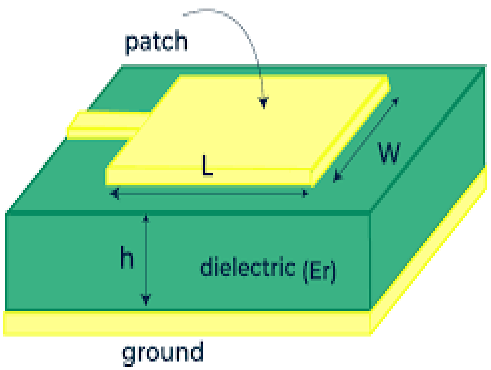
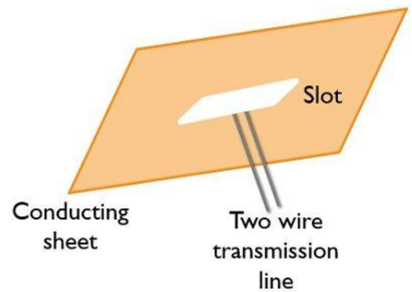
# 7REC02 Antennas and Propagation

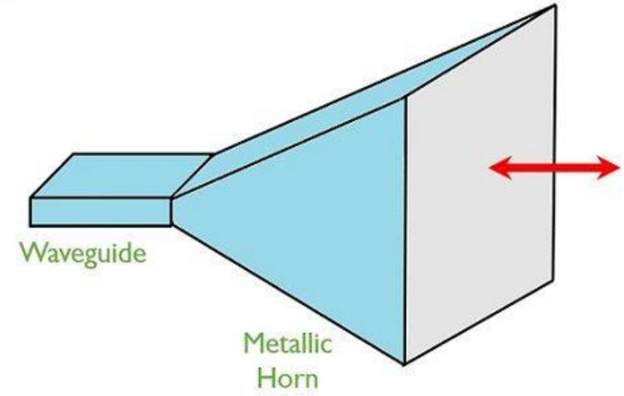
## Unit – 4

# Practical Antennas



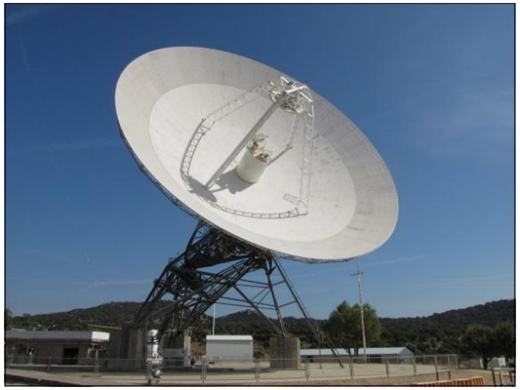



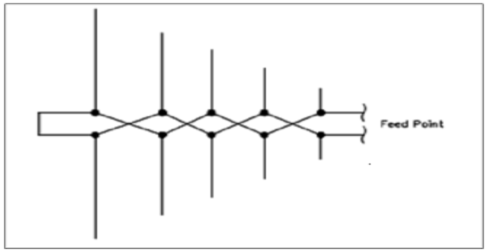

Slot Antenna




Horn Antenna

Electronics Desk



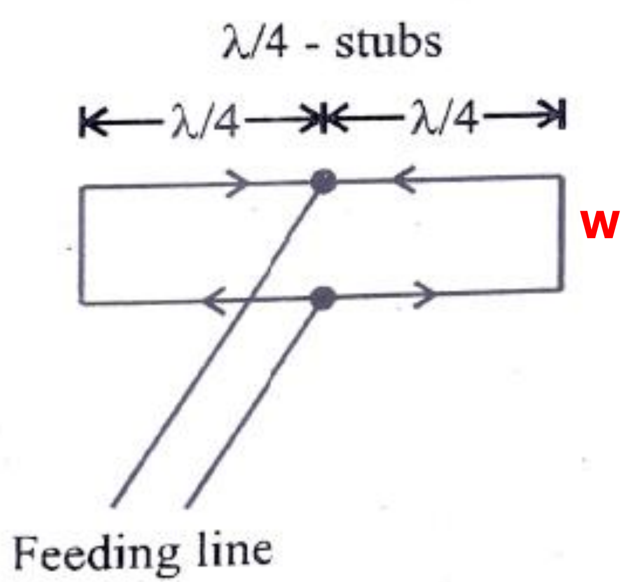



# Practical Antennas

- 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

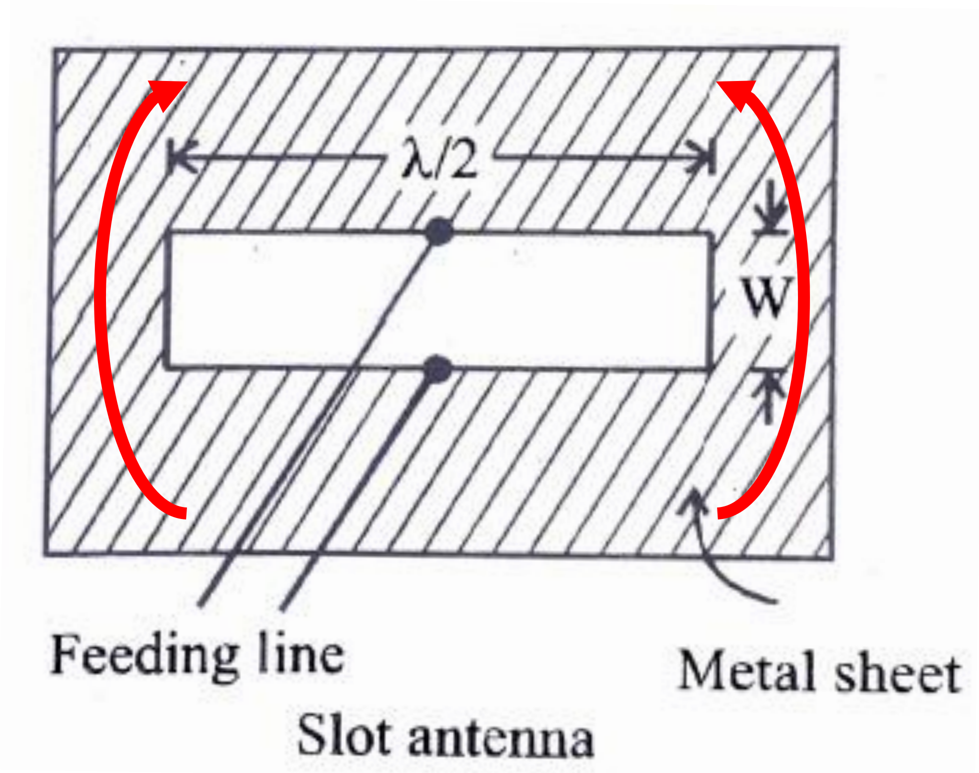
- A slot antenna consists of a metal surface, usually a flat plate, with one or more holes or slots cut out.
- Slot antennas are useful where low profile (small dimension) or flush mountings (inside) are required. Ex. High speed aircrafts
- Consider a system which contains two resonant $\lambda/4$ stubs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




- It is an inefficient radiator because
  - long wires are closely placed ($W \ll \lambda$) 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.

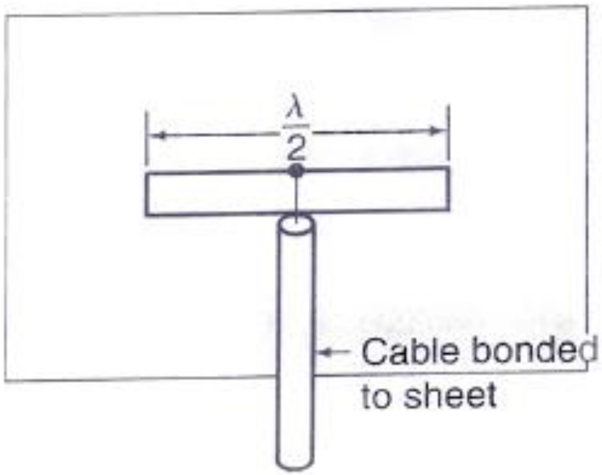
- Instead λ/4 stubs if λ/2 slot is cut in a flat metal sheet, the antenna will be very efficient




- 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

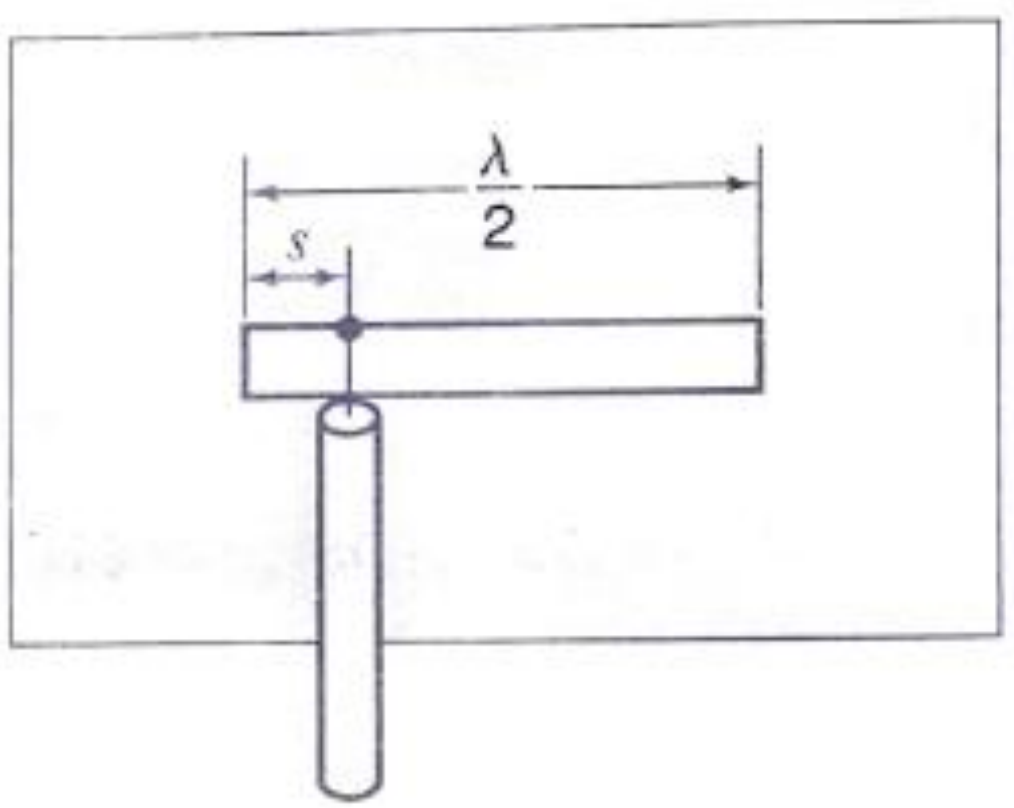



- radiation occurs equally from both sides of the sheet
- Outer conductor is bonded to the metal sheet

- The terminal resistance at the centre of a resonant $\lambda/2$ slot in a large sheet is about 500$\Omega$
- Characteristics impedance of coaxial transmission line is usually much less
- hence impedance mismatch takes place

