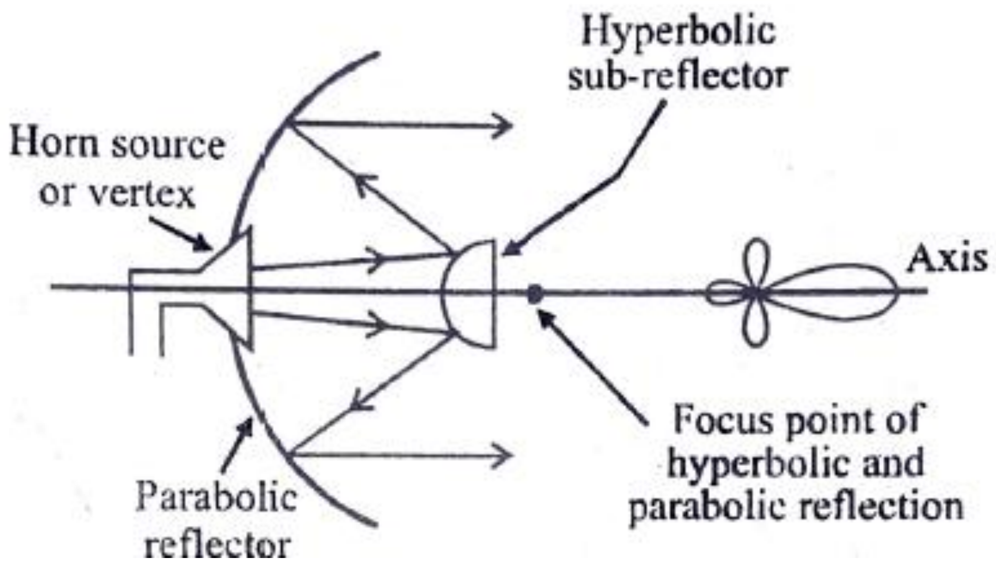
Antenna with Parabolic Reflector

Parabolic reflectors are based on :

- **Geometric optical principle, feeder arrangement is also by optical method**
- **not by transmission line, co-axial cable etc.**

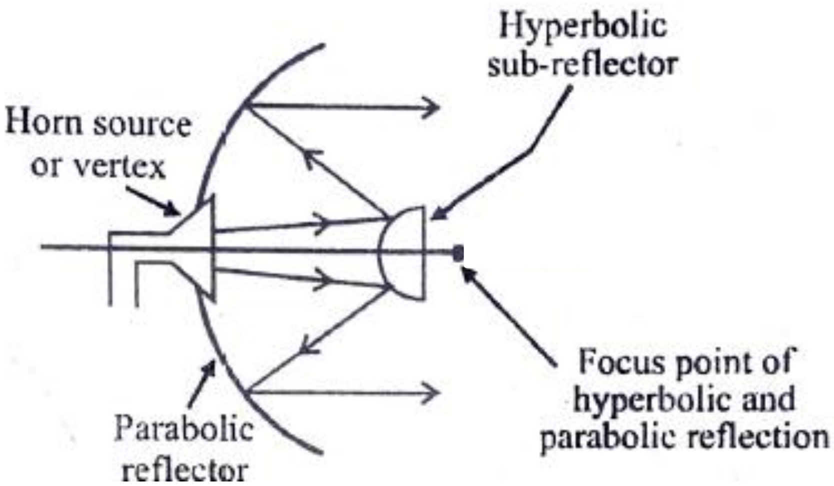
- **These antennas are most commonly used in microwave frequencies**
- **Transmitting and receiving antennas in microwave spectrum are more directive (high gain and narrow bandwidth in both E and H plane)**

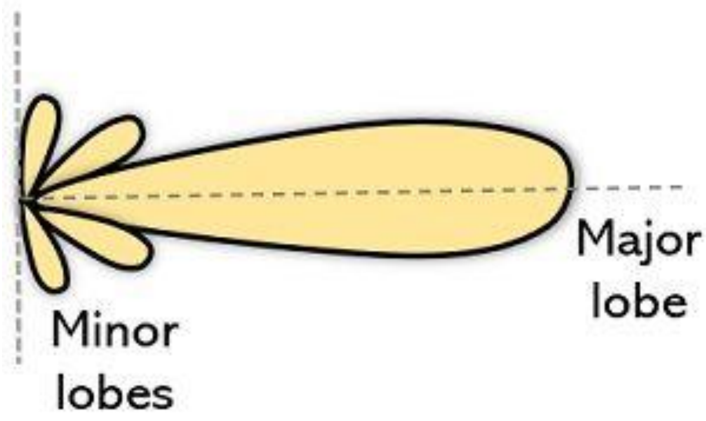
Parabolic Reflector – geometrical relation



- **converts the spherical waves originated by the radiator at the focus of the parabola in to plane wave across the moth (aperture)**
- **ratio of focal length (f) to aperture size (D) i.e. (f/D) is an important characteristics of a parabola**
    - **normally f/D ranges from 0.25 to 0.5**

Reflector type Antennas (Dish Antenna) contd.





- antenna placed at the focal point of a parabola - feed radiator (simply feed or primary radiator)
    - its radiation pattern – primary pattern
- parabolic reflector – secondary radiator
    - radiation pattern of entire antenna (reflector+source) – secondary pattern
- antenna pattern → secondary pattern
- feed pattern → primary pattern

Reflector type Antennas (Dish Antenna) contd.

For the primary antenna, isotropic paraboloid

circular aperture

$$BWFN = \frac{140}{D_\lambda}$$

$$HPBW = \frac{58}{D_\lambda}$$

$$Directivity, D_0 = 9.87 D_\lambda^{\ 2}$$

$$\text{Power gain}, G = 6 D_\lambda^{\ 2}$$ **for a λ/2 dipole**

rectangular aperture

$$BWFN = \frac{115}{L_\lambda}$$

$$HPBW = \frac{51}{L_\lambda}$$

$$Directivity, D_0 = \frac{4\pi}{\lambda^2}(L \times W)$$

W → width of aperture

$$\text{Power gain}, G = 7.7 L_\lambda^{\ 2}$$

Square aperture

$$Directivity, D_0 = 12.6 L_\lambda^{\ 2}$$

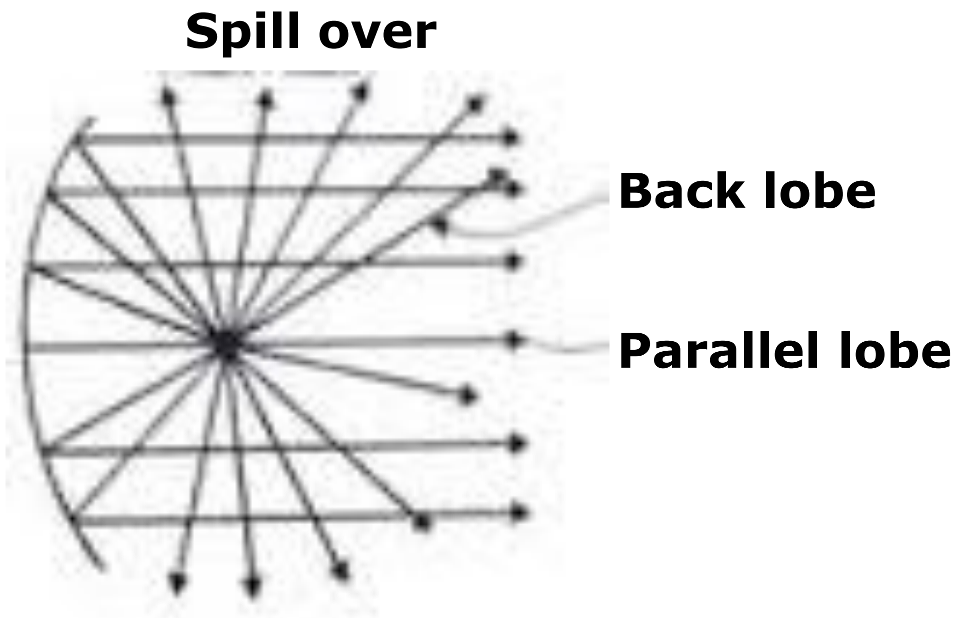
$$D_\lambda = \frac{D}{\lambda} \qquad D \rightarrow diameter\ of\ aperture\ in\ meters$$

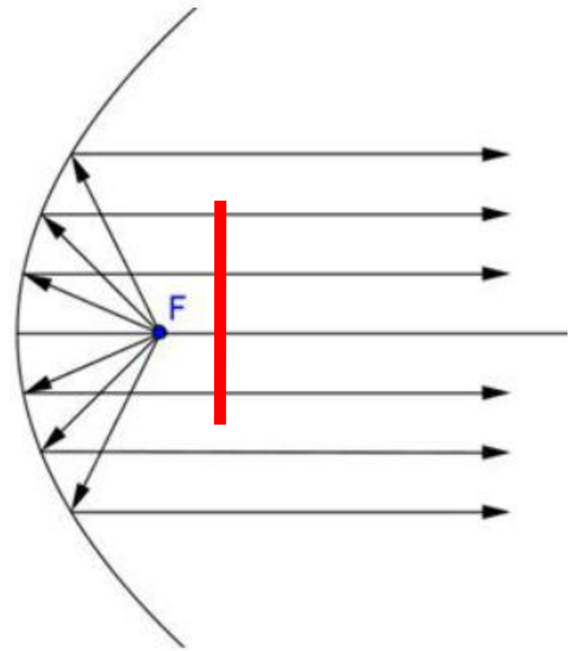
$$L_\lambda = \frac{L}{\lambda} \qquad L \rightarrow Length\ of\ aperture$$

Reflector type Antennas (Dish Antenna) contd.

Feeding techniques for parabolic antenna

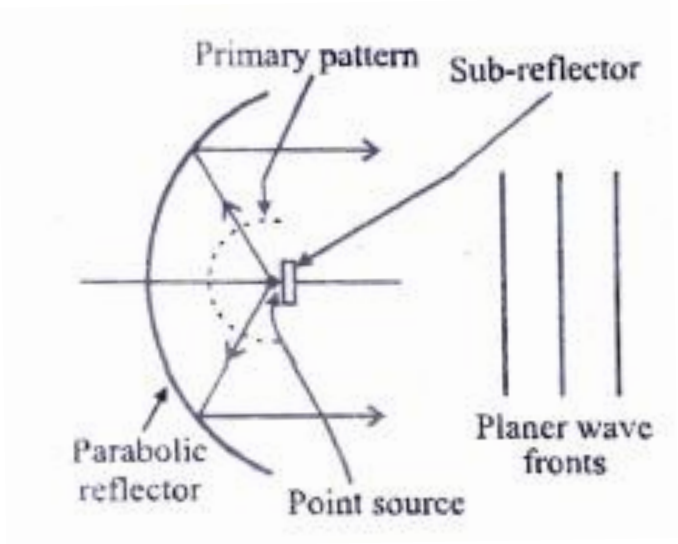
- **feed system should direct all of its energy substantially against the reflecting surface**



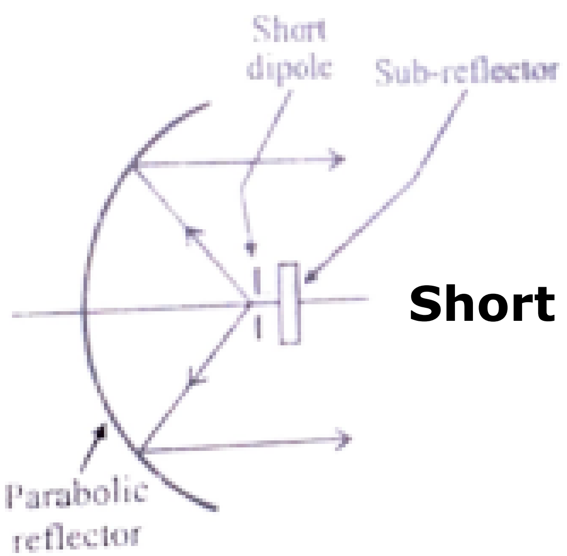


- **Loss of power (gain) can be prevented by properly shaping the aperture and using sub reflector**

Reflector type Antennas (Dish Antenna) contd.

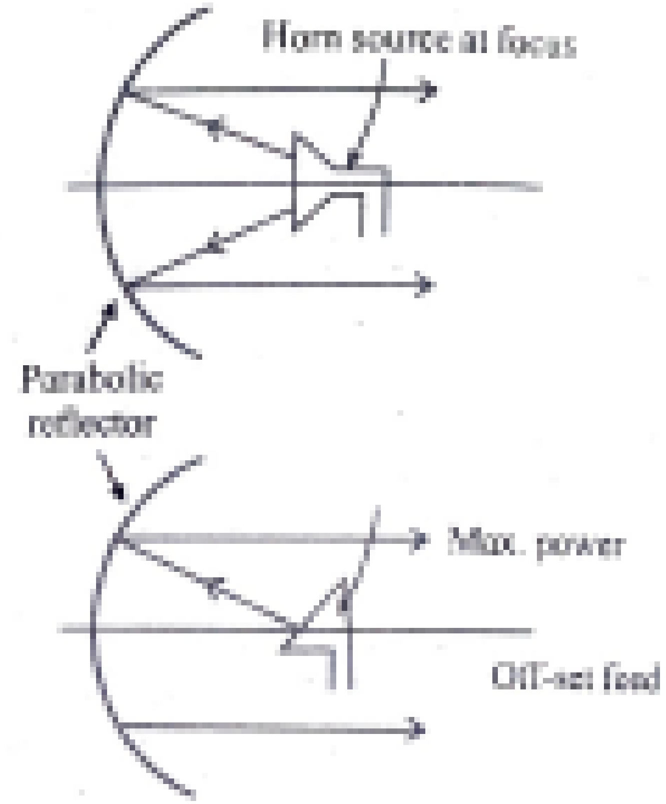


Point source feed



Short dipole feed

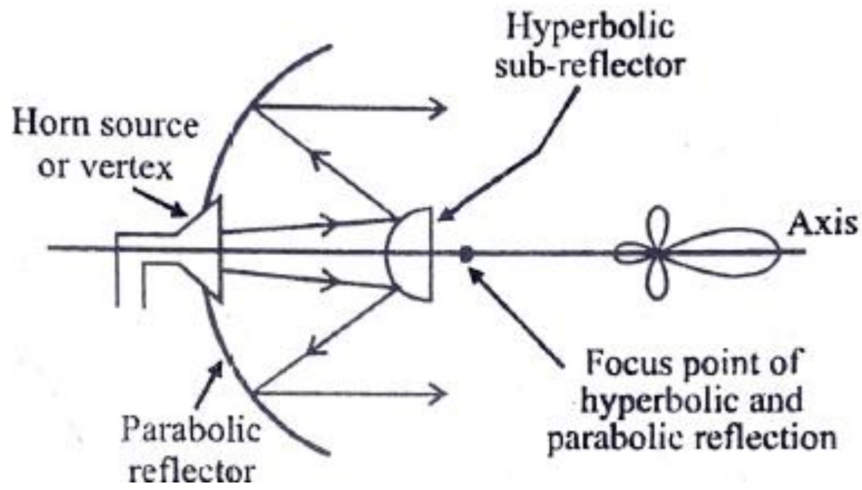
Horn feed



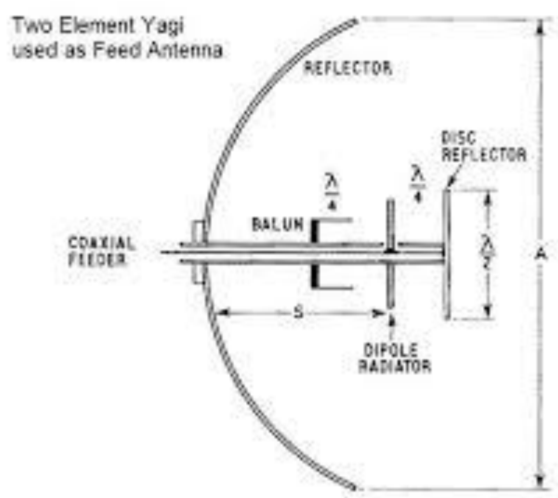
Horn feed (offset reflector)

Reflector type Antennas (Dish Antenna) contd.

Cassegrain feed

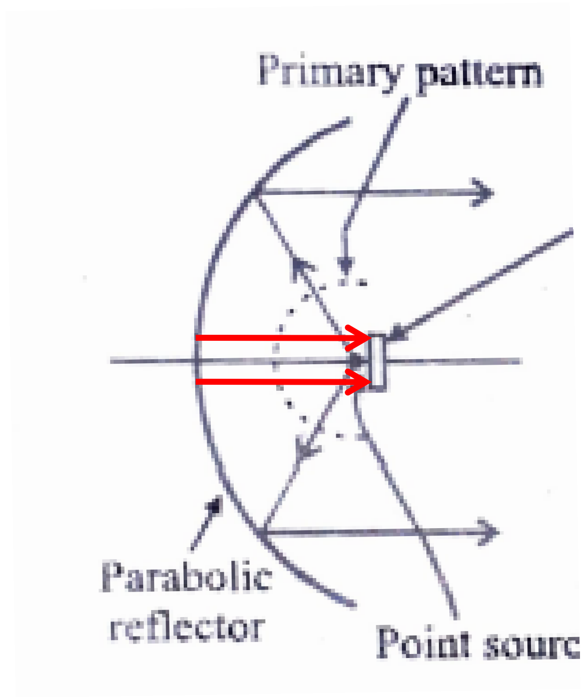


Yagi antenna feed



Reflector type Antennas (Dish Antenna) contd.

- **The primary feed radiator is is positioned around an opening near the vertex instead of the focus**
- **employs secondary reflector whose foci coincides with focus of paraboloid**



Reflector type Antennas (Dish Antenna) contd.

Advantages

- reduction in spill over and minor lobe radiation
- ability to place the feed in convenient location
- capability for scanning or broadening of the beam by moving one of the reflectors

Disadvantages

- some of the reflected waves are obstructed (more with small dimensions)
    - this can be avoided using an offset reflector
- dimension of secondary reflector depends on distance between horn feed and sub reflector, mouth of horn

Problems

P1. A 64m diameter dish antenna operating at a frequency of 1.43 GHz is fed by a non directional antenna. Calculate (i) HPBW (ii) BWFN (iii) Directivity and (iv) Gain with respect to λ/2 dipole.

Soln.

$$\lambda = \frac{C}{f} = \frac{3 \times 10^8}{1.43 \times 10^9} = 0.21m$$

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

$$D_\lambda = \frac{D}{\lambda} = \frac{64}{0.21} = 304.76$$

$$D_\lambda = \frac{D}{\lambda}$$

$$BWFN = \frac{140}{D_\lambda} = \frac{140}{304.76} = 0.46^\circ$$

$$BWFN = \frac{140}{D_\lambda}$$

$$HPBW = \frac{58}{D_\lambda} = \frac{58}{304.76} = 0.19^\circ$$

$$HPBW = \frac{58}{D_\lambda}$$

$$Directivity = 9.87 {D_\lambda}^2 = 9.87 \times 304.76^2 = 916712$$

$$Directivity = 9.87 {D_\lambda}^2$$

$$\text{Power gain}, G = 6{D_\lambda}^2 = 6 \times 304.76^2 = 557271$$

$$\text{Power gain}, G = 6{D_\lambda}^2$$

Problems

P2. Estimate the power gain of a paraboloid reflector of open mouth aperture of 10λ.

Soln.

$$D_\lambda = \frac{D}{\lambda}$$

$$D_\lambda = \frac{D}{\lambda} = \frac{10\lambda}{\lambda} = 10$$

$$\text{Power gain}, G = 6{D_\lambda}^2$$

$$\text{Power gain}, G = 6{D_\lambda}^2 = 6 \times 10^2 = 600$$

$$G\ in\ dB = 10Log_{10}600 = 27.78\ dB$$

Problems

P3. An isotropic antenna with rectangular reflector of length 4m and width 3m is operating at a frequency of 3 GHz. Calculate (i) HPBW (ii) BWFN (iii) Directivity and (iv) Gain with respect to λ/2 dipole.

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

Soln.

$$\lambda = \frac{C}{f} = \frac{3\times 10^8}{3\times 10^9} = 0.1m \qquad L_\lambda = \frac{L}{\lambda} = \frac{4}{0.1} = 40$$

$$L_\lambda = \frac{L}{\lambda}$$

$$BWFN = \frac{115}{L_\lambda} = \frac{115}{40} = 2.875^\circ$$

$$HPBW = \frac{51}{L_\lambda}$$

$$HPBW = \frac{51}{L_\lambda} = \frac{51}{40} = 1.275^\circ$$

$$BWFN = \frac{115}{L_\lambda}$$

$$Directivity = \frac{4\pi}{\lambda^2}(L\times W) = \frac{4\pi}{0.1^2}(4\times 3) = 15079$$

$$Directivity, D_0 = \frac{4\pi}{\lambda^2}(L\times W)$$

$$\text{Power gain}, G = 7.7{L_\lambda}^2$$

$$\text{Power gain}, G = 7.7{L_\lambda}^2 = 7.7\times 40^2 = 12320$$

Problems

P3. Calculate (i) HPBW (ii) BWFN (iii) Directivity and (iv) Gain with respect to λ/2 dipole for an isotropic antenna with square reflector of area 9m² operating at a frequency of 2 GHz. .

Soln.

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

$$\lambda = \frac{C}{f} = \frac{3 \times 10^8}{2 \times 10^9} = 0.15\, m \qquad Since\ area = 9m^2, L = W = 3m$$

$$L_\lambda = \frac{L}{\lambda}$$

$$L_\lambda = \frac{L}{\lambda} = \frac{3}{0.15} = 20$$

$$HPBW = \frac{51}{L_\lambda}$$

$$BWFN = \frac{115}{L_\lambda} = \frac{115}{20} = 5.75^\circ$$

$$BWFN = \frac{115}{L_\lambda}$$

$$HPBW = \frac{51}{L_\lambda} = \frac{51}{20} = 2.55^\circ$$

$$Directivity = 12.6\, {L_\lambda}^2 = 12.6 \times 20^2 = 5040 \qquad Directivity, D_0 = \frac{4\pi}{\lambda^2}(L \times W)$$

$$\text{Power gain}, G = 7.7{L_\lambda}^2 = 7.7 \times 20^2 = 3080 \qquad \text{Power gain}, G = 7.7{L_\lambda}^2$$

Antennas for special applications

- **Antennas for terrestrial mobile communication**
- **Antenna for ground penetrating radar (GPR)**
- **Embedded antennas**
- **Ultra wideband antennas for digital application**
- **Plasma antenna**

(Qualitative analysis)

Antennas for terrestrial mobile communication

- the rapid development of mobile communication systems has led to the use of novel antenna for base station and mobile station
- frequencies of terrestrial mobile radio systems range from 200MHz to 60 GHz
- most significant of these are the analog and digital cellular radio systems whose main frequency ranges are 800 to 1000 MHz and 1700 to 2200 MHz
- wireless local are network (WLAN) use the frequencies 2.4 to 2.5, 5.1 to 5.8 and 17 GHz
- bandwidth of cellular systems vary from 8 to 17%

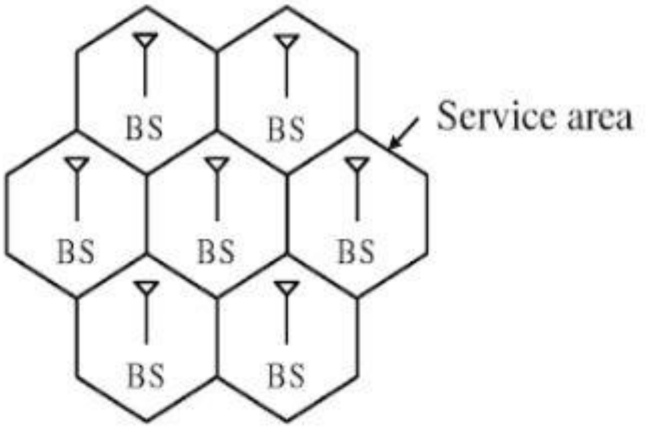
Antennas for terrestrial mobile communication con.

Base station antennas

▪ base station antennas are used to direct the power to the area to be covered

▪ each cell has radius of about 1 to 15 kms

▪ each cell has a base station antenna



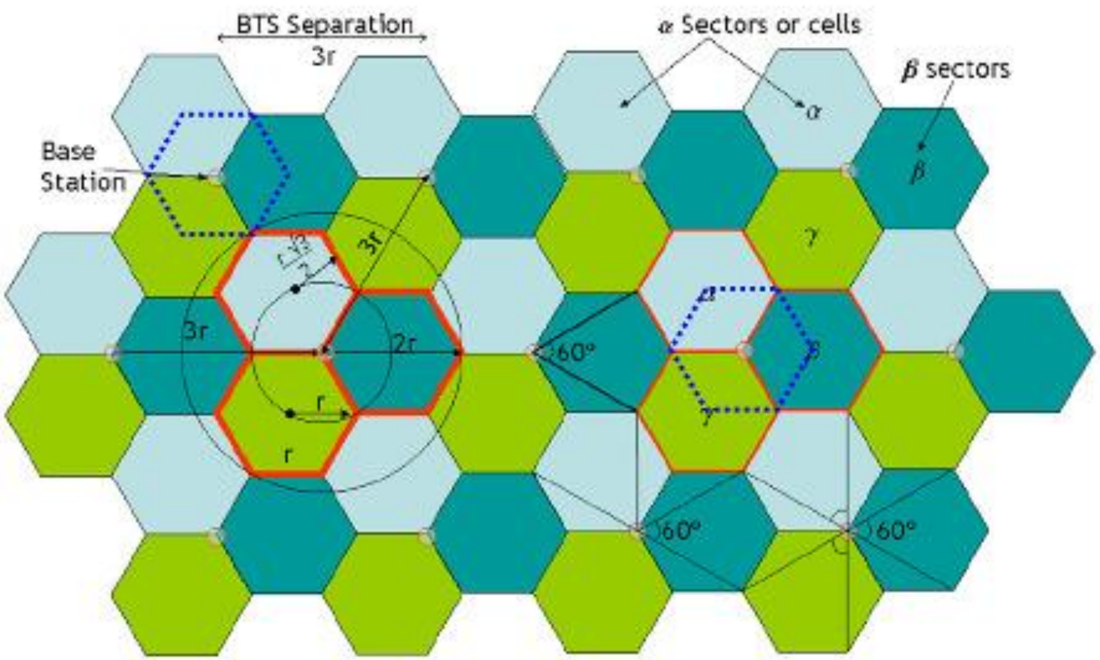
▪ In cellular system the power distribution is restricted to minimize the frequency reuse distance

▪ base station antenna should cover a large area irrespective directivity in horizontal plane

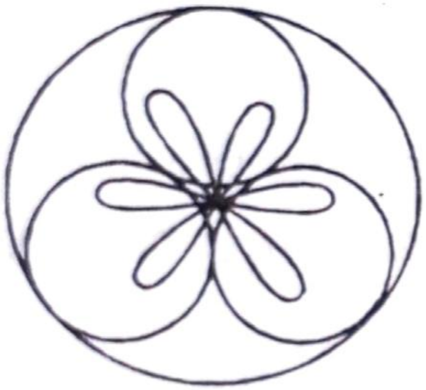
▪ vertical plane beam width is reduced to increase the directivity (to achieve 5 to 17dB)

Antennas for terrestrial mobile communication con.

- horizontal plane beam width is between 50˚ 360˚
- directive antenna are used for sector base station systems
- a 3-sector system power pattern in horizontal and vertical planes is as shown (3-antenna placed 120˚apart)



Source:MIMO and Smart Antennas for 3G and 4G Wireless Systems.3G Americas May 2010



Horizontal plane pattern

Vertical plane pattern

Antennas for terrestrial mobile communication con.

- **beam width of each directive antenna in horizontal plane is 65°**
- **vertical beam width is nearly 10 to 70°**
- **antenna is tilted slightly downwards to reduce the interference of neighbor cells**
- **parameters to be considered**
  - **weight, wind load, size and appearance**
  - **common types are dipoles, corner reflector, patch arrays and horns**
  - **in corner reflectors, using corner angle of 60° to 270° horizontal HPBW of 60° to 180° is obtained**
- **for cables having a diameter of 20 mm, attenuation will be of about 5dB at 900 MHz**
- **cable can be terminated with matched load or antenna**
- **base station power is around 300W outdoor and 30W indoor**

Antennas for terrestrial mobile communication con.

Antenna Diversity

- To reduce multipath fading in base station – diversity technique is used
    - several receiving antennas are used to obtain independent samples of incoming field
- for cellular base station, the diversity techniques are space and polarization diversity
    - space diversity – receivers are placed at quite far off depending upon the angular distribution of the multipath signals (20λ to 40λ)
    - polarization diversity between horizontal and vertical polarization is preferred for tilted mobiles under use

Antennas for terrestrial mobile communication con.

Adaptive base station antennas

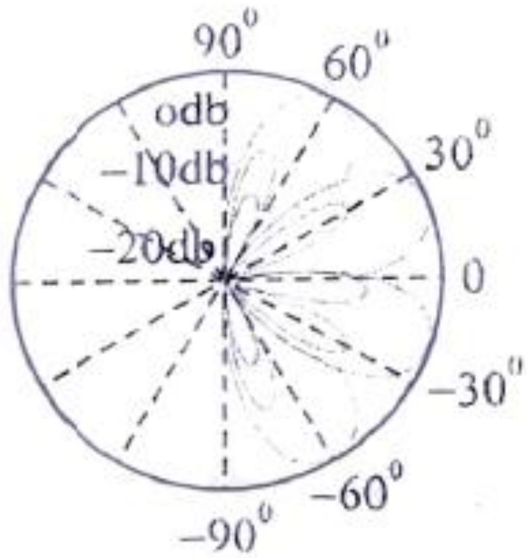
- array of antennas and associated signal processing that together are able to change its radiation pattern dynamically to adjust to noise, interference and multipath.
- adaptive system is used to improve SNR, maximize the coupling between base station and user and minimizing the coupling between base station and other users
- benefits of adaptive base station antennas are
  - increased capacity due to increased signal to interference and noise ratio
  - increased coverage due to higher apparent gain of the baseband antenna
  - reduced output power especially at the mobile station where battery lifetime is crucial

Antennas for terrestrial mobile communication con.