# Slot Antenna contd.

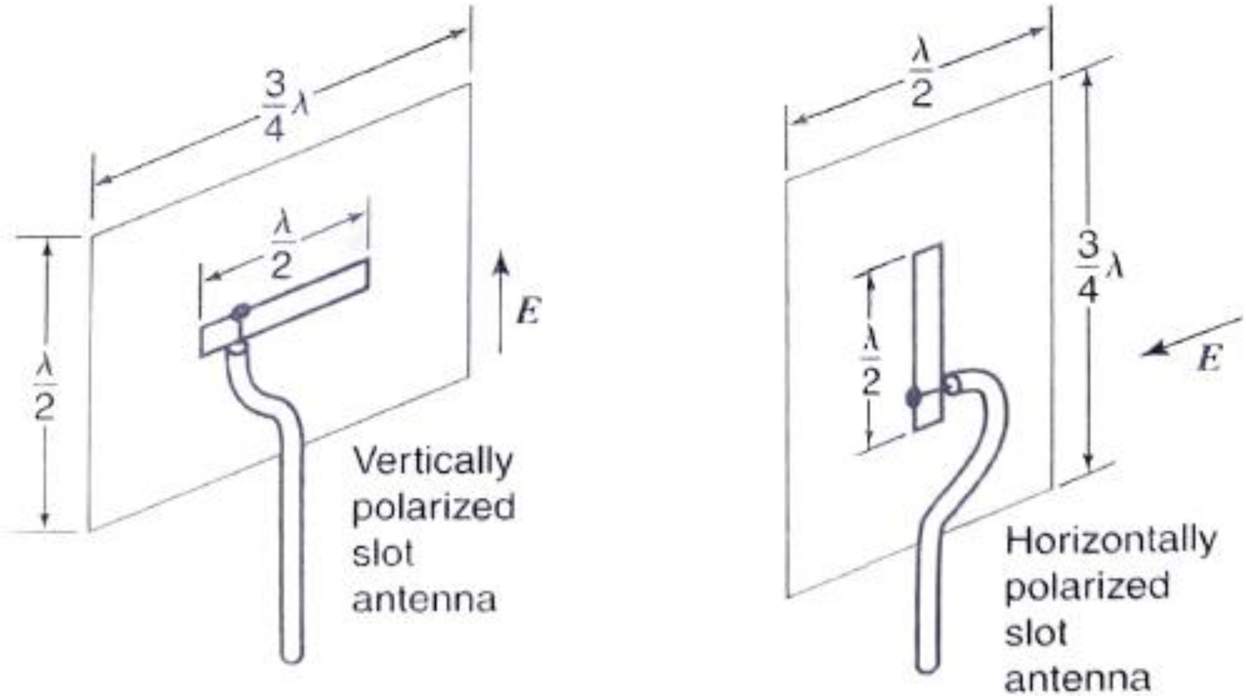
- An off-centre feed may be used to provide better impedance match




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

# Slot Antenna contd.

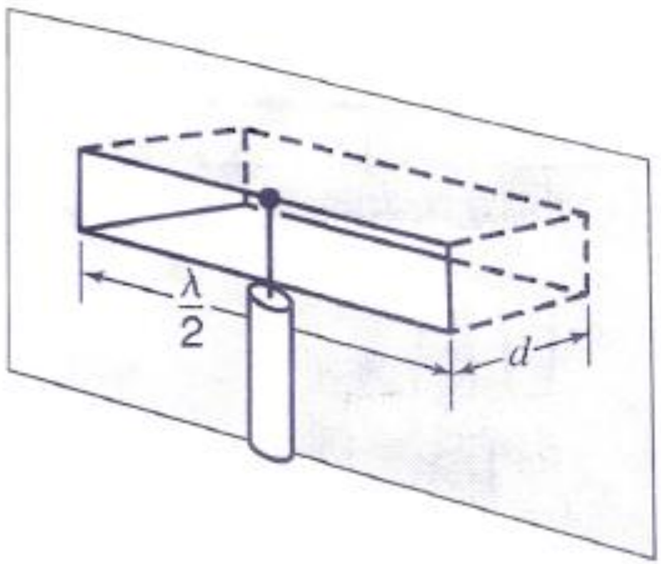
- Slot antenna fed by a coaxial cable in off-centre manner are




- 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.

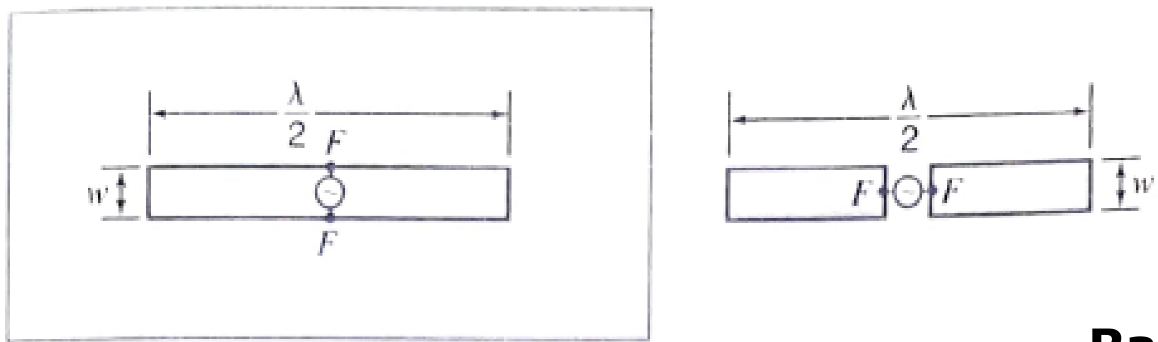
- A flat sheet with a $\lambda/2$ slot radiates equally on both sides of the sheet
- If the sheet is very large (ideally infinite) and boxed, radiation occurs only from one side

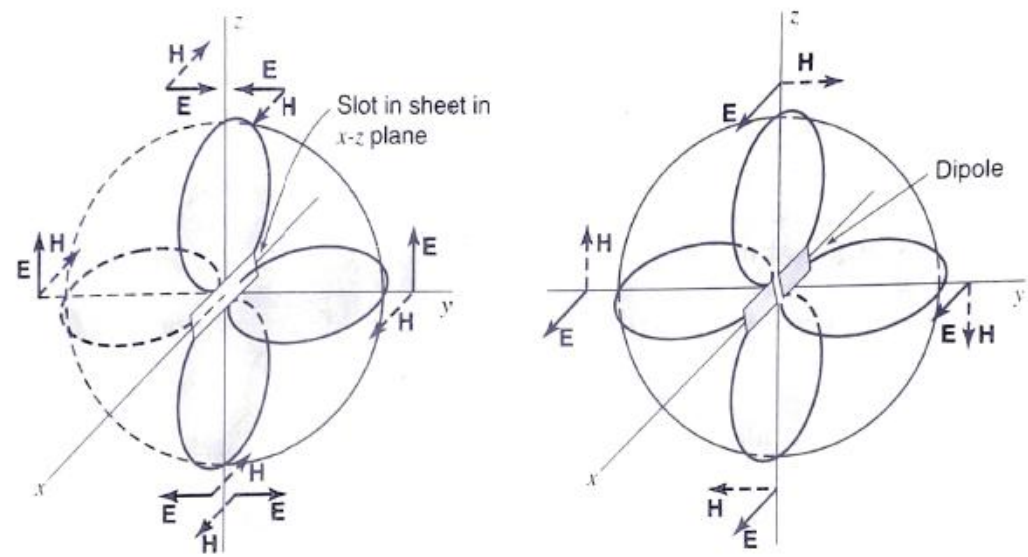


# Slot Antenna contd.

## Patterns of slot antenna in flat sheet

- Consider a λ/2 slot antenna and complementary λ/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

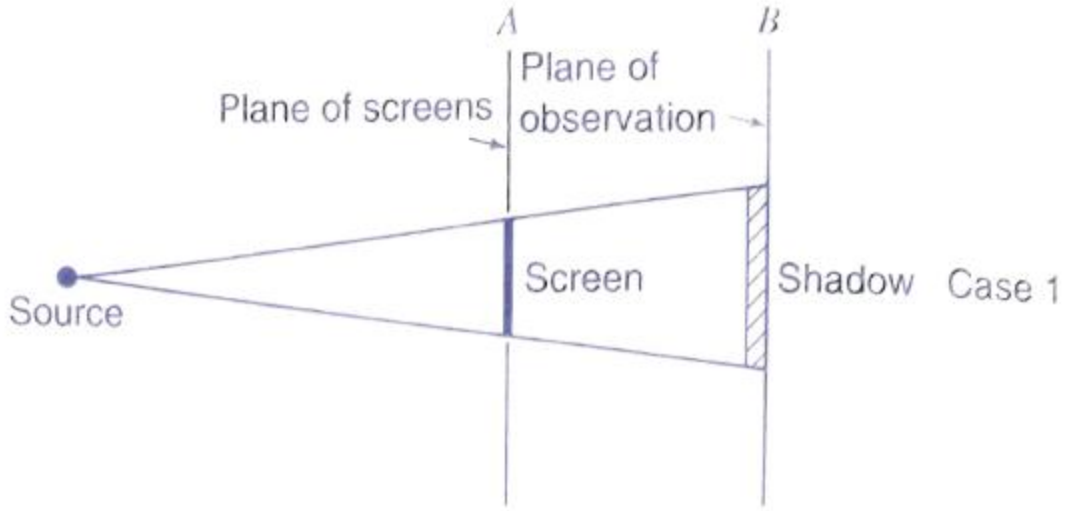
- **Babinet's principles can be used to reduce the problems of slot antennas**

- **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**

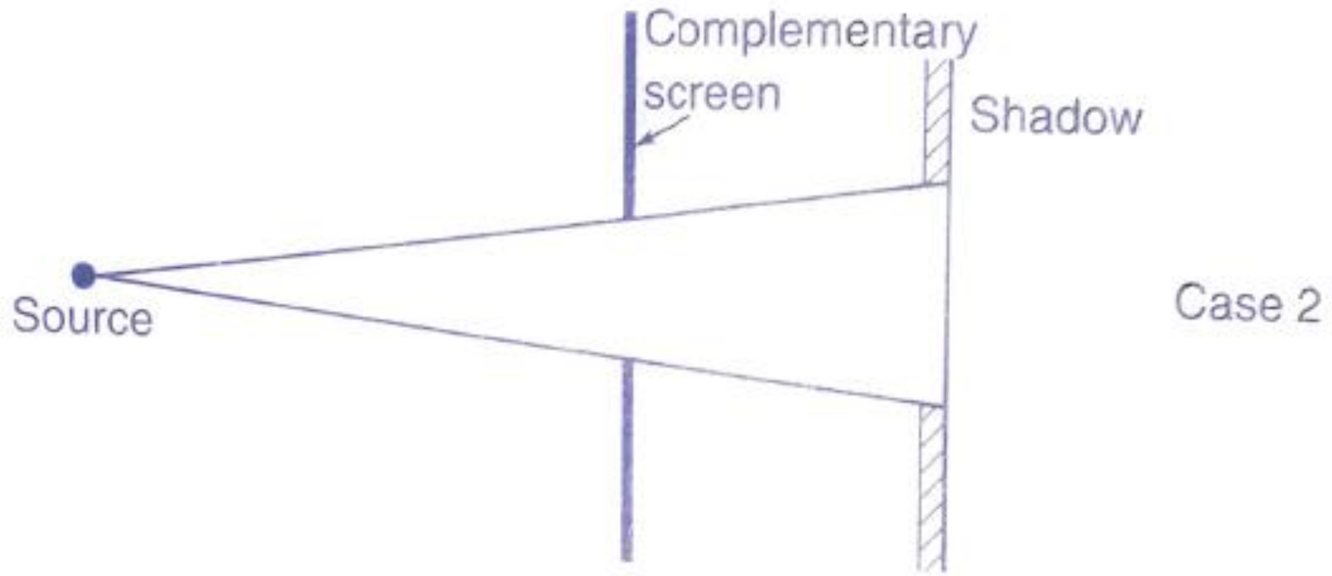
# Contd.

- **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)**



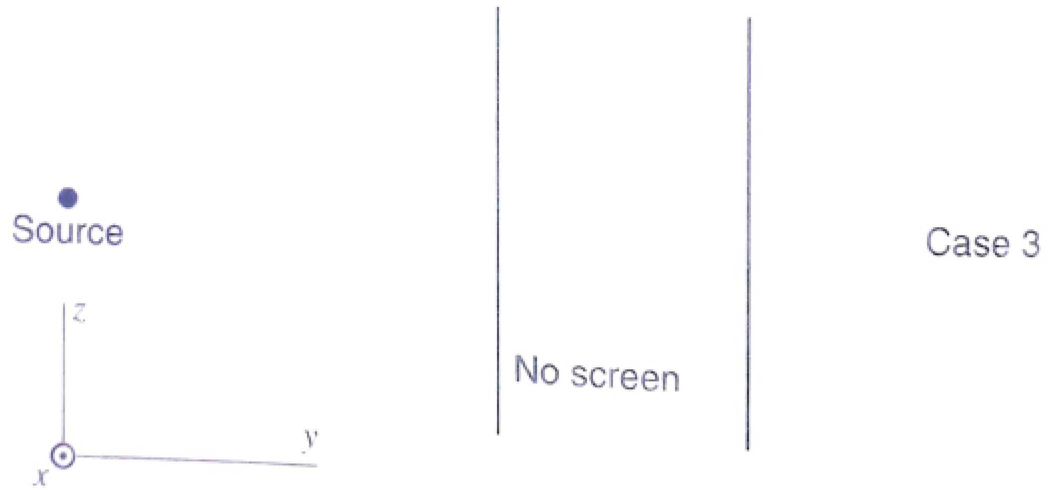
# Contd.