Adaptive options

(i) Switched beam antennas

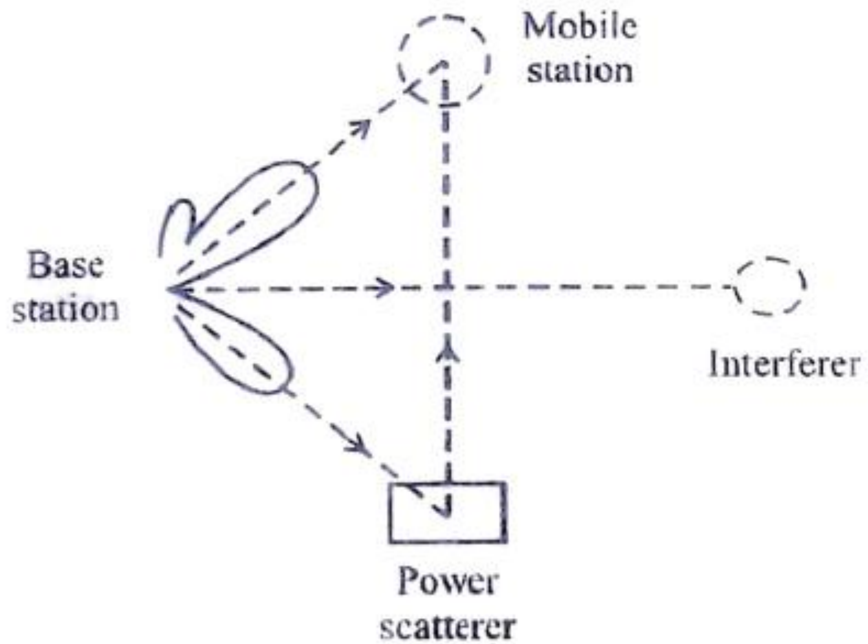
- base station antenna has several selectable beams of which each covers a part of the cell area
- constructed based on butler matrix, which provides one beam per antenna element
- operation is very simple but limited adaptability



Antennas for terrestrial mobile communication con.

(ii) Beam forming

- is a technique of providing main pattern or lobe towards wanted direction and nulls in unwanted direction

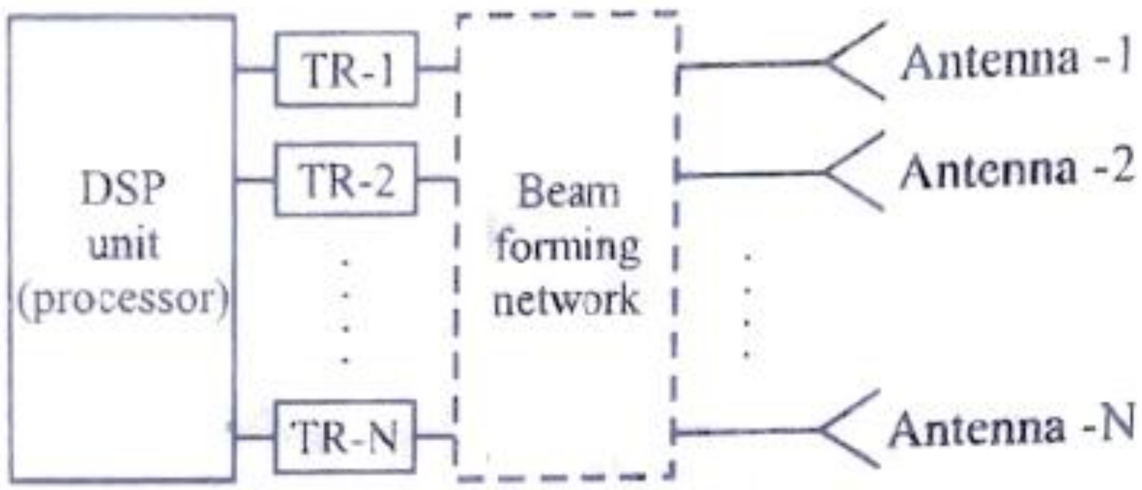


- since number of antenna elements are limited, only few maxima and nulls can be realized simultaneously

Antennas for terrestrial mobile communication con.

(iii) Adaptive arrays

- system consists of several antennas
- each antenna is connected to separate transreceiver and digital signal processor (DSP)
- DSP controls the signal level to each element depending upon requirement



Antennas for terrestrial mobile communication con.

Mobile station antennas

- antenna should be able to enable for the required signal at random places and random direction
- very difficult to design antenna for a particular polarization
- most of the time polarization is vertical
- vertical dipole is preferred
- critical performances in antenna design are bandwidth and efficiency

(i) Dipole and monopole

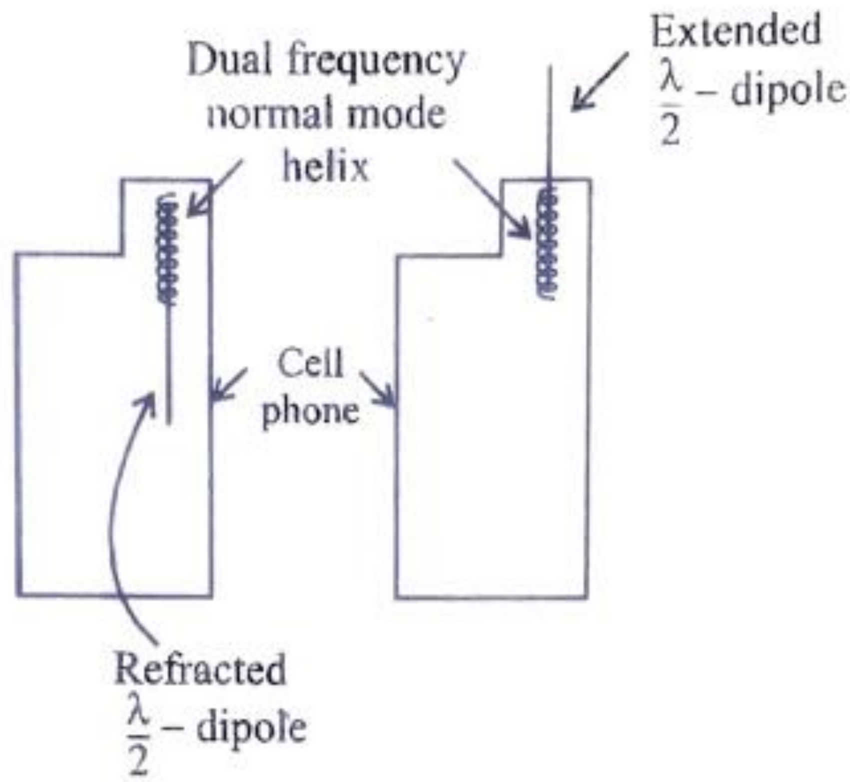
- retractable whip antenna of length

$\lambda/2$ can be used ($\lambda/2$ dipole or $\lambda/4$ monopole)

Antennas for terrestrial mobile communication con.

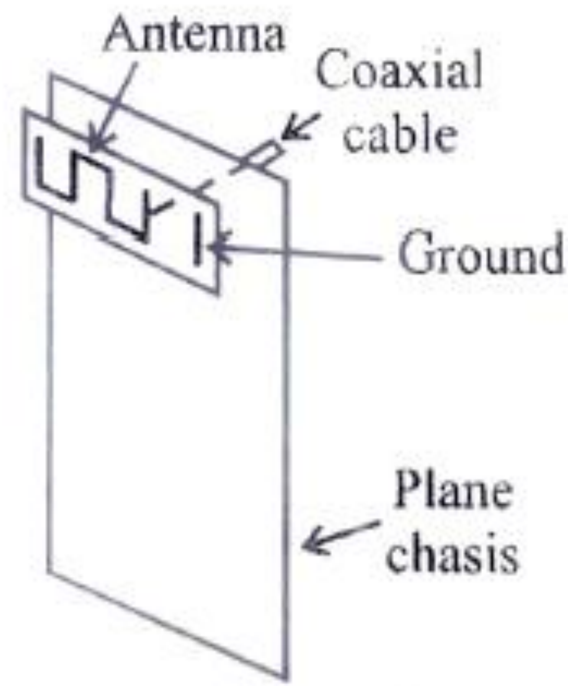
(ii) Normal mode helical antenna

- for circular polarization normal mode helical antenna can be used



(iii) Internal antenna

- antenna may be enclosed inside the handset
- two types of internal antennas
    - planar antenna and chip antenna



- planar antenna is usually $\lambda/4$ microstrip mounted on the conducting chasis of handset
- chip antenna is very small and can be mounted on the circuit board
- performance of internal antenna is less than external antenna

(iv)Antenna diversity

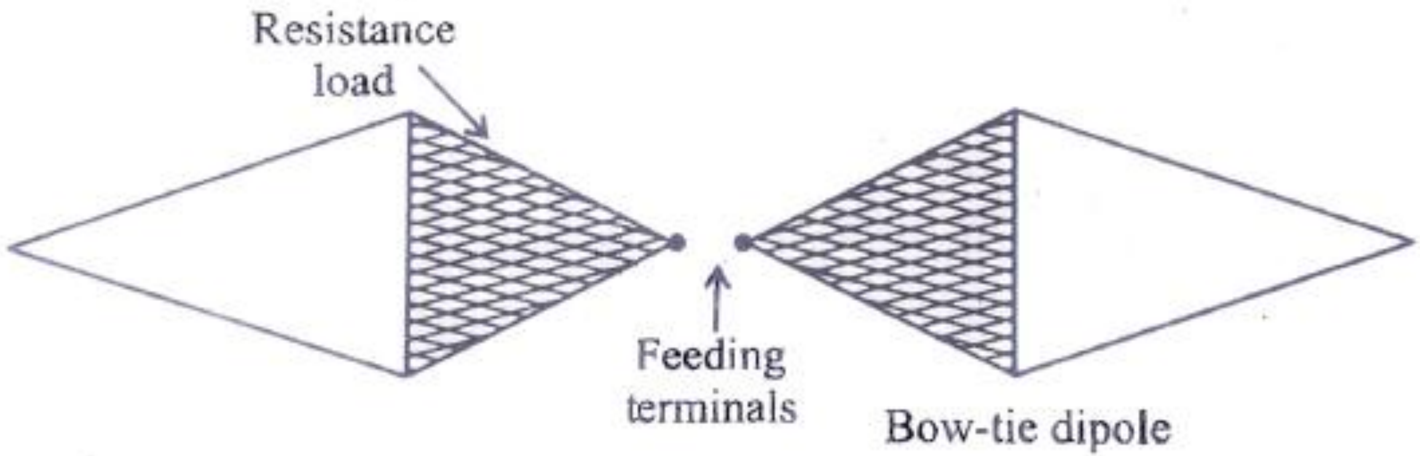
- in mobile station is difficult due to limited space

Antennas for Ground Penetrating Radar (GPR)

- Radars : used for detecting moving objects such as aircrafts and ships in wars
- GPRs can be used to detect underground anomalies (natural and manmade)
- anomalies : buried metallic or non-metallic objects, earth abnormalities
- pulse and its echo pulse are used for processing
- basic difference between GPR and above earth radar are
    - total distance travelled is not large, hence radar equation for far-fields cannot be used without modification
    - ground is lossy medium (10dB/m at 3 to 300MHz), hence power required is large
    - large mismatch at air-ground interface

Antennas for Ground Penetrating Radar (GPR) cont.

- as the distance or total time is very small pulse width should be very small (few nano seconds)
- antenna is very critical in GPR
- Usually two dipole antennas are placed very close to earth surface (one for transmission and one for reception)
- to reduce bouncing and ringing the dipole elements are constructed with resistance loaded in the form of bow tie



Embedded antennas

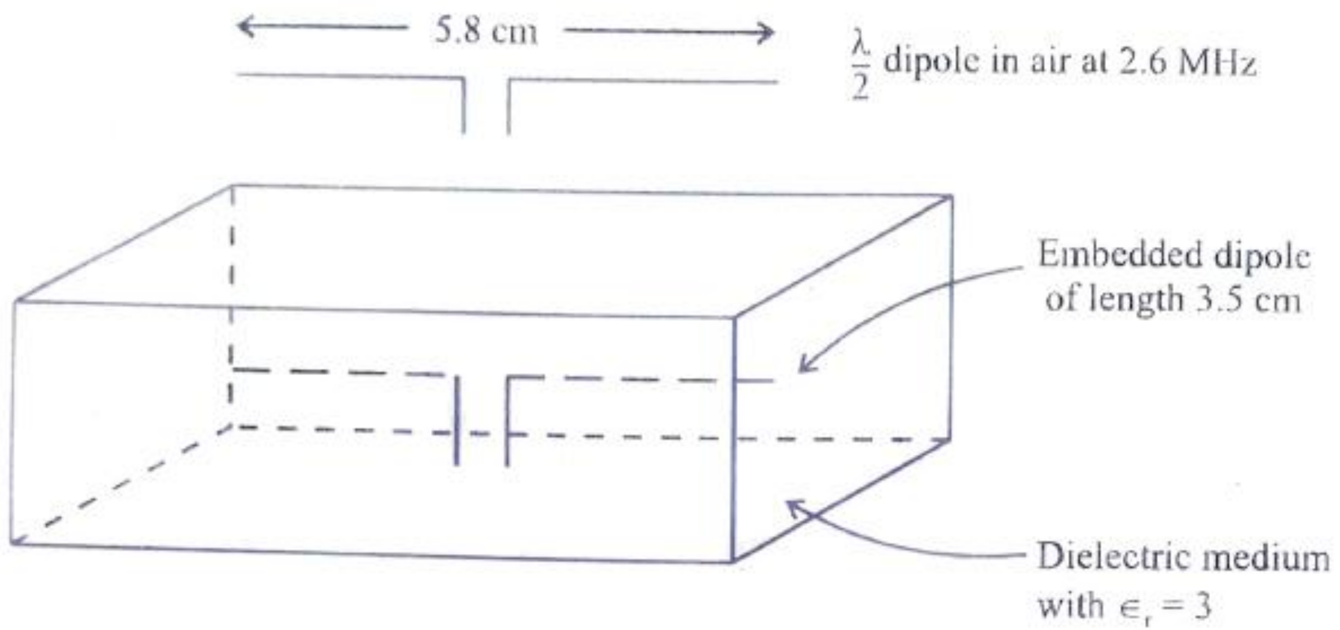
- modern trend in manufacturing electronic systems is to integrate everything on a common substrate
- embedded antenna is one such (embedded in dielectric medium)
  - suitable for mobile handsets
- embedded antenna is constructed embedding a $\lambda/2$ dipole on a dielectric substrate
- dimensions should be very small (few mm or cm)
- length can be calculated from the relation

$$l = \frac{\lambda}{2\sqrt{\epsilon_r}}$$

- with ϵ_r greater than one dimensions will be small

Embedded antennas contd.