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

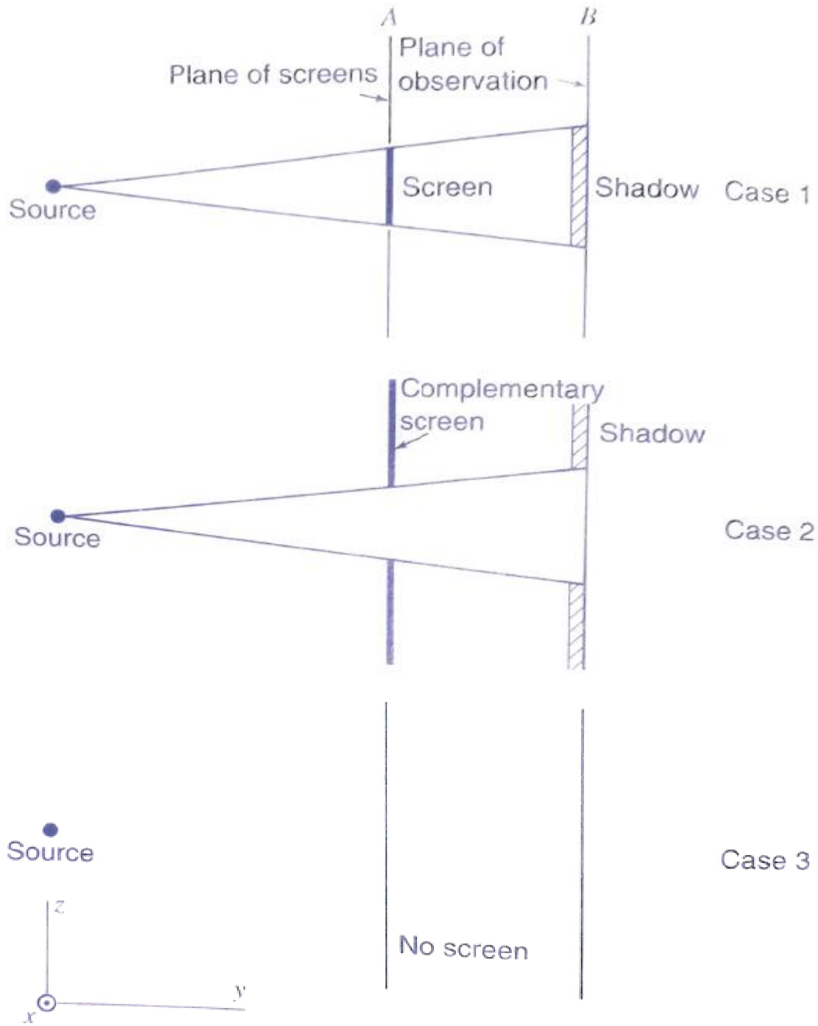


# Contd.

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



# Contd.




$$Fs + Fcs = Fo$$

**Babinet's principle states that**

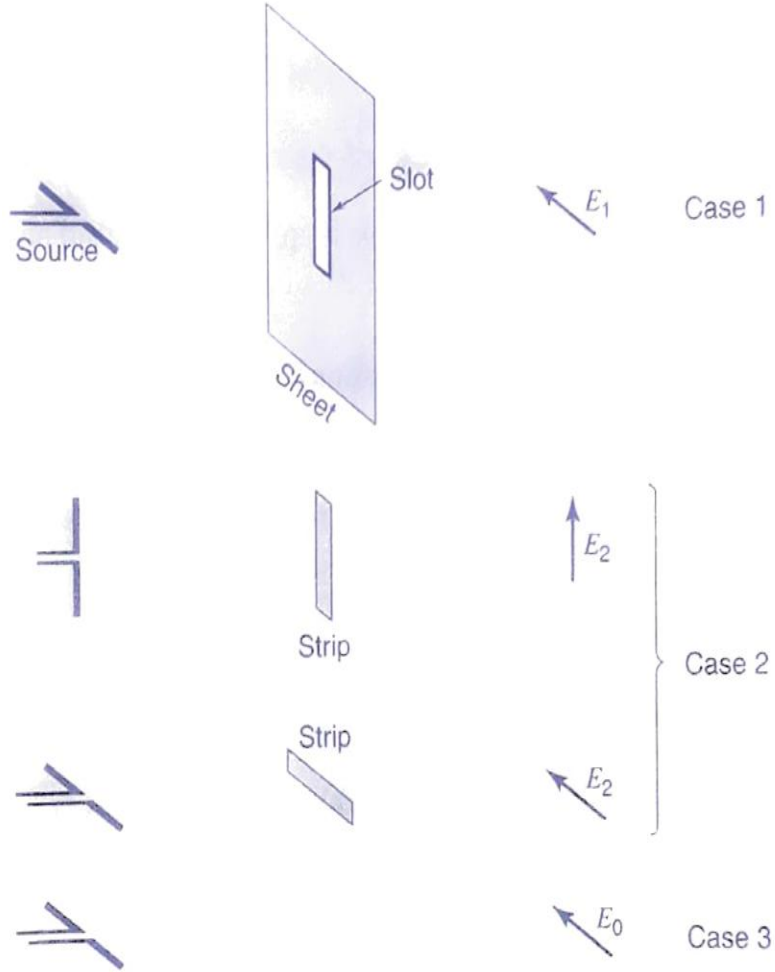
**"The field at any point behind a plane having a screen, if added to the field at the same point when the complementary screen is substituted, is equal to the field when no screen is present (in optics).**

**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.



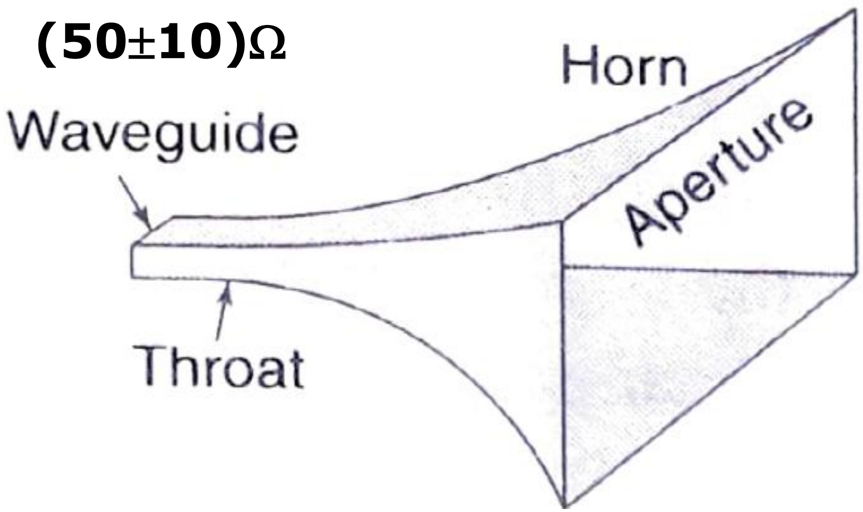

- **Case 1: Dipole is horizontal and screen is perfectly conducting thin sheet with a vertical slot cut. At point P behind the screen the field is E1**
- **Case 2: Complementary screen perfectly conducting thin strip of the same dimensions of the slot. At point P the field is E2**
- **Case 3: No screen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

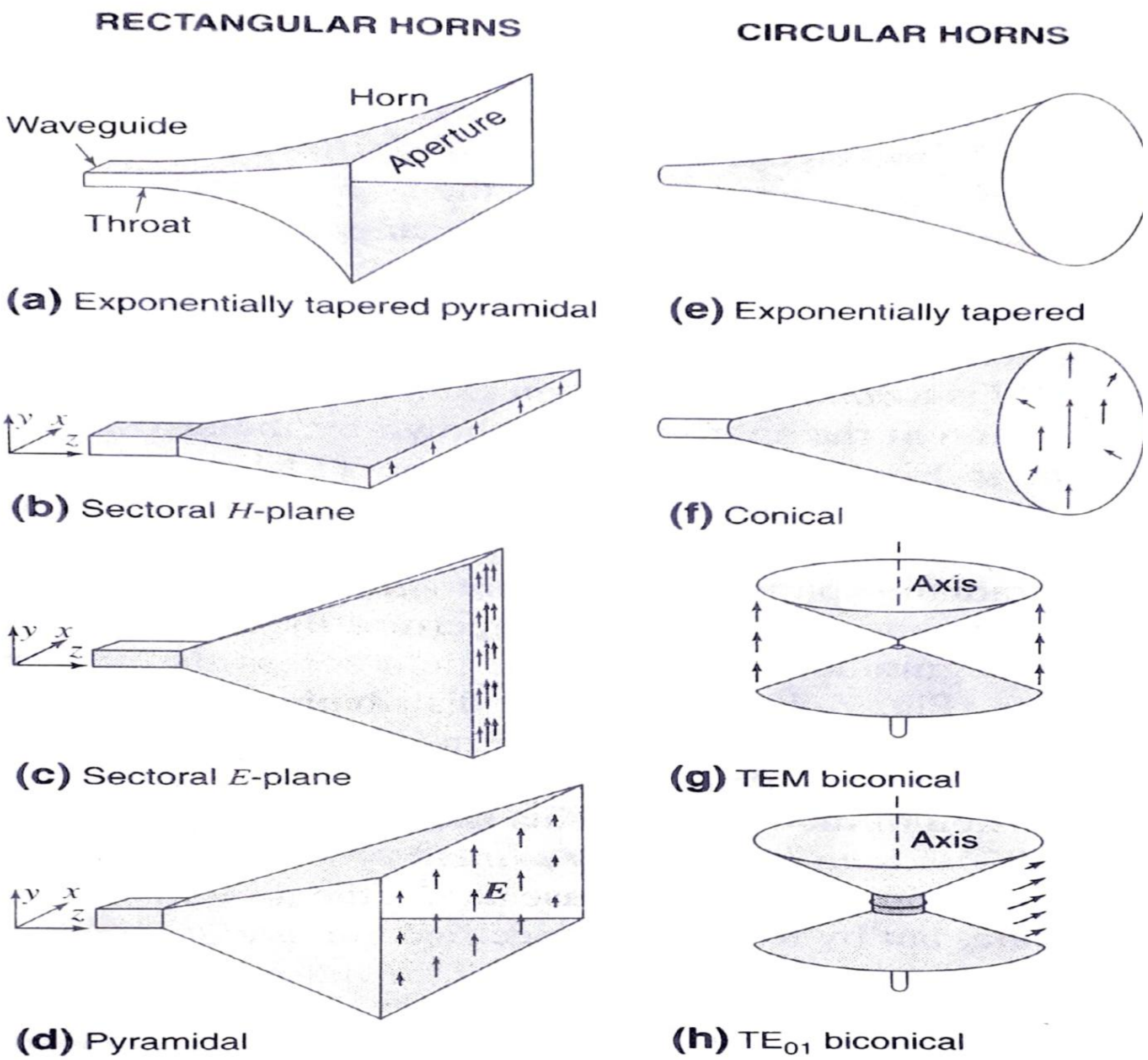
- A Horn antenna is a flared out (opened out) waveguide
  - It improves directivity and impedance matching
- Horn antenna produces
  - Uniform phase front with a larger aperture than that of waveguide, hence greater directivity
- J C Bose constructed a pyramid horn in 1897

(50±10)Ω

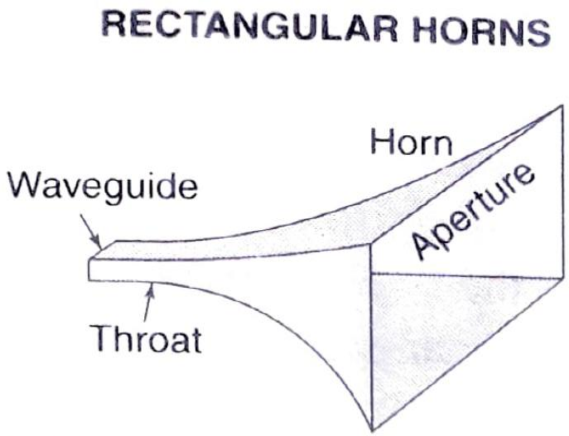



Free space
377Ω

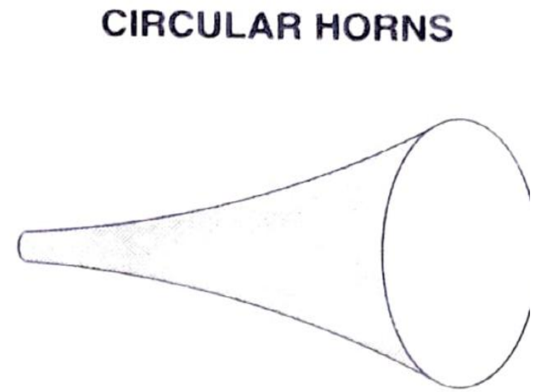
# Horn Antenna - Types



# Horn Antenna contd.




(a) Exponentially tapered pyramidal

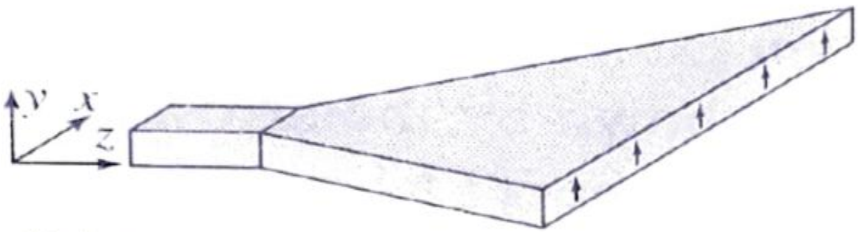



(e) Exponentially tapered

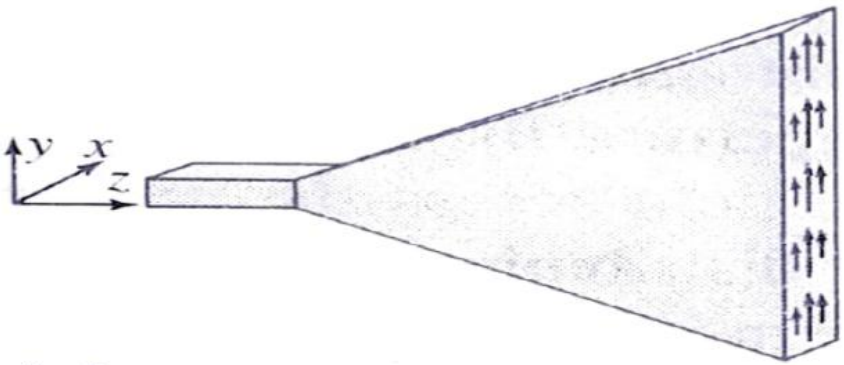
- **To minimize reflections of the waveguide, the horn between the waveguide at the throat and the free space at the aperture could be given a gradual exponential taper (transition region)**

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

# Horn Antenna contd.



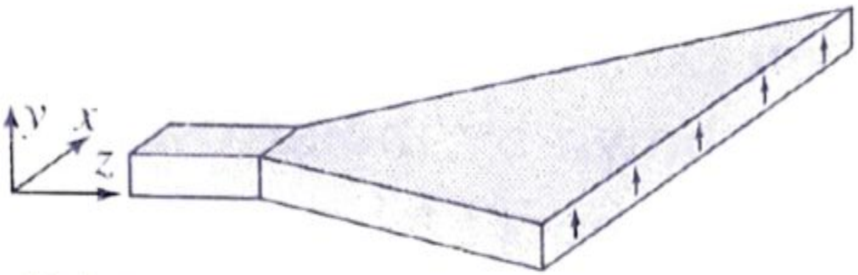

(b) Sectoral *H*-plane



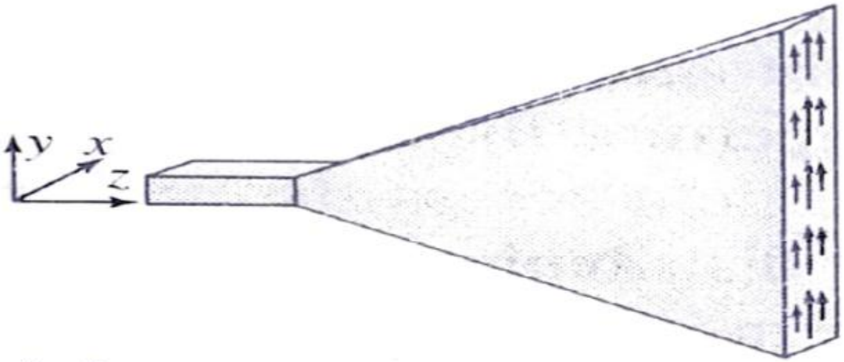

(c) Sectoral *E*-plane

- **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.

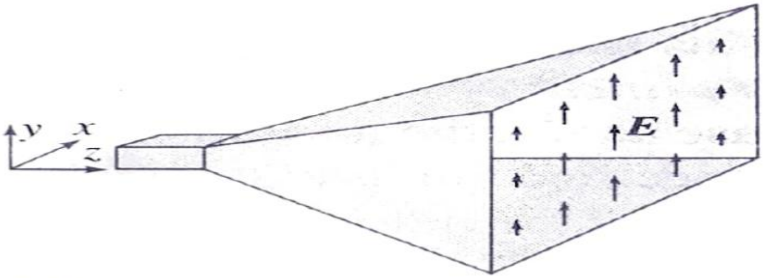



(b) Sectoral *H*-plane




(c) Sectoral *E*-plane

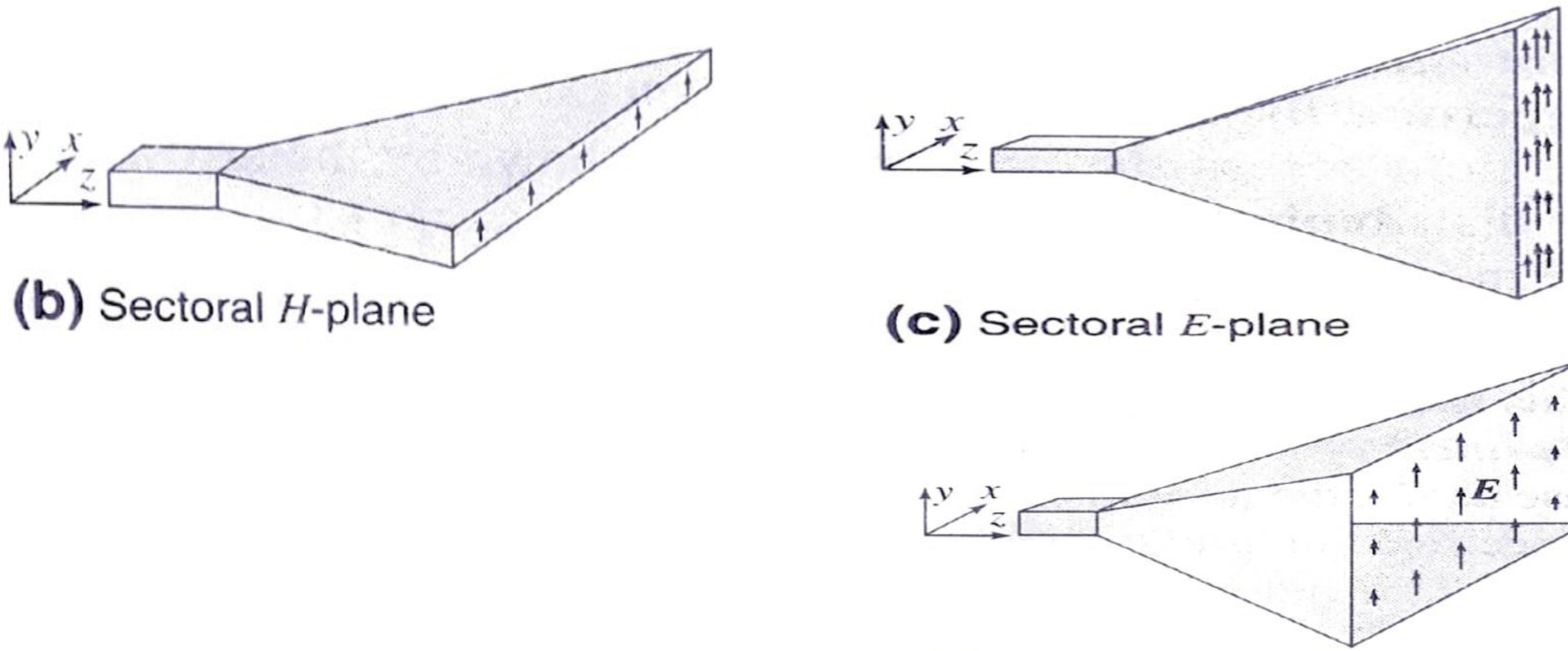
- **If horn is flared out in a plane of the electric field E [Fig. (c)]**
- **Sectoral horn flared in E plane (E-plane sectoral horn)**
- **Rectangular antenna with flare on both sides is called pyramidal horn**




(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



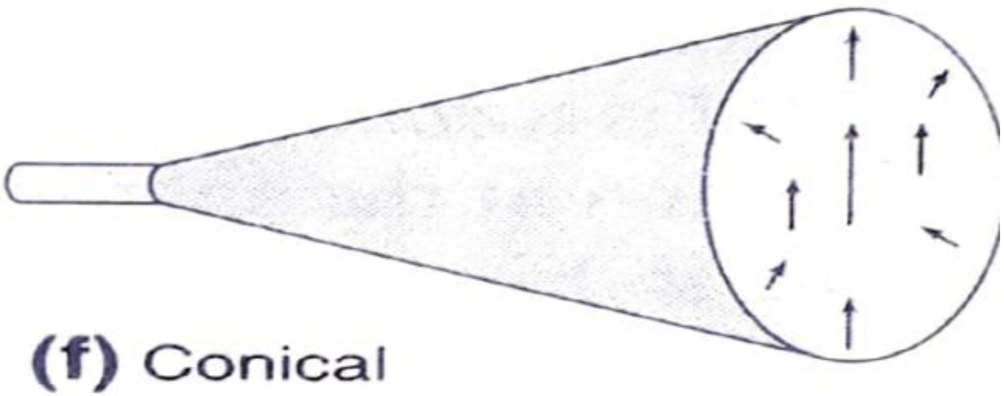

(b) Sectoral *H*-plane

(c) Sectoral *E*-plane

(d) Pyramidal

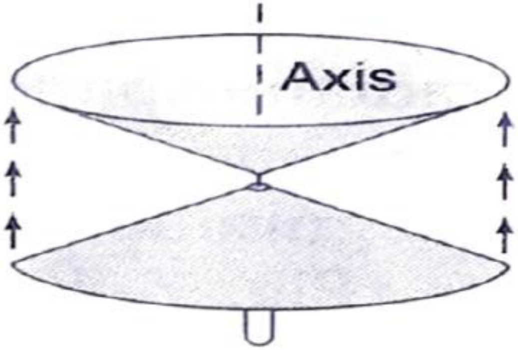
- arrow indicates the direction of E and length gives approximate magnitude of E

# Horn Antenna contd.

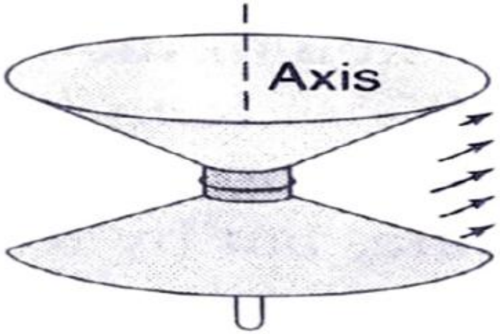



- **The horn is conical type**
- **excited with circular guide in $TE_{11}$ mode**
  - **$TE_{11}$ → electric field and magnetic field are perpendicular to direction of propagation**

# Horn Antenna contd.



(g) TEM biconical

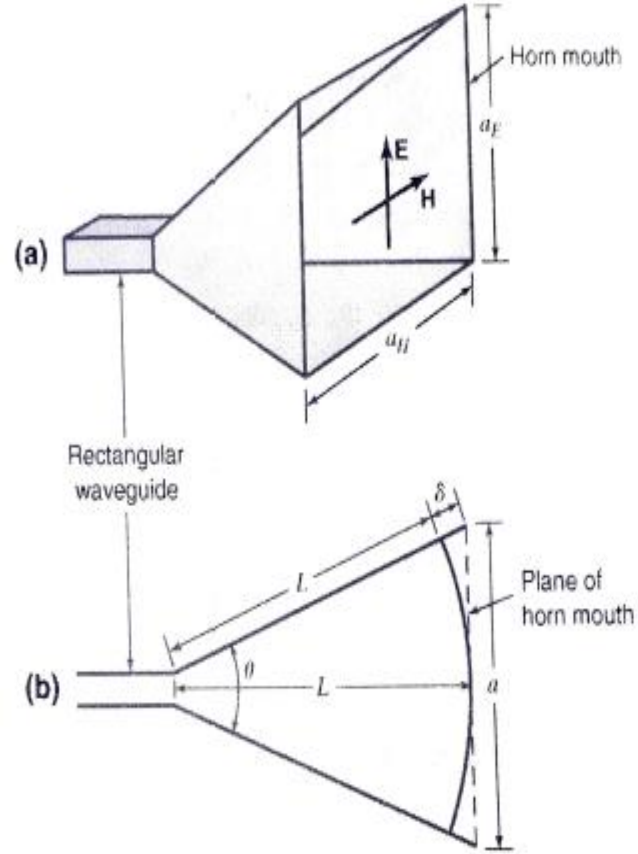


(h) $TE_{01}$ biconical

- **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.