▪ antennas used in this system are microstrip antennas made by depositing copper on dielectric substrate

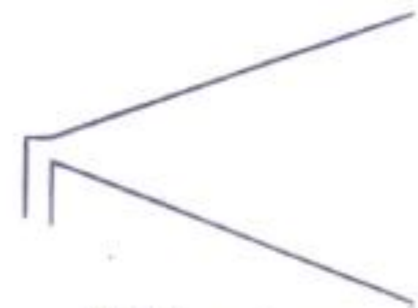


Ultra wideband antennas for digital application

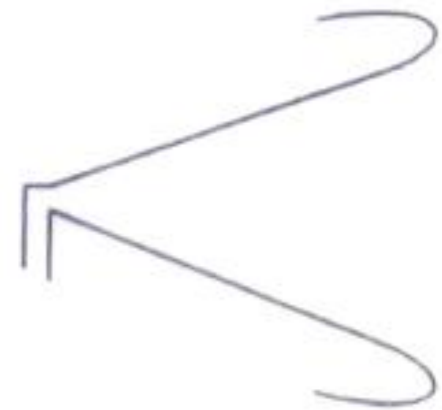
- **Ultra wide band antennas should cater the needs for pulse systems (digital)**

- **rhombic vee antenna is suitable for pulse applications and hence can be regarded as ultra wideband antenna**

- **rhombic and vee shapes help in achieving impedance matching over the wide frequency range**



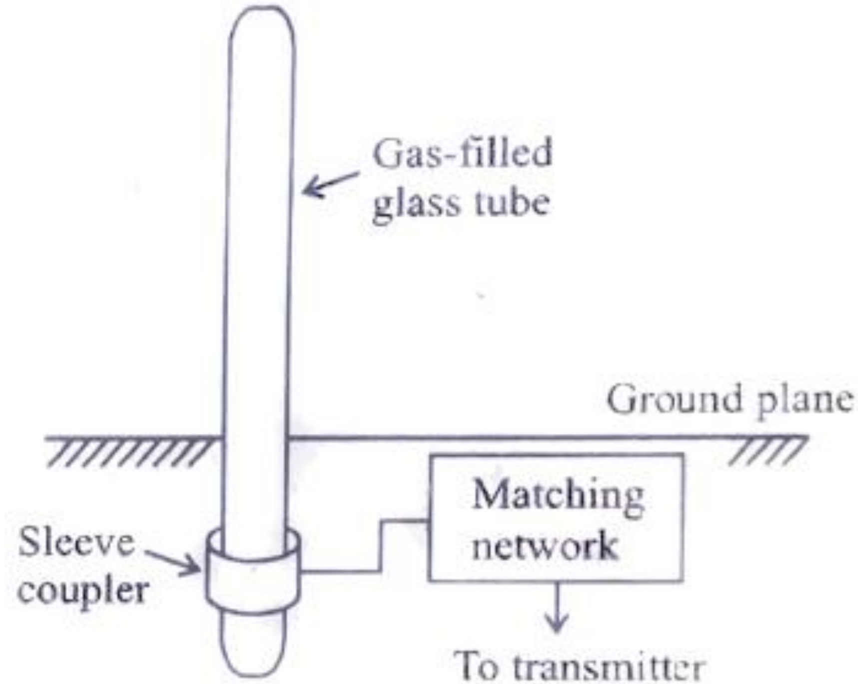
(a) V - antenna



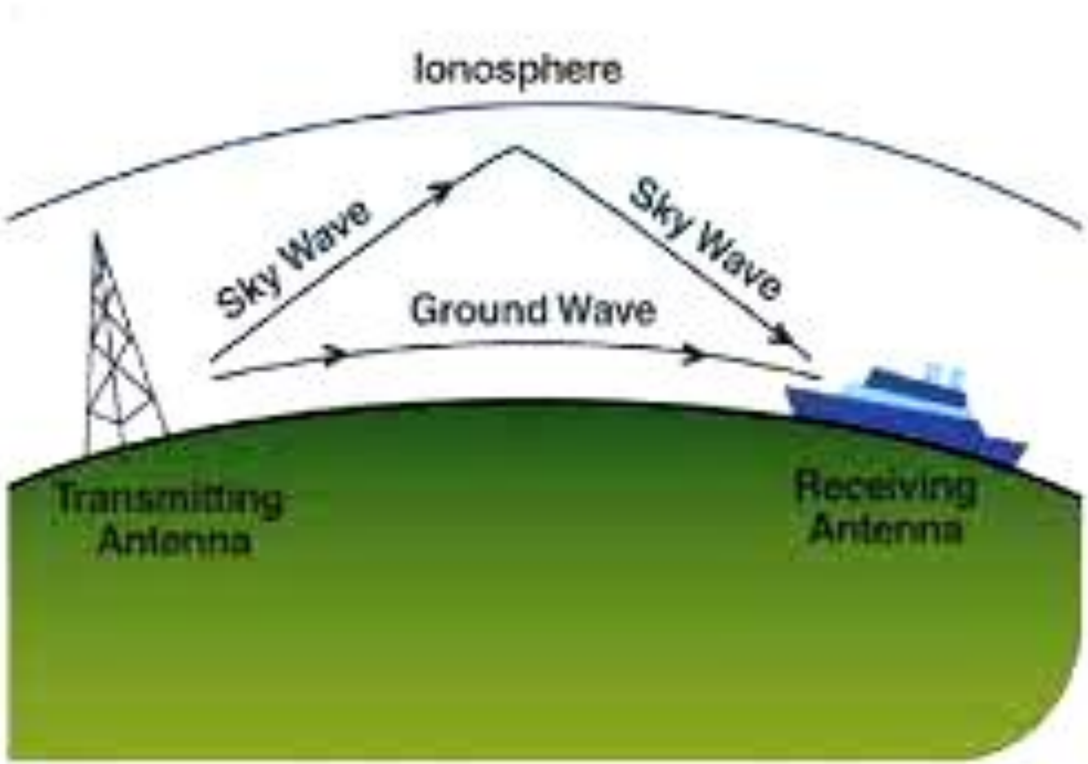
(b) Tapered smooth V - antenna

Plasma antenna

- Plasma tube antenna consists of glass tube filled with a gas (argon) at low pressure
- when this gas is subjected to electric discharge a plasma is formed in the long column glass tube, which generates plasma surface wave
- since plasma is a conductive Surface, it acts as an antenna
- radiation efficiency of 25 to 50% can be achieved
- can be used where the antenna cross section should be small when not used



7REC02 Antennas and Propagation



Unit – 5

Wave Propagation

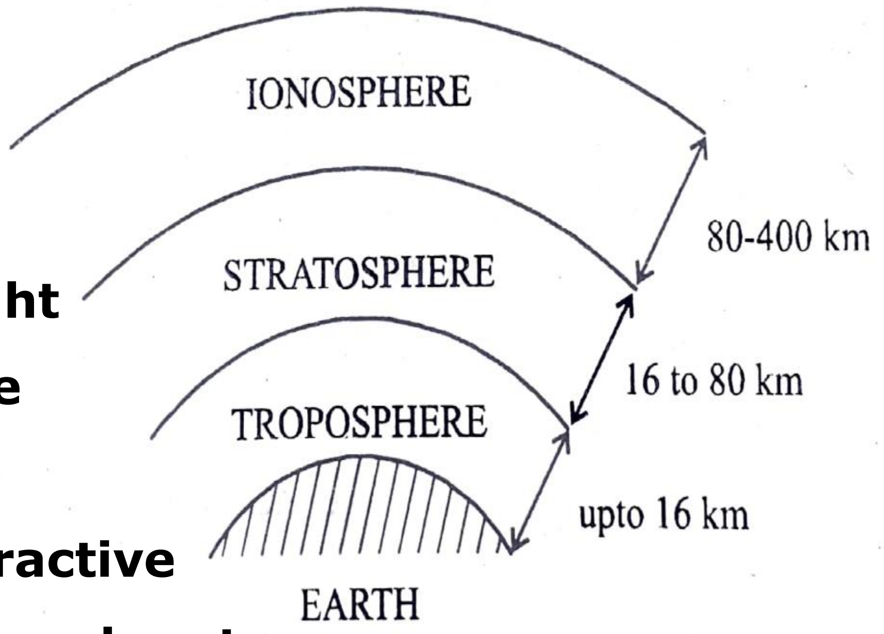
Syllabus

- **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.

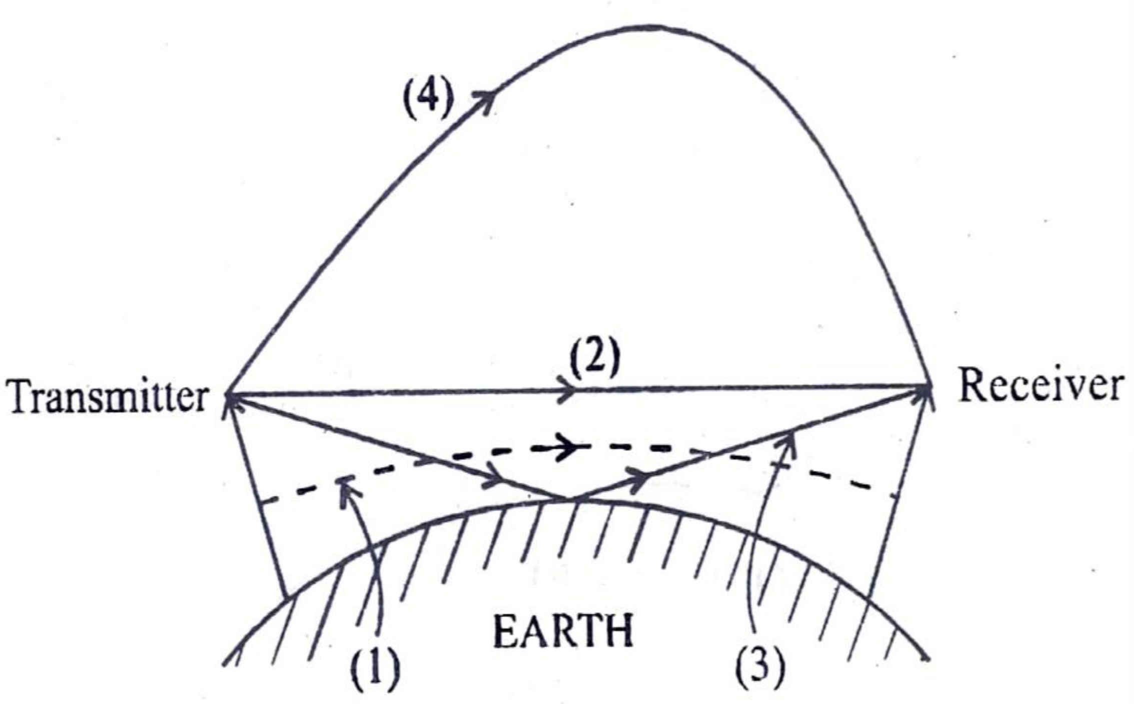
Factors that affect propagation

- 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.

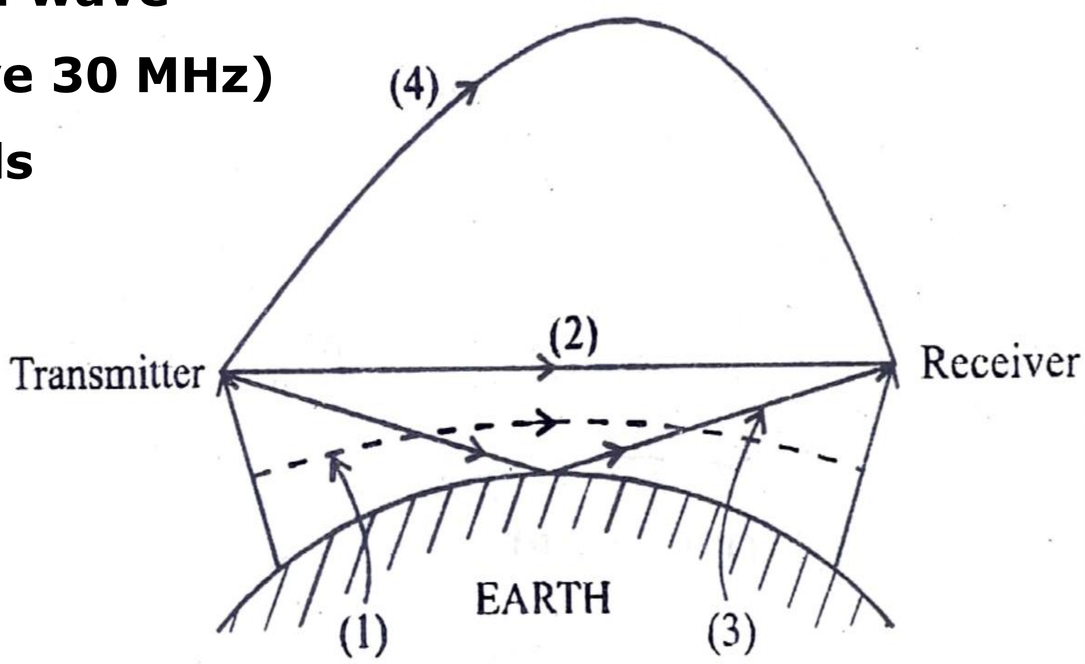
Space wave propagation

- 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

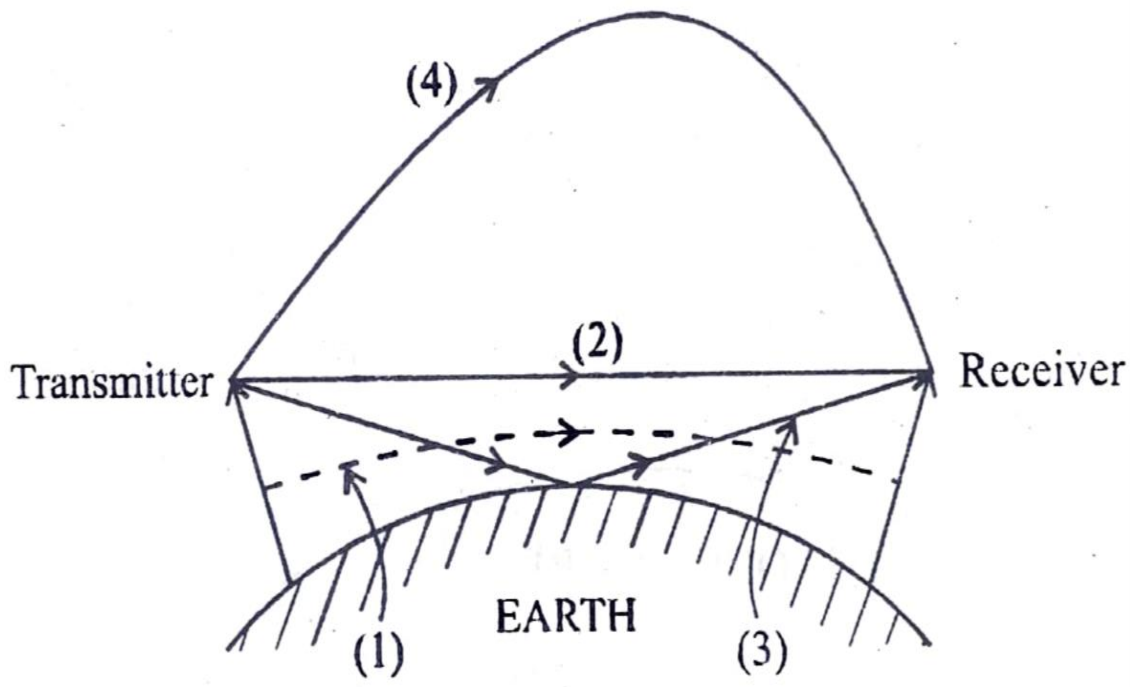
- high frequency range (above 30 MHz)
- Ex. TV, FM and Radar Signals



Radio wave propagation contd.