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

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

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

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

$\theta_E \rightarrow for\ E-plane$

$\theta_H \rightarrow for\ H-plane$

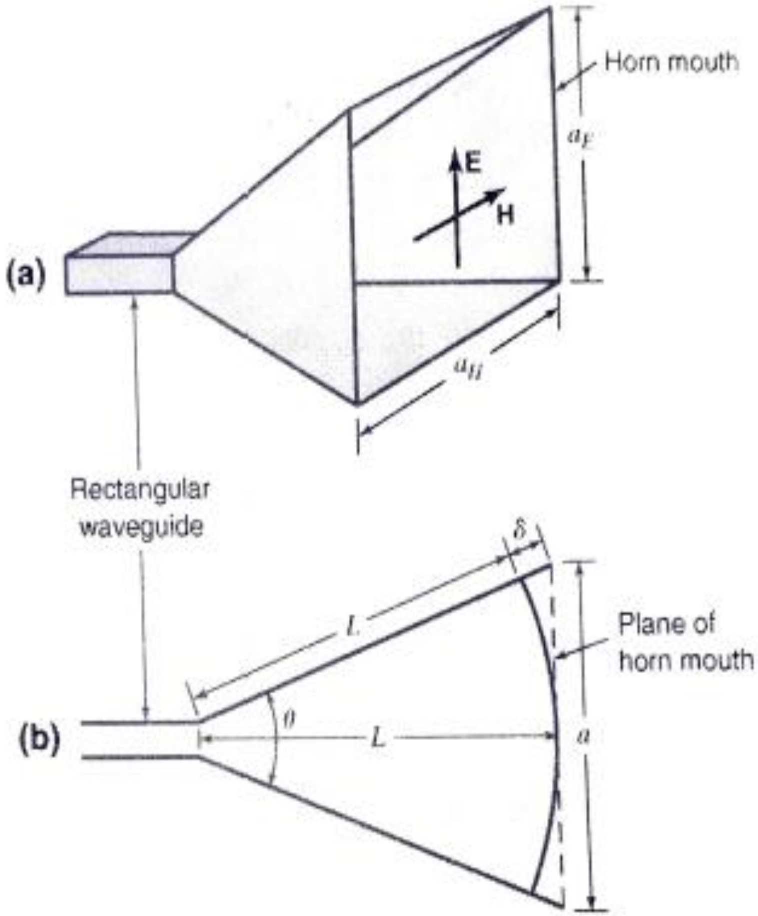
$a \rightarrow aperture\ in\ meters$

$a_E \rightarrow for\ E-plane$

$a_H \rightarrow for\ H-plane$

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

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



# Horn Antenna contd.

**From the geometry we have that**

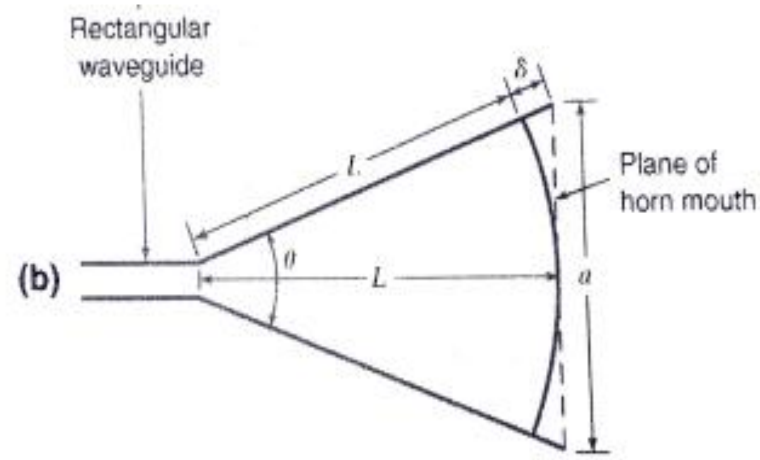
$$(L+\delta)^2 = L^2 + \left(\frac{a}{2}\right)^2$$

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

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

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

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




**In the E-plane of horn, $\delta$ is usually held to 0.25λ or less**

**In the H-plane, $\delta$ is 0.4λ or greater**

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

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

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

# 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

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

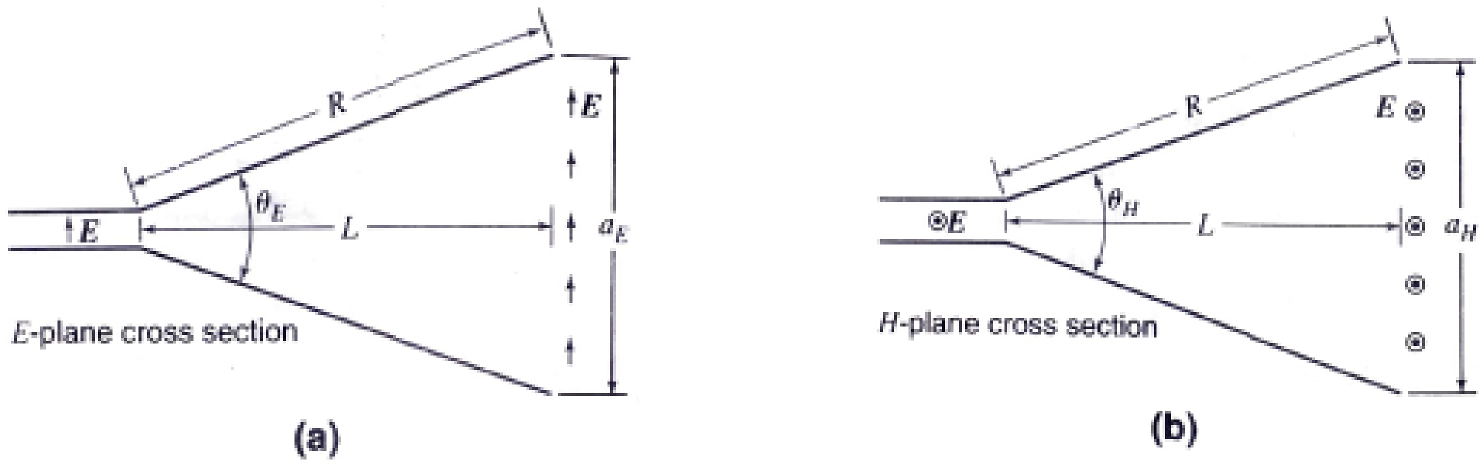
$$L = \frac{\delta_0\,Cos\,\frac{\theta}{2}}{1 - Cos\,\frac{\theta}{2}} \rightarrow optimum\,Length$$

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

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

# 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**

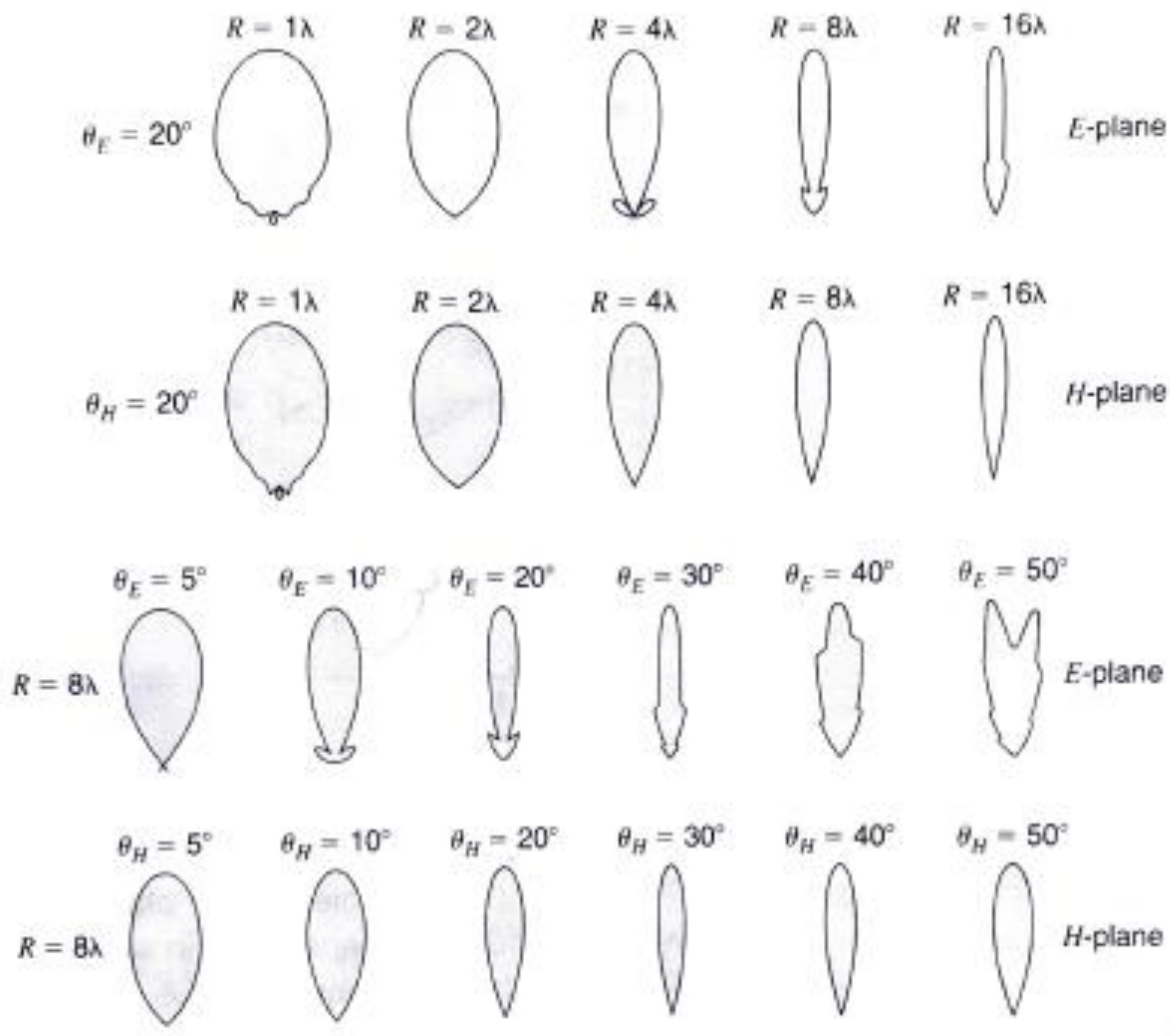



- **The measured E and H plane field patterns of rectangular horn as a function of flare angle and horn length for $a_E > 1\lambda$ and $a_H > 1\lambda$ is**

# 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.**

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

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

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

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

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

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

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

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

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

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

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

# 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.**

$$A = a^2$$

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

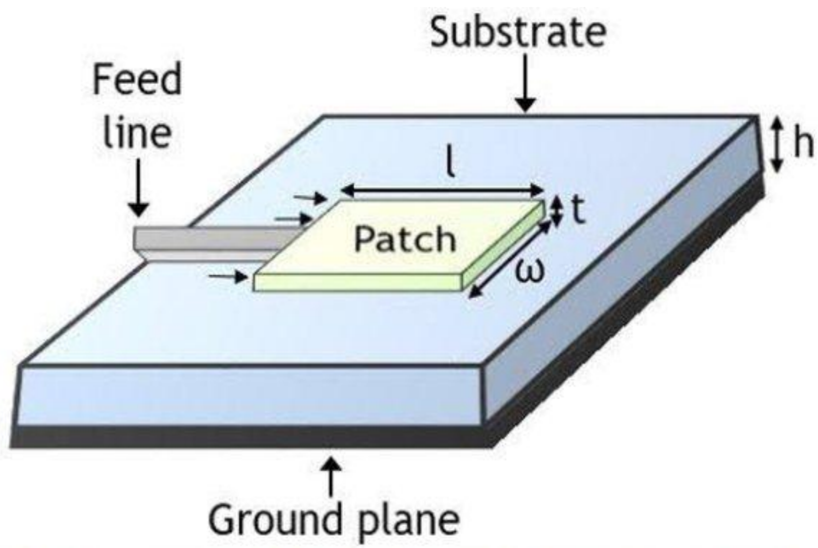
$$Gain = 4.5\frac{A}{\lambda^2}$$

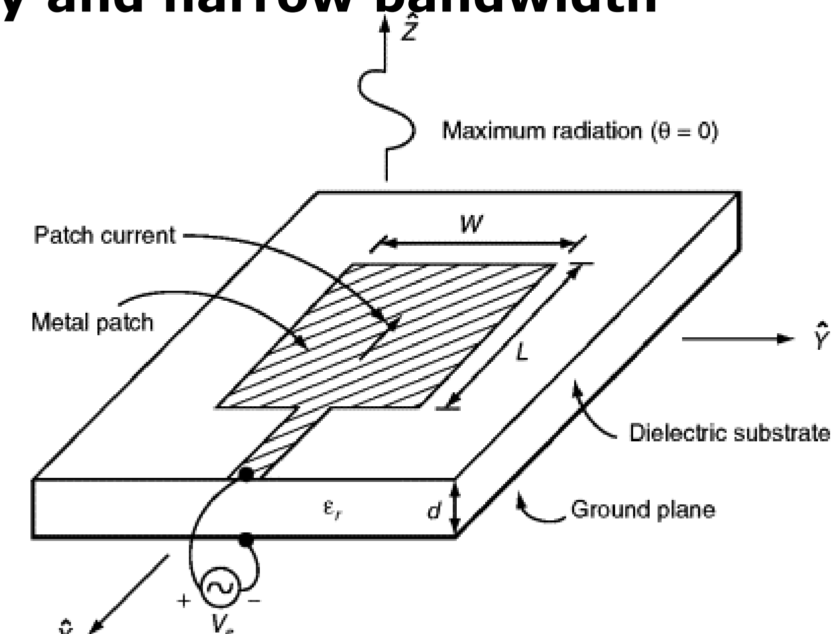
$$Gain = 4.5\frac{A}{\lambda^2} = 450$$

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

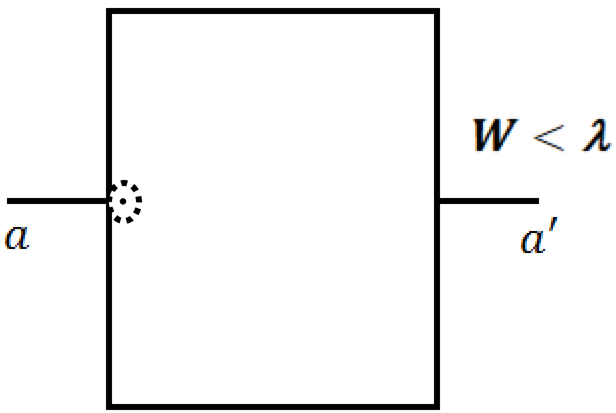
# Patch or Microstrip Antenna

- **Popular for low profile and frequencies above 100 MHz ($\lambda_0$ < 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**

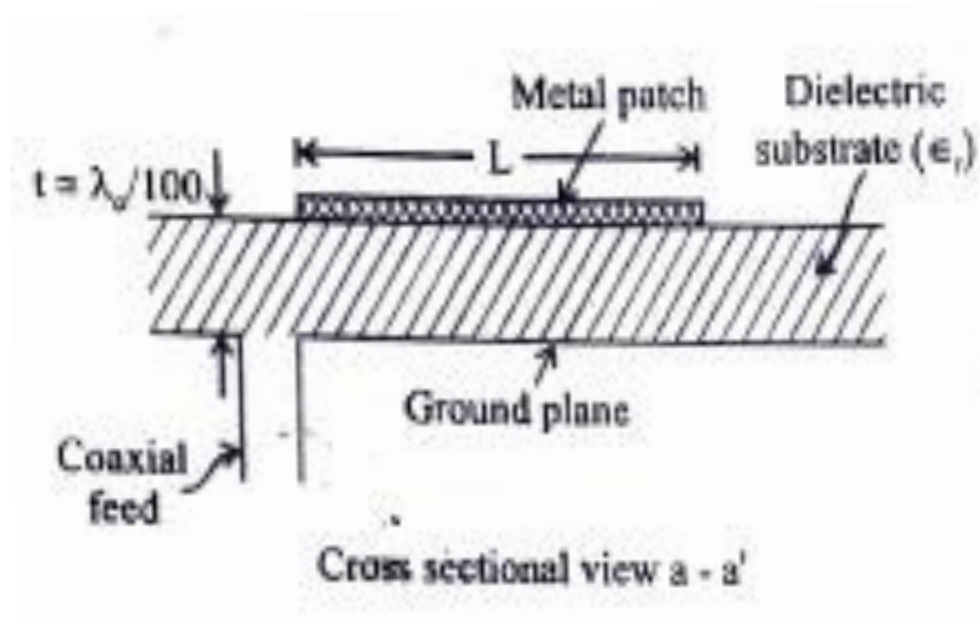


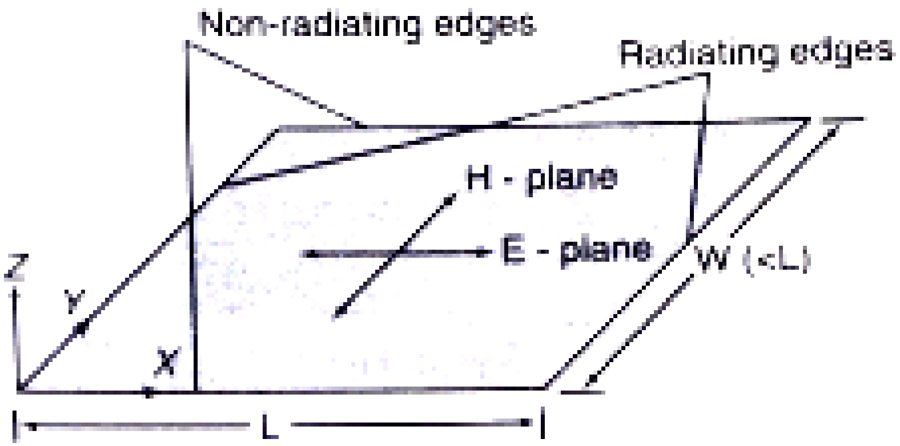
## Typical dimensions of patch

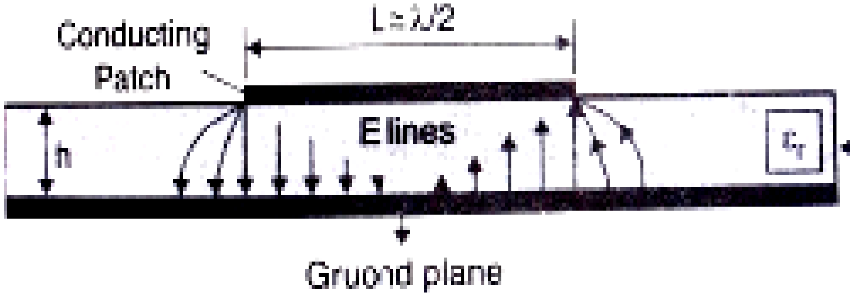



$$L < \frac{\lambda}{2}$$



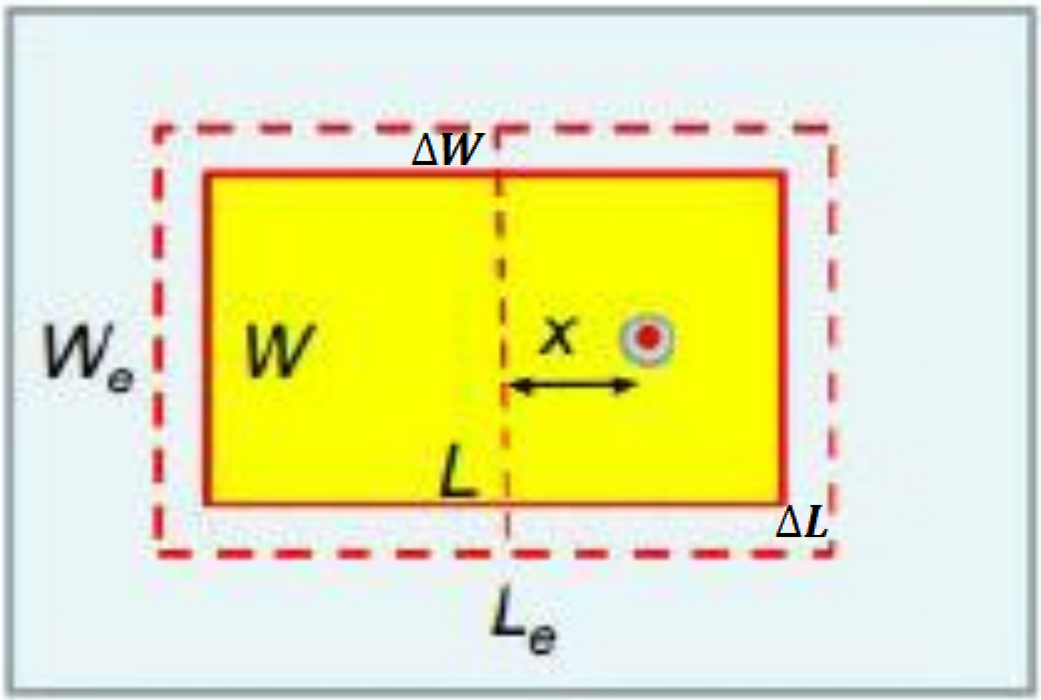
# Patch or Microstrip Antenna contd.