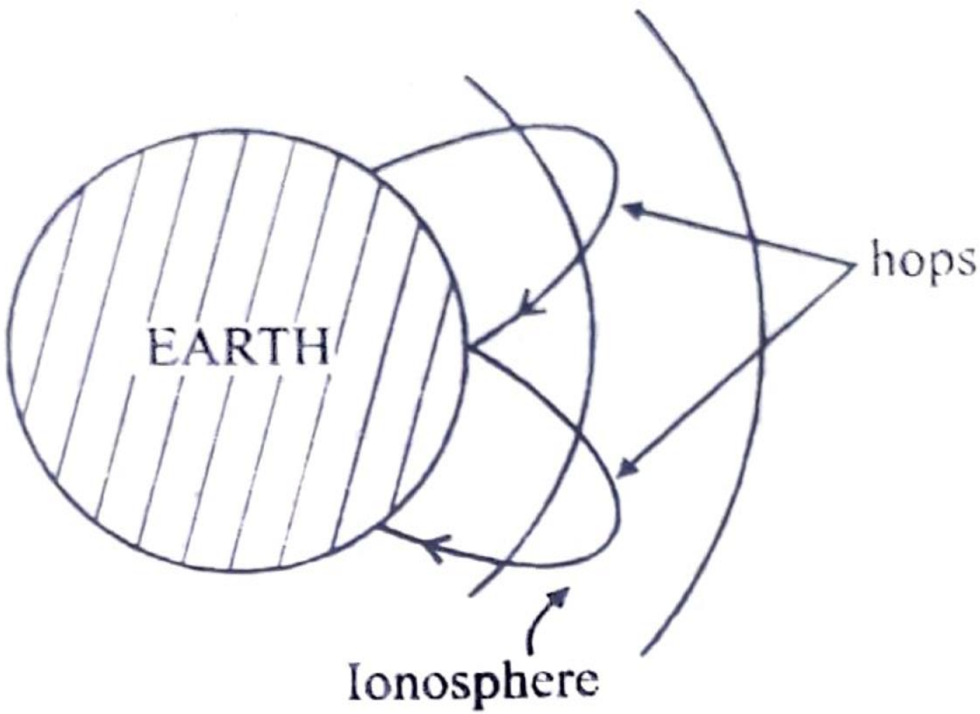
Sky wave propagation

- 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.

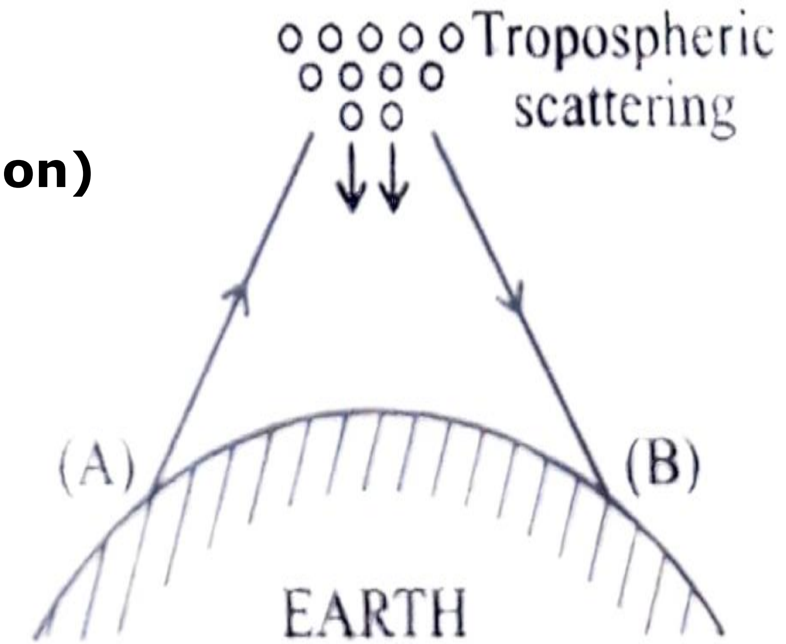
- **Sky wave propagation with multiple hops**
- **no limitations on distance of communication**



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.

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
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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.

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
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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
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
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7. SHF	3-30 GHz	Space wave (LOS)	Relay links, Satellite communication

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.

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
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7. SHF	3-30 GHz	Space wave (LOS)	Relay links, Satellite communication

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.

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
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7. SHF	3-30 GHz	Space wave (LOS)	Relay links, Satellite communication

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.

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
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7. SHF	3-30 GHz	Space wave (LOS)	Relay links, Satellite communication

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
1. VLF	3-30 kHz	Ground wave	World Wide Telegraphy
2. LF	30-300 kHz	Ground wave	Navigation, Broadcasting
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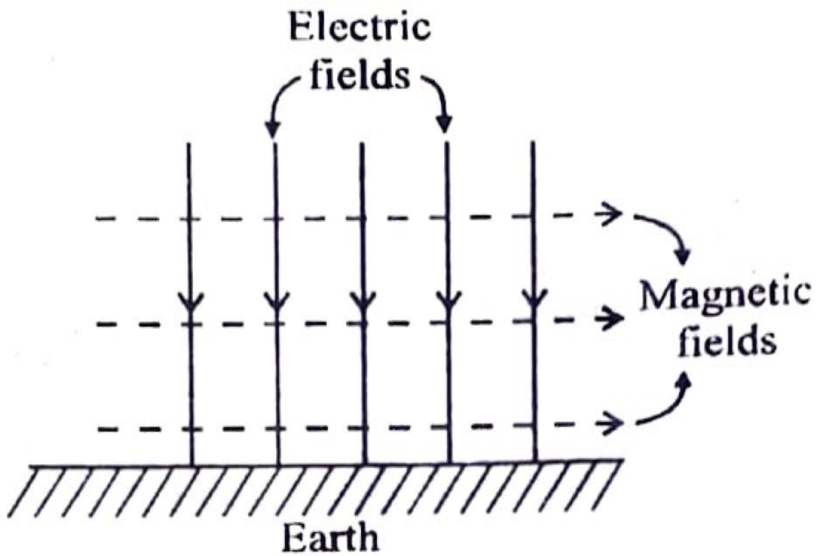
Super high frequency (SHF) (centimeter band):

- **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

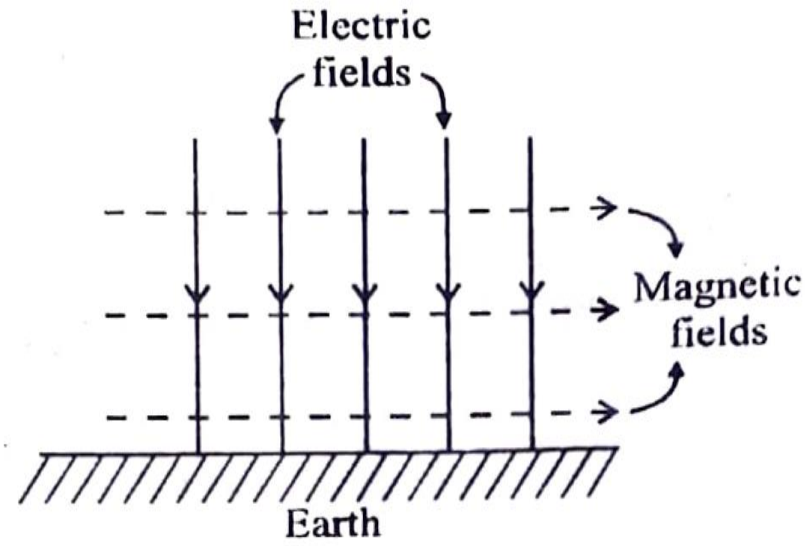
- **Ground wave propagation is by gliding over the surface of earth**
- **It exists for the vertically polarized antenna,**
- **electric field is maintained normal to earth surface to reduce attenuation due to earth's conduction**



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

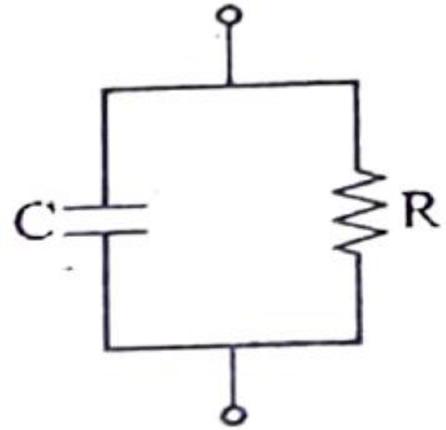
Ground wave propagation contd.

- 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

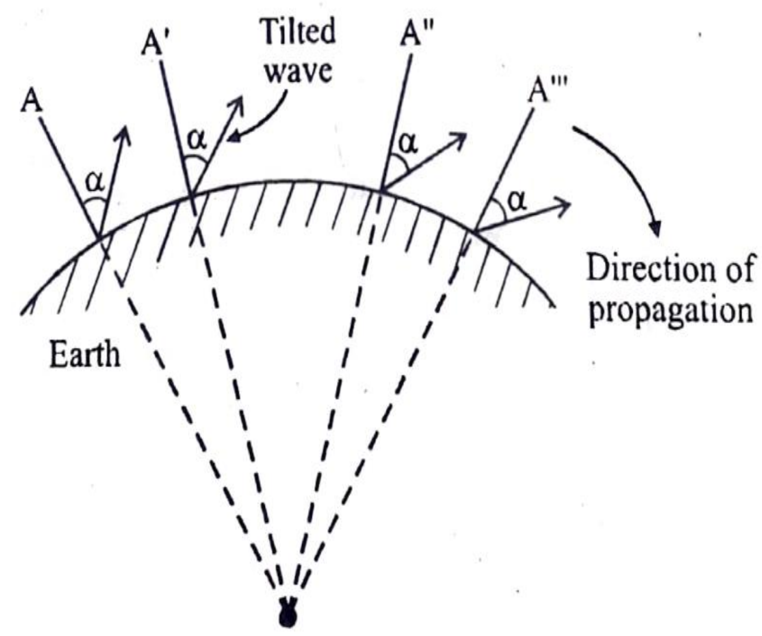
Ground wave propagation contd.

- 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

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

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

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

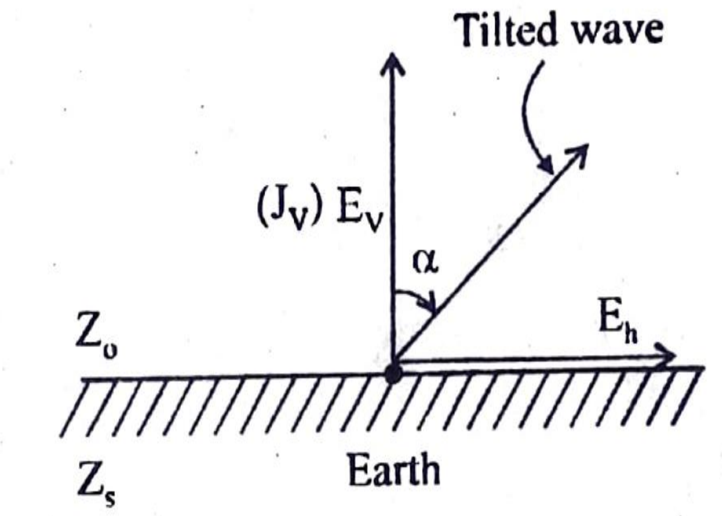
$A \rightarrow Attenuation\ factor$

$d \rightarrow distance$

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

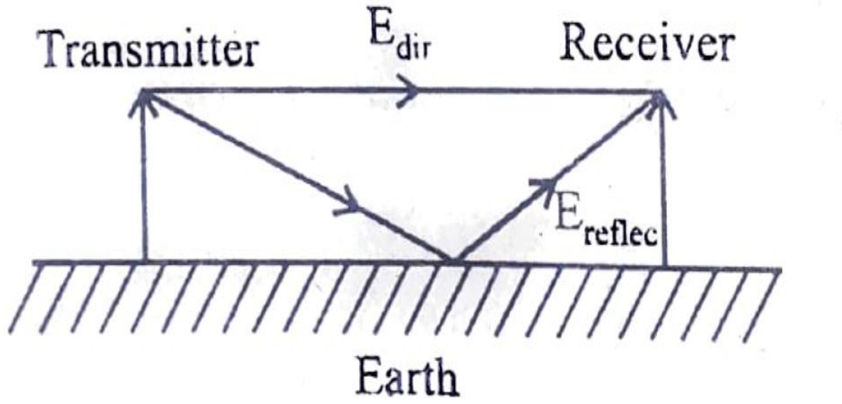
$$\frac{E_h}{E_v} = \frac{Z_s}{Z_0} \qquad Assuming\, J_h = J_v$$