- **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**

## 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

# Problems

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

**Soln.**

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

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

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

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

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

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

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

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

# Problems

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

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

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

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

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

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

# 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.**

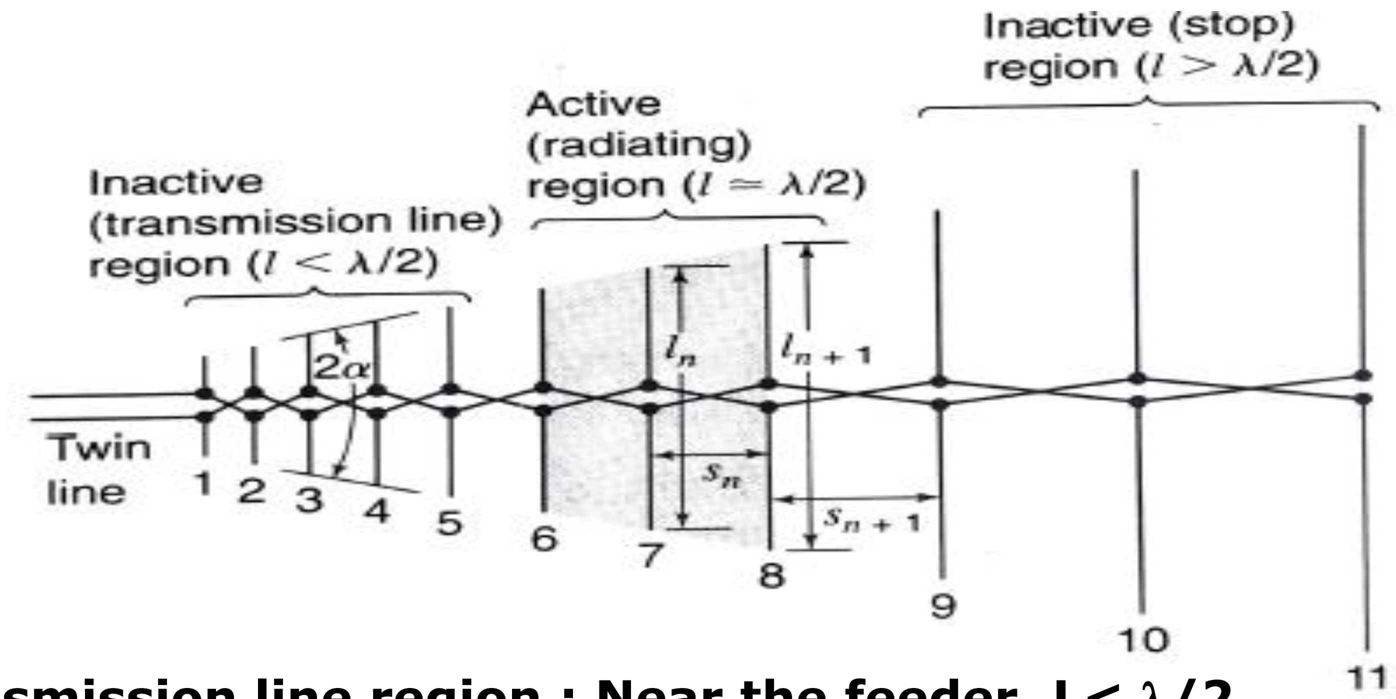
# Log Periodic Dipole Antenna (LPDA)

- **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.



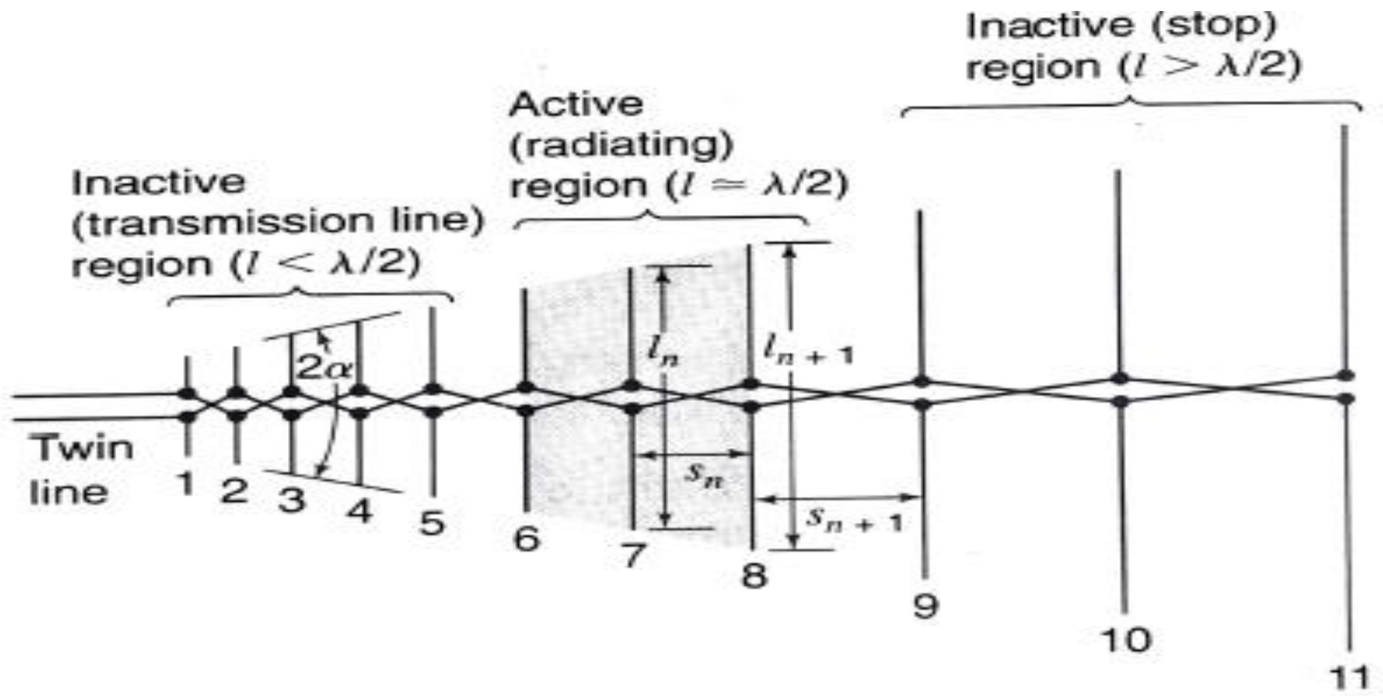

**(1) Transmission line region : Near the feeder, L< $\lambda/2$**

- **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.

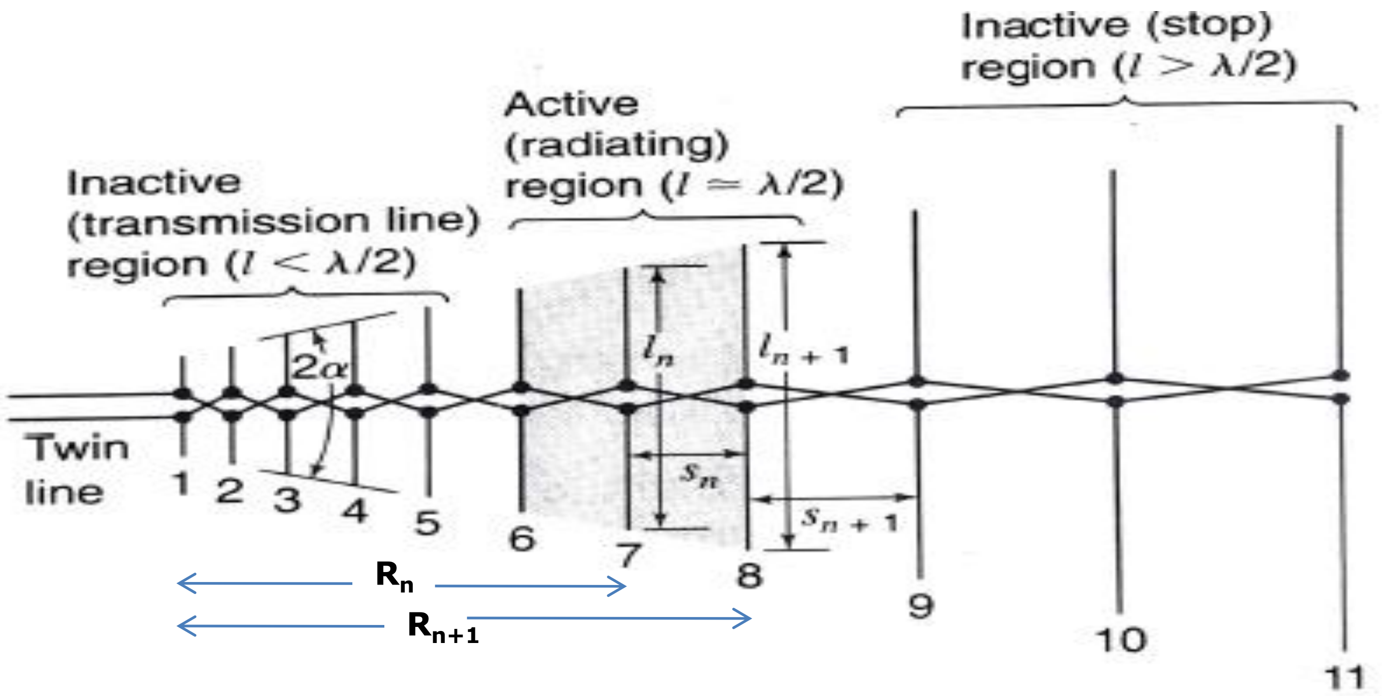



**(3) Reflective region (Inactive region) : L> $\lambda/2$**

- **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.