- 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

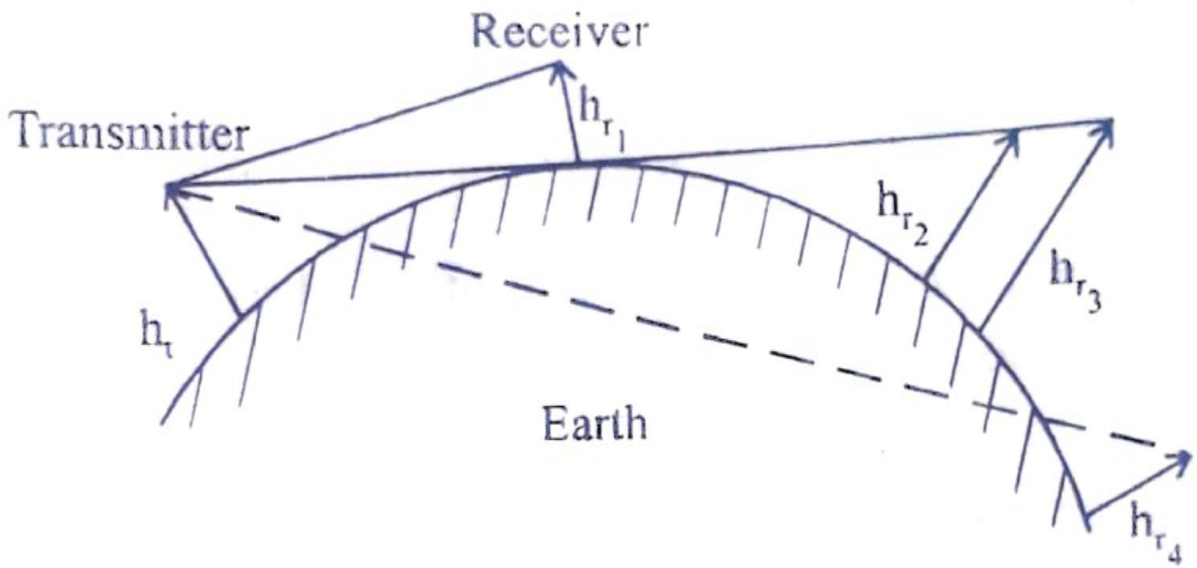


$$E_{space} = E_{dir} + E_{reflection}$$

- 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

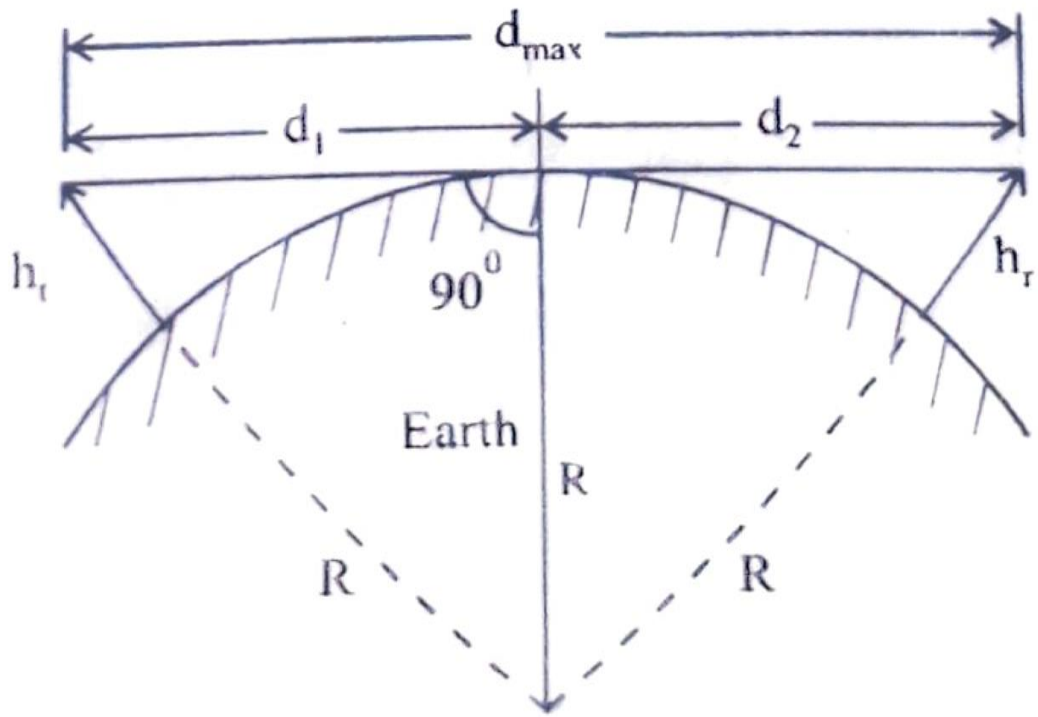


- consider a transmitter mounted at a height h_t
  - h_{r1} can receive both direct and reflected wave
  - h_{r2} and h_{r3} can receive only direct wave
  - h_{r4} cannot receive any signal (due to earth's curvature)

Space wave propagation contd.

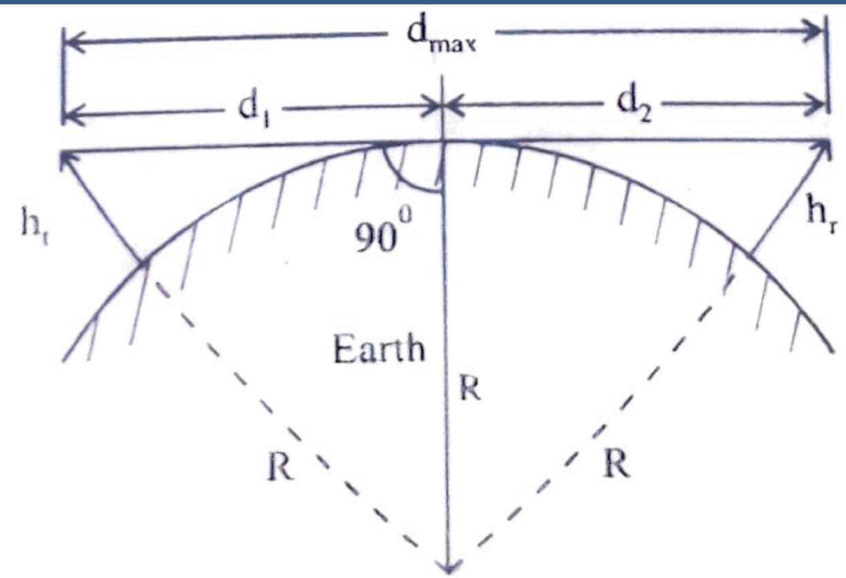
Range or distance of communication

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

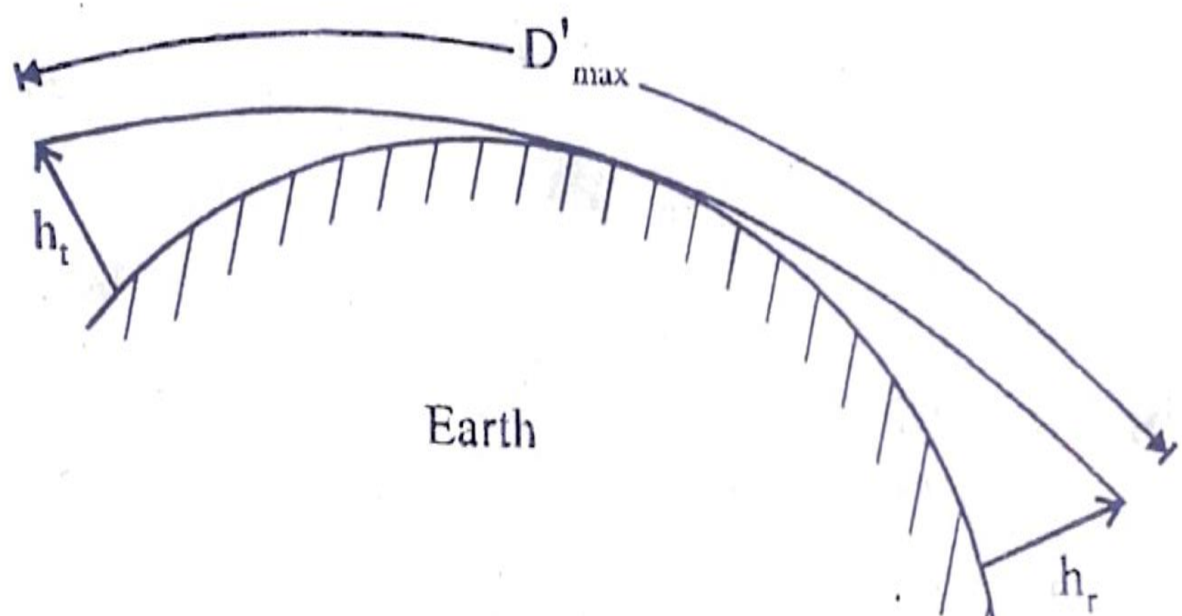
$$d_2 = \sqrt{2Rh_r}$$

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

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, $R' = \dfrac{4}{3}R$

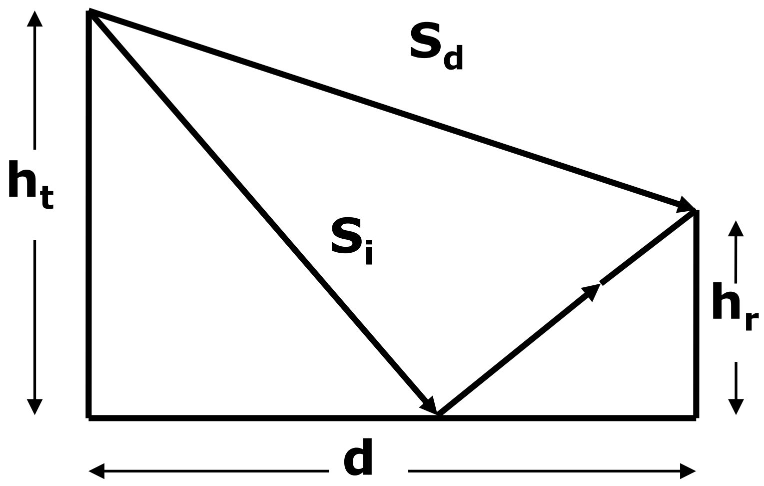
Space wave propagation contd.

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,

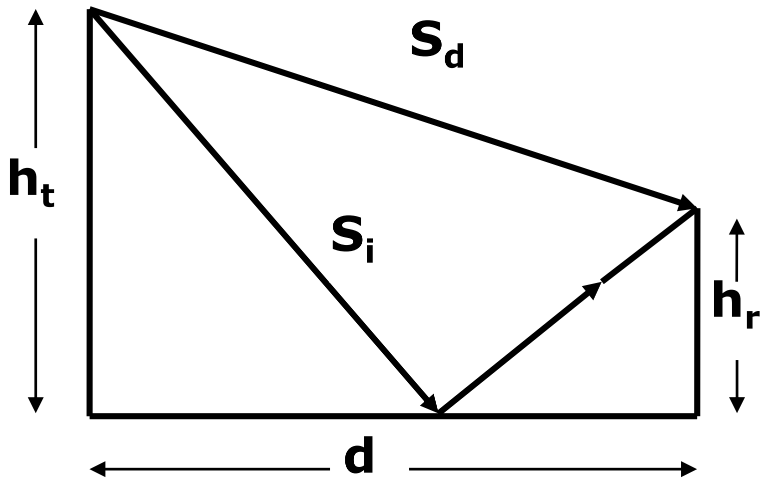
then phase angle difference is

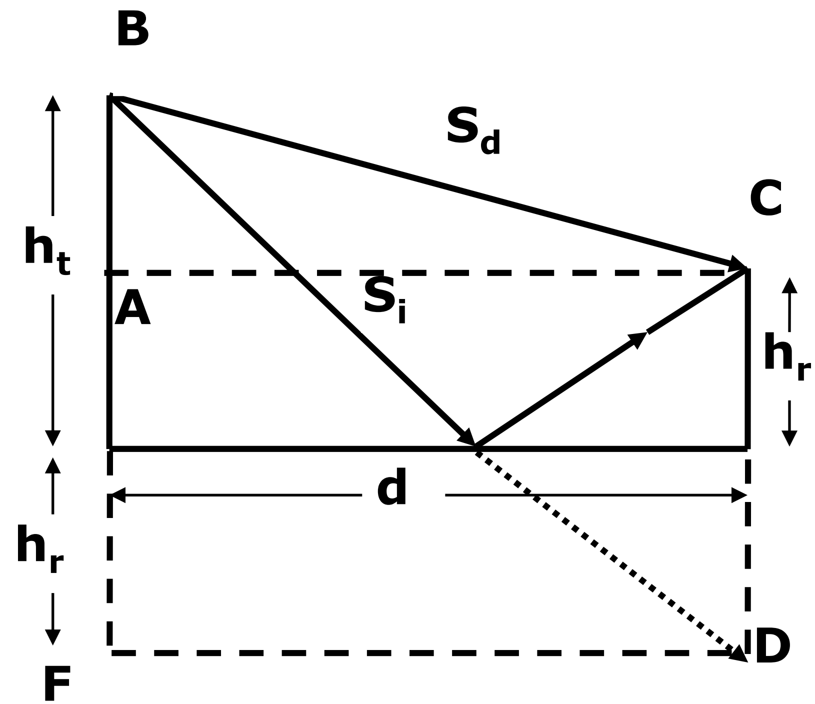
$$\emptyset_s = \frac{2\pi}{\lambda} \Delta s$$



Space wave propagation contd.

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

$$S_i = S_d = d$$

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

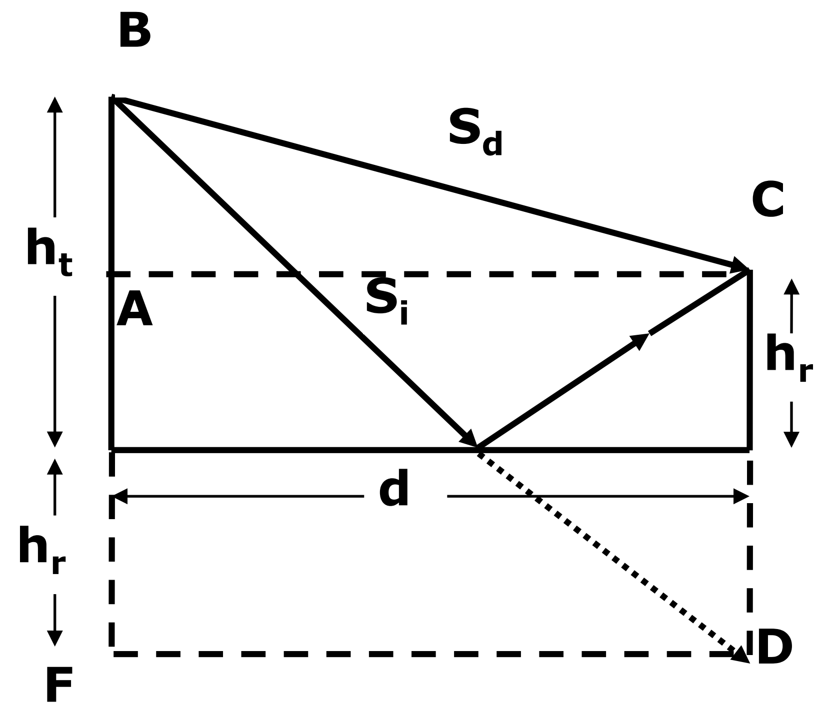
We have

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

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

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

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



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.

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

$$x = \frac{5 \times 10^{-3}}{2\pi \times 1 \times 10^{6} \times 10 \times 8.854 \times 10^{-12}} = 8.98$$

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

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

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.

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

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

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

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

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

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

$$x = 20.44$$

Problems

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

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

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

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

Problems

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

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

Soln.

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

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

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

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.

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

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

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

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

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

$$x = 8.668$$

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

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

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

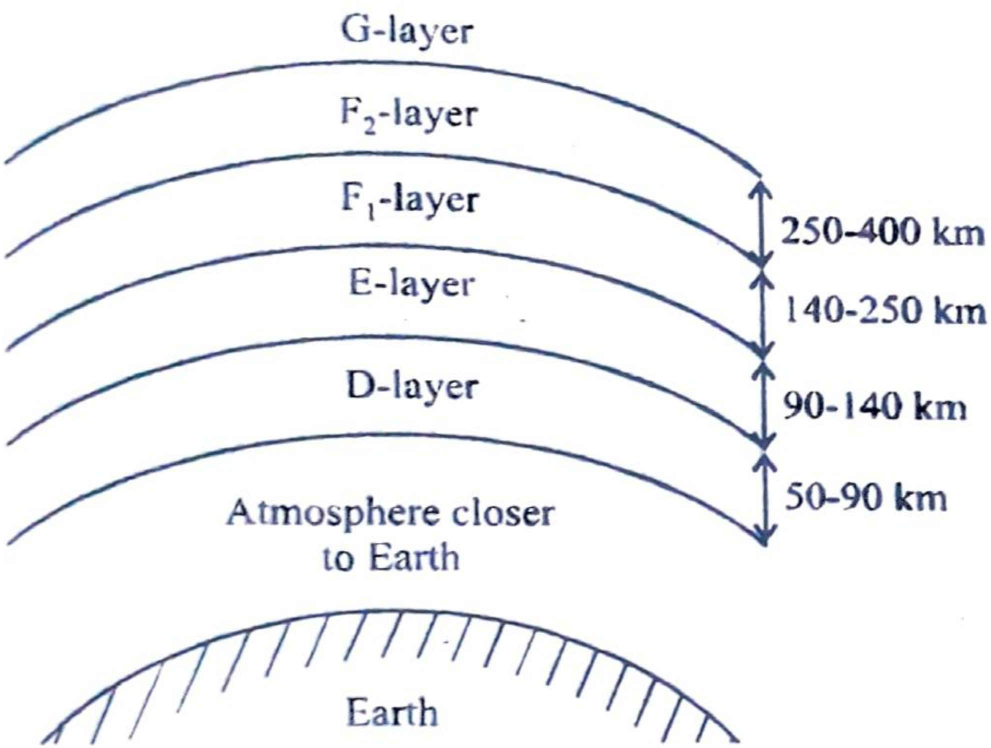
- The ions, electrons and atoms move at random and frequently collide with each other and process of recombination continues
- ionized molecules does not remain ionized indefinitely
- in lower part of atmosphere, collisions are more frequent and hence air molecules do not remain ionized for a longer 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

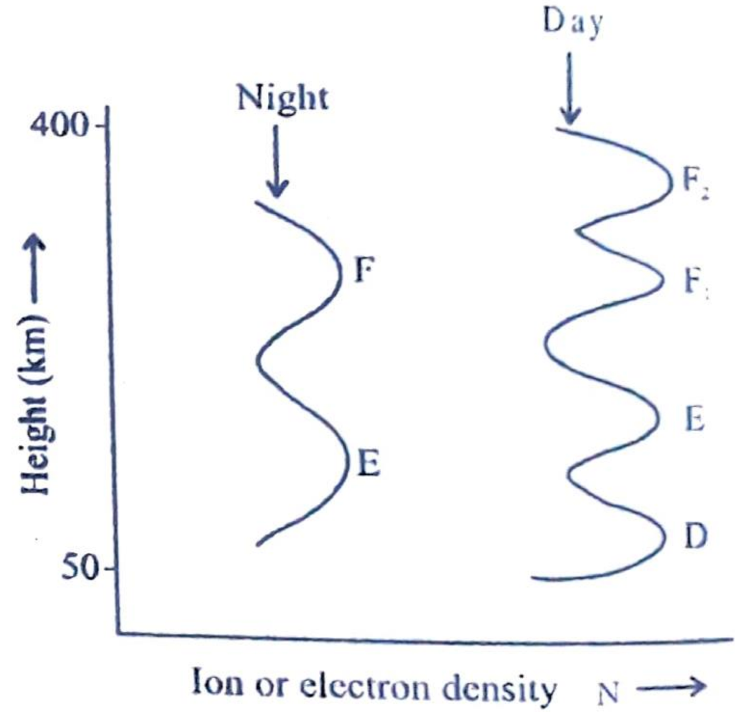
Ionospheric Propagation contd.

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.

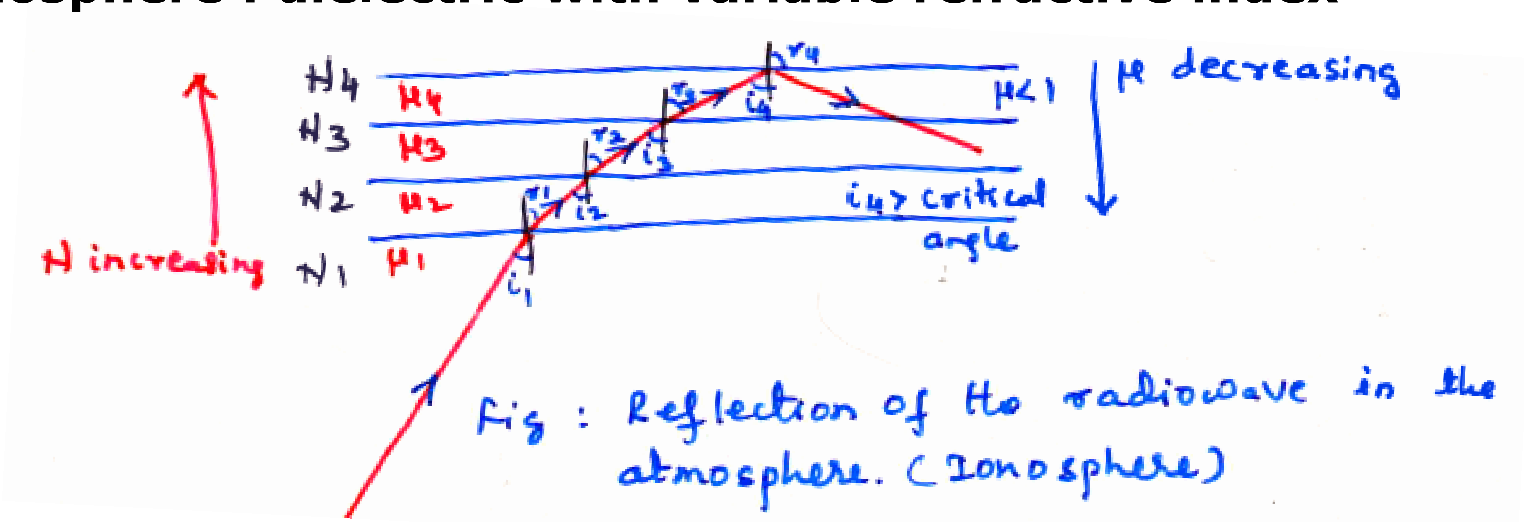
Characteristics of different layers of ionosphere

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	–	–	–	–

Ionospheric Propagation contd.

Wave propagation in ionosphere

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

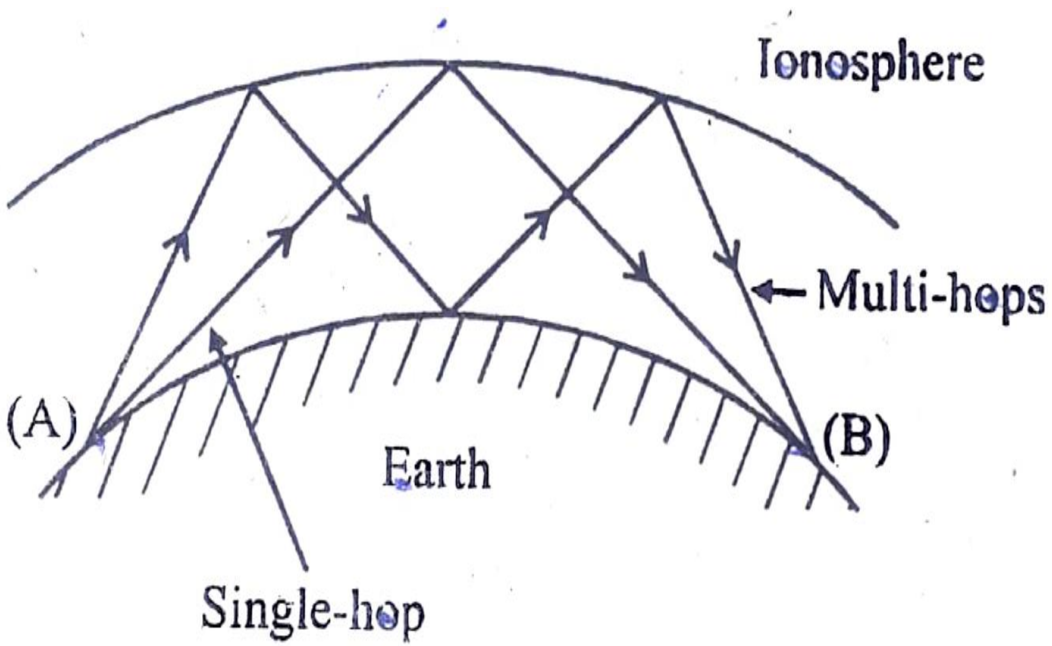


- **for simplicity the ionosphere can be divided into number of thin strips of constant electron density**
- **increase in electron density with increasing height, decreases the refractive index, hence incident ray will bend**
- **once the incident angle becomes greater than critical angle total internal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

Ionospheric Propagation contd.

Rafractive index (a)

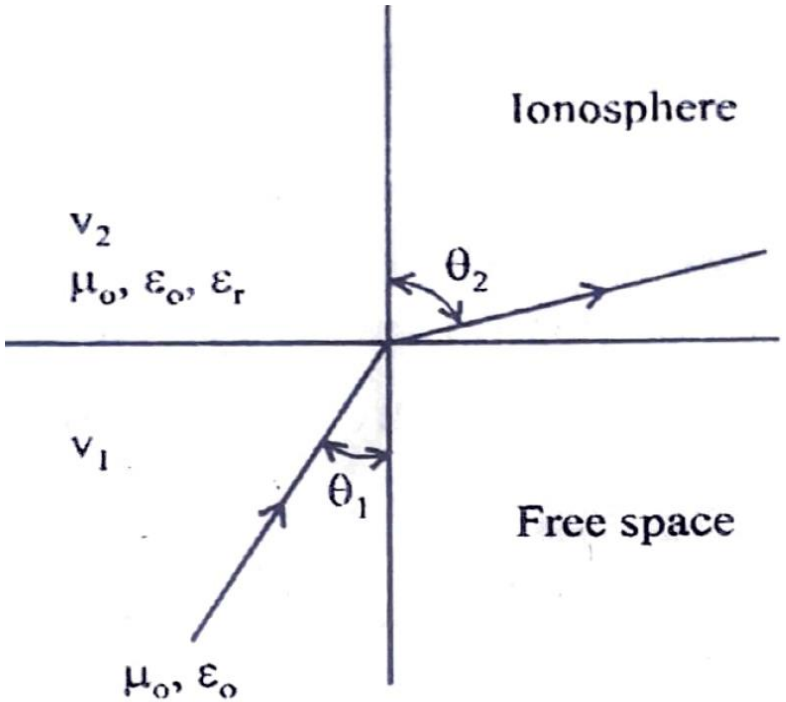
- refractive index of ionosphere with respect to free space is given by

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

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}

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

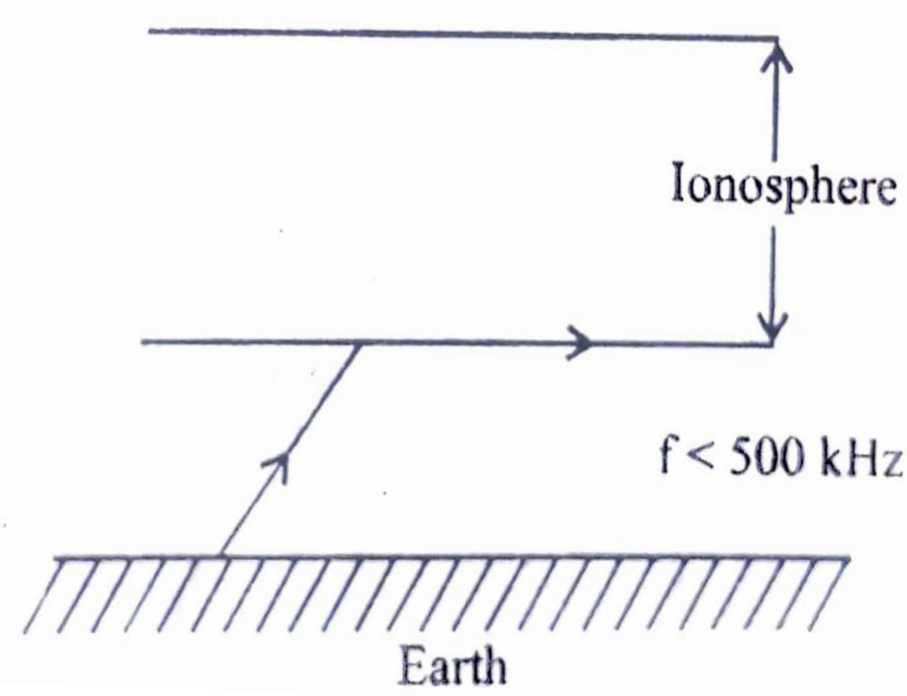
then

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

Ionospheric Propagation contd.

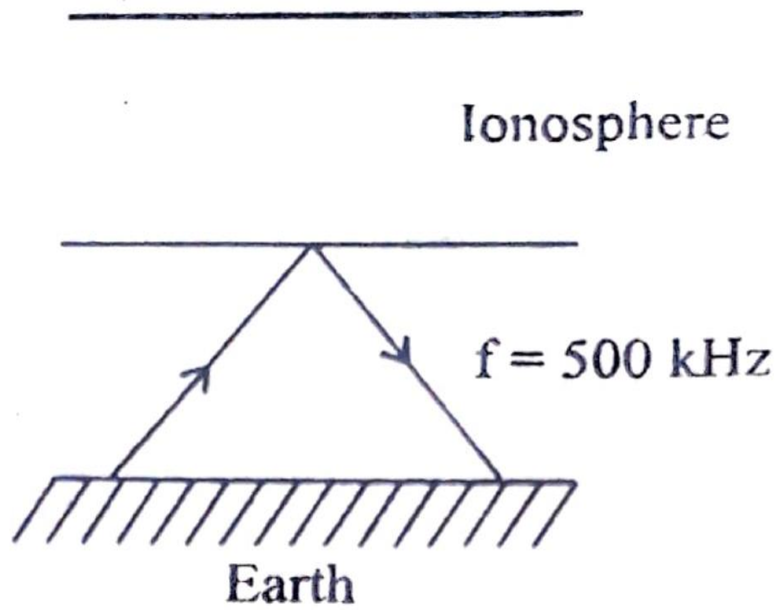
Use of ionosphere for different frequencies

VLF (less than 500 KHz)



No reflection, travels along bottom edge of ionosphere

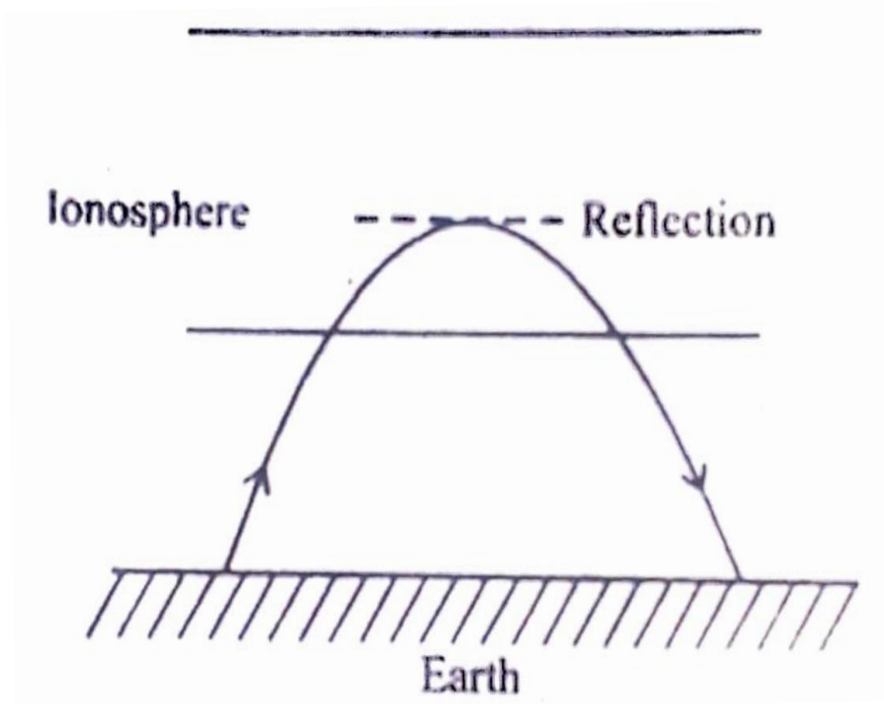
above 500 KHZ



Reflects back from ionosphere

Ionospheric Propagation contd.

MF (500 KHz to 2 MHz)

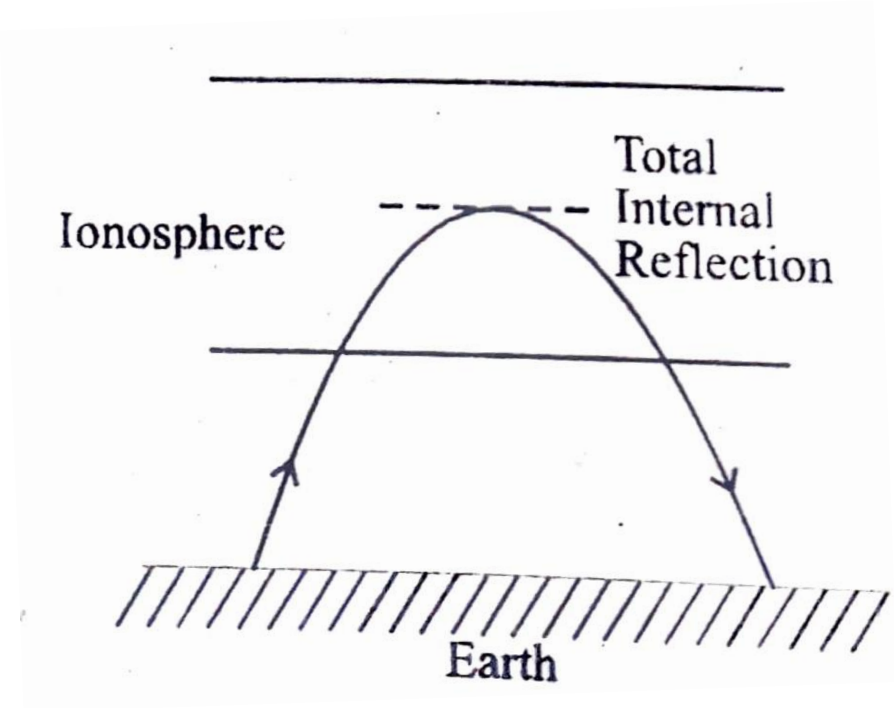


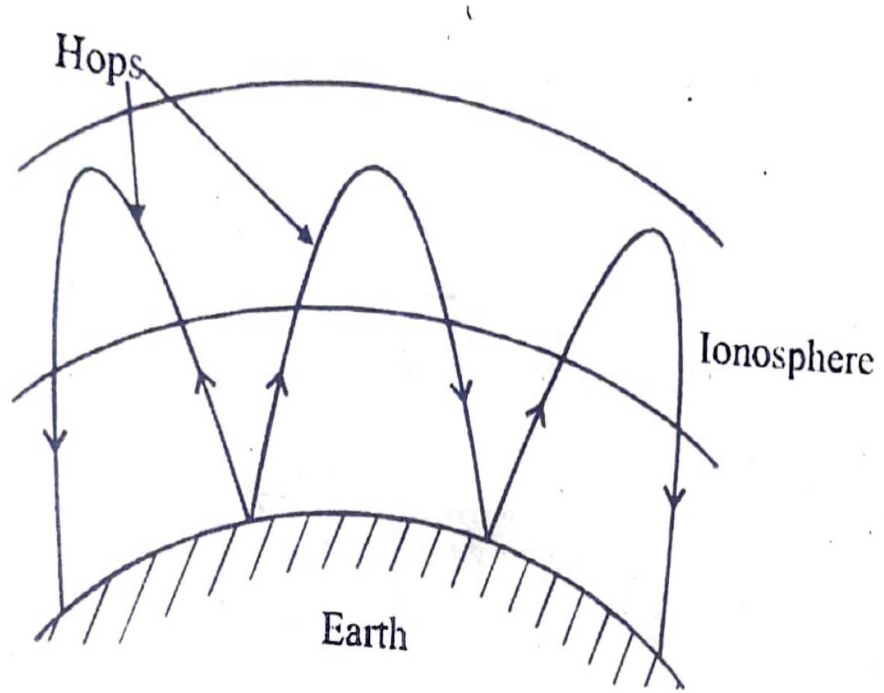
enters ionosphere, undergoes irregular refraction and received back.

Received power is less and distance covered is limited

Ionospheric Propagation contd.

HF (2 MHz to 30 MHz)

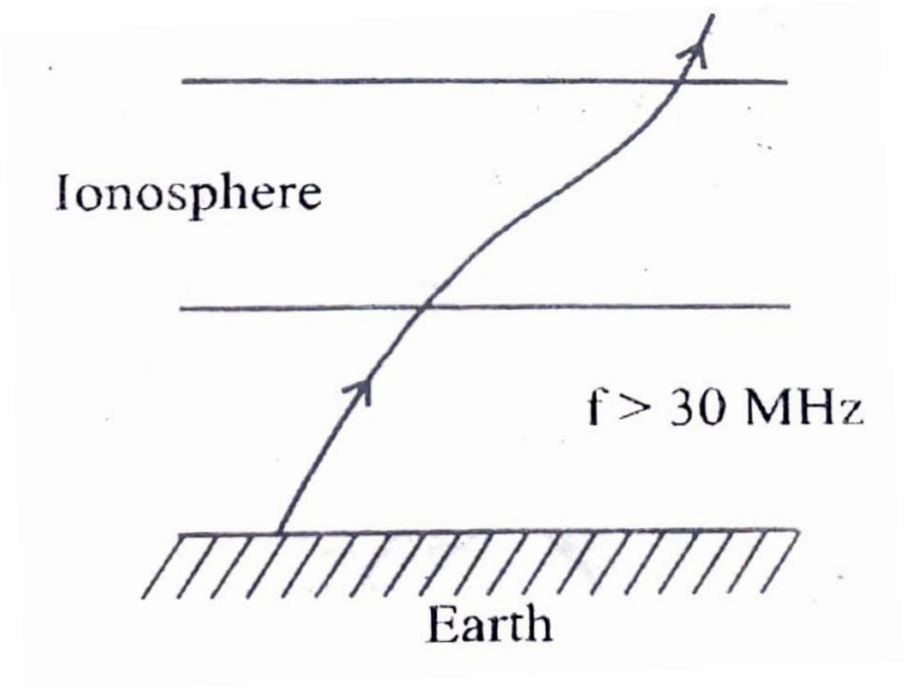




Wave undergoes total internal reflection, received power is large, no limitation on distance of communication due to multiple hops

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

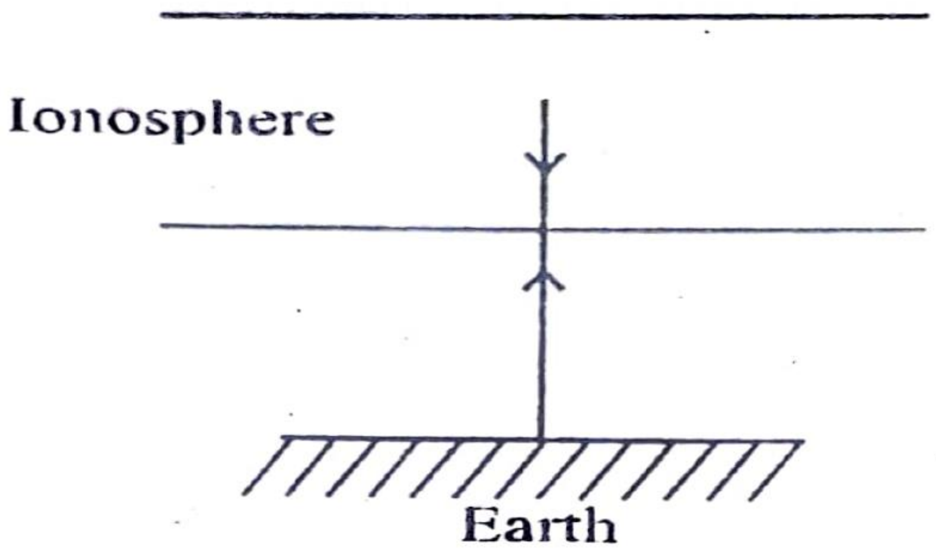
Ionospheric propagation is possible for frequencies ranging between 500 KHz and 30 MHz

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

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

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

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

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

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

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

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

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

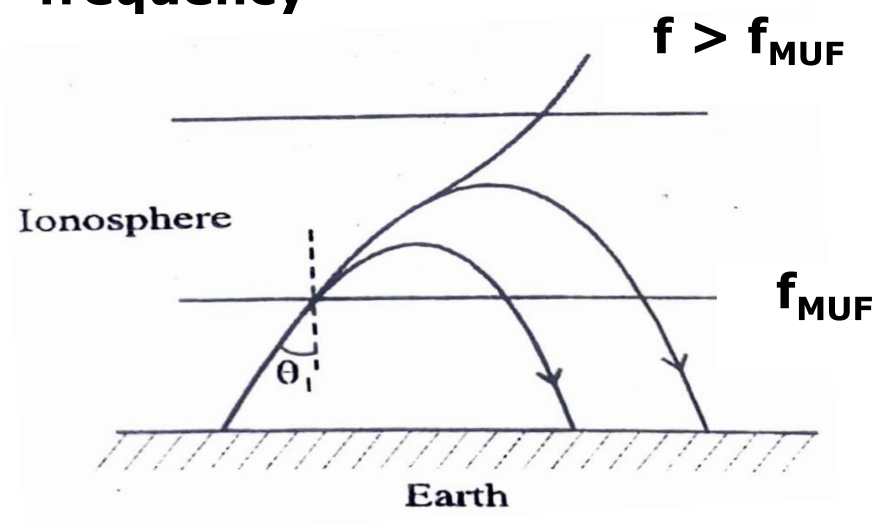
f_c is in MHz when the density N_{max} is in ions or electrons/m^3

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

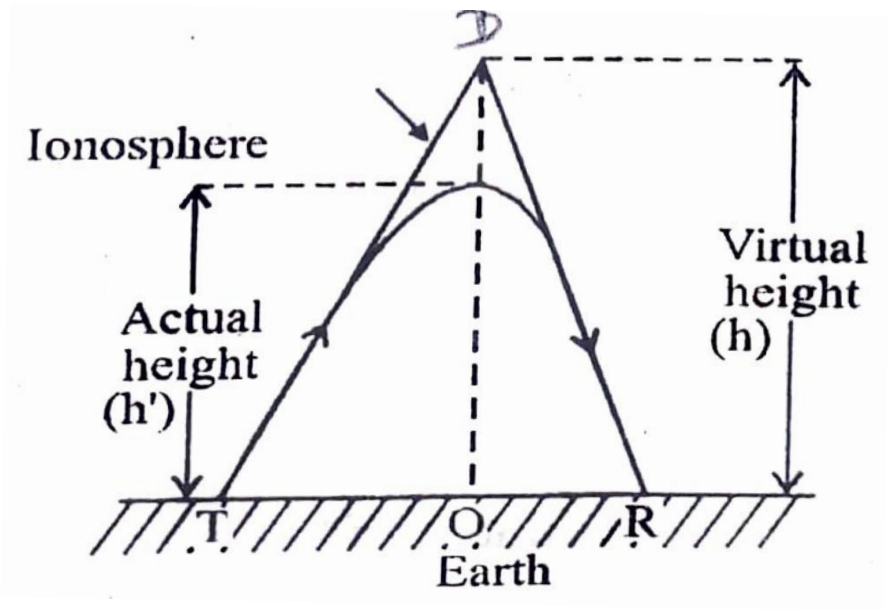
$$f_{MUF} = \frac{9\sqrt{N_{max}}}{Cos\ \theta_1}$$

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

Ionospheric Propagation contd.

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

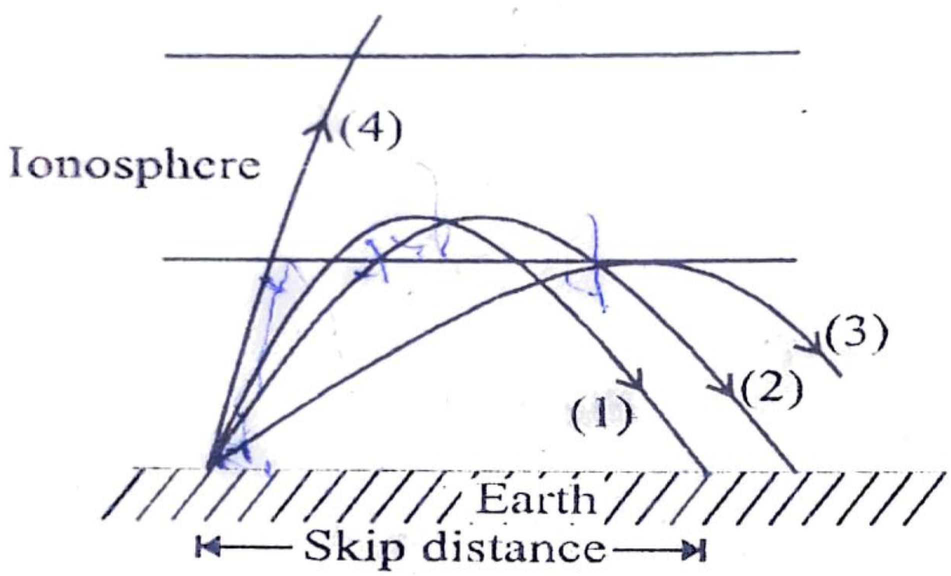
▪ approximate height can be obtained considering straight paths TD and DR

▪ 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 10⁶/cm³.

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.

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

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

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

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 2X10⁶/m³. 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) $3 \times 10^6 = 18\sqrt{N_{max2}}$

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

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