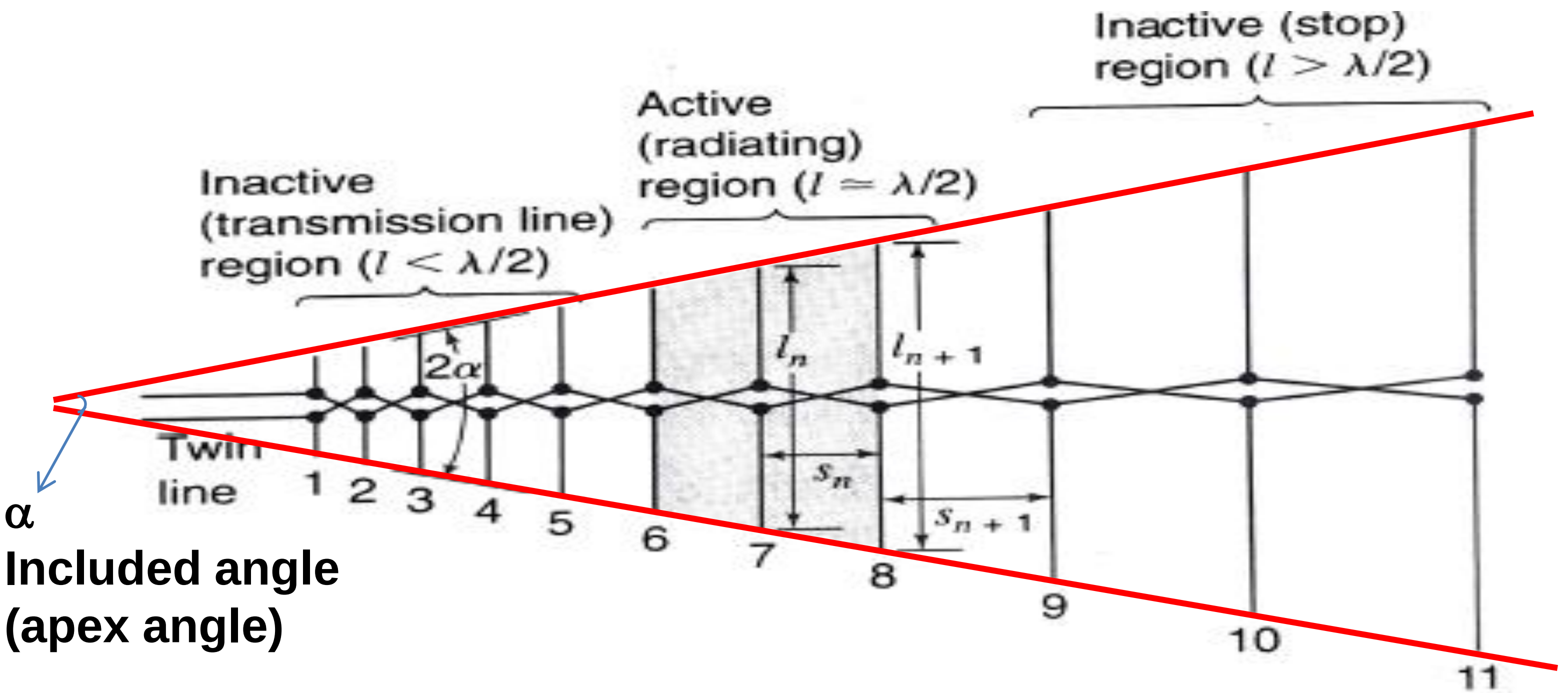

**Relation between Length (L), distance from origin (R) is**

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

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

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

# 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**

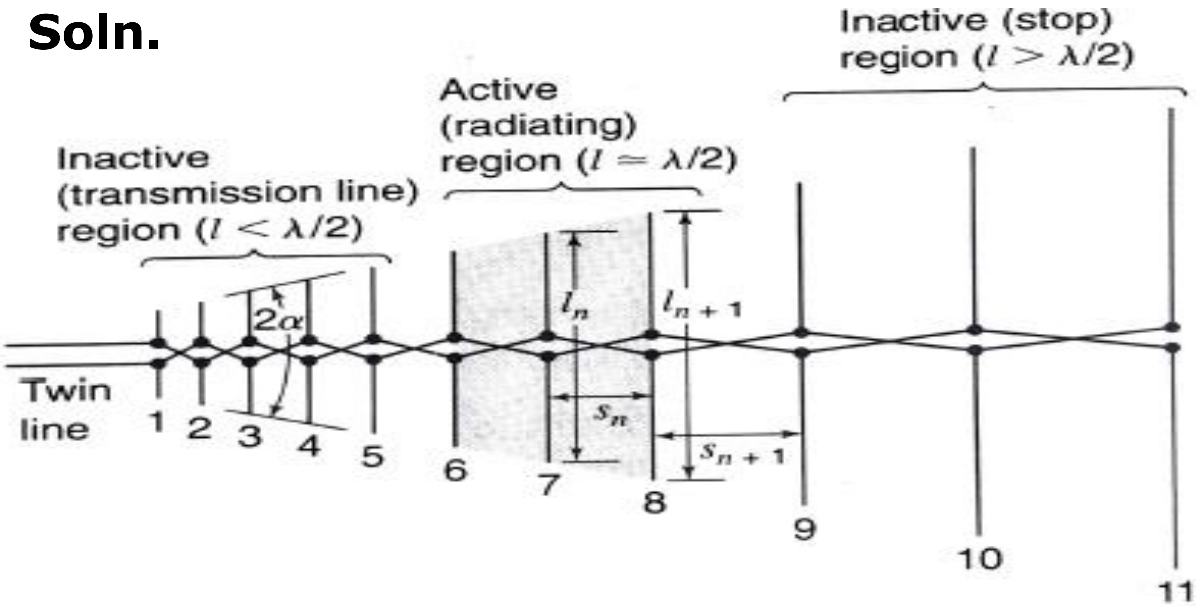
- less gain (compared to Yagi antenna of same size)
- quite expensive
- mounting platform must be strong to hold large elements
- large number of elements for low frequency

# 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.**




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

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

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

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

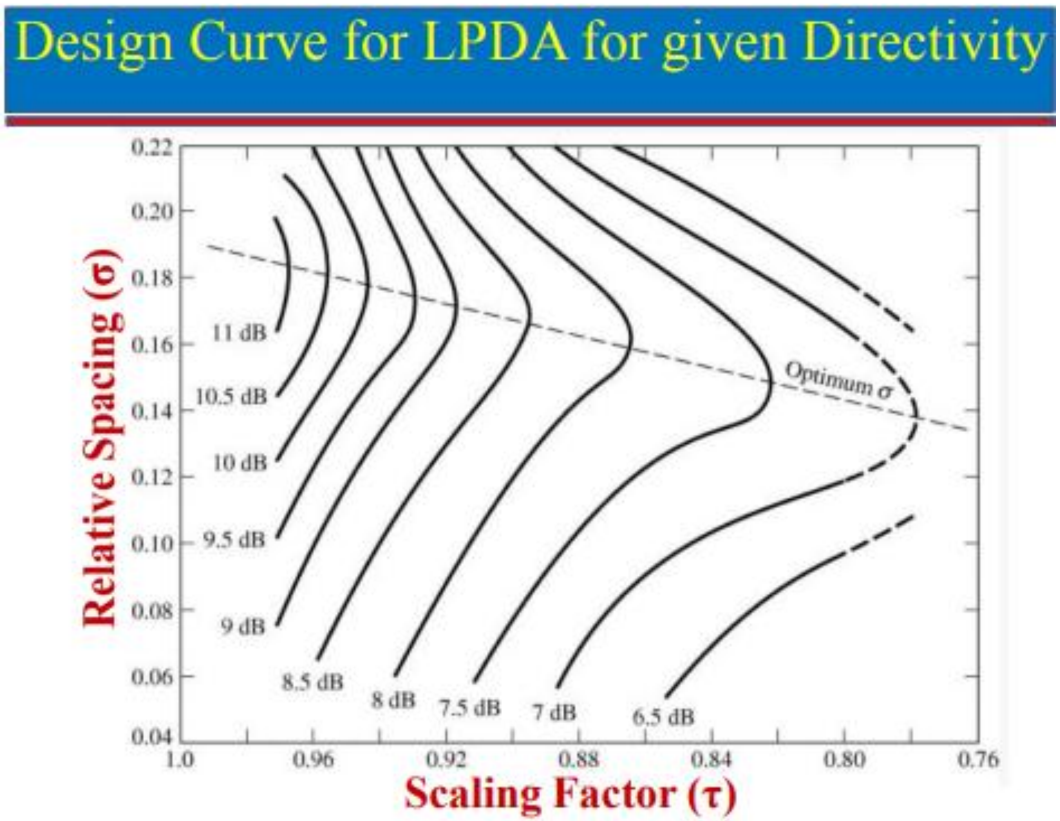
$f_L \rightarrow lowest\ frequency\ of\ operation$

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

**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.**




**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**

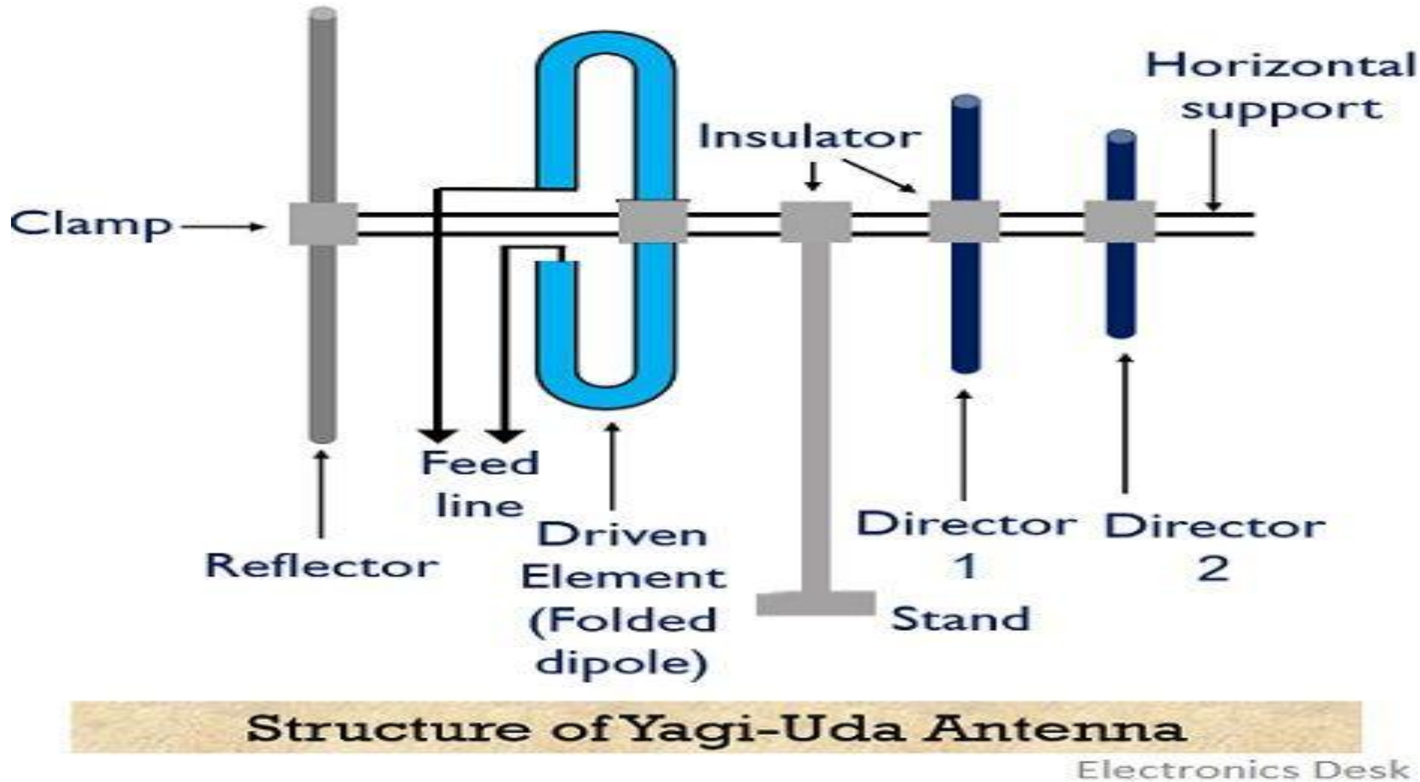
$$L_4 = 1.248\ m \qquad L_7 = 2.245\ m$$

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

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

# 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**

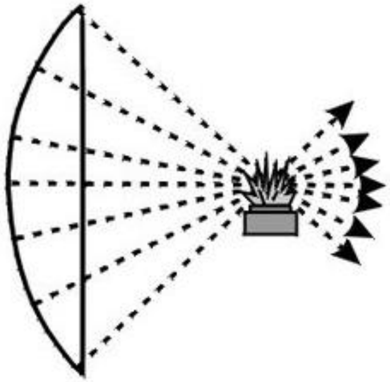


# Reflector type Antennas contd.

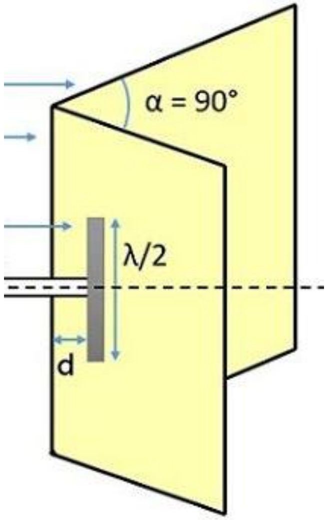
## Types of reflectors

**Flat sheet**

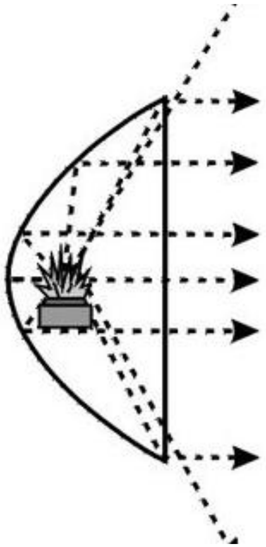
**Spherical**



**Corner**



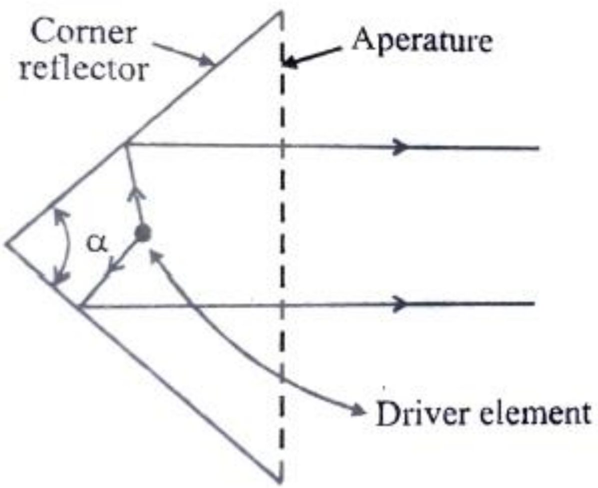

**Parabolic**

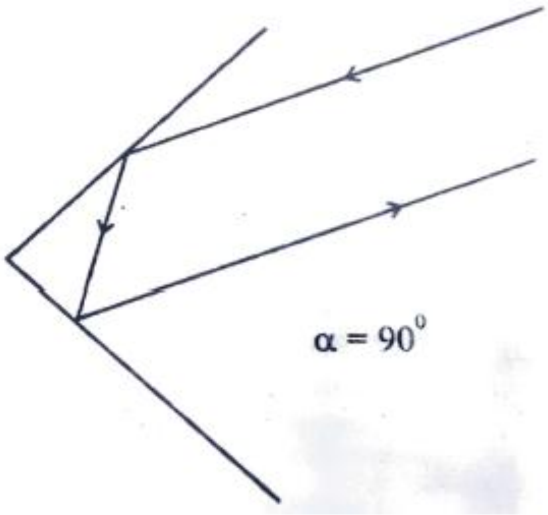


# Reflector type Antennas contd.

## 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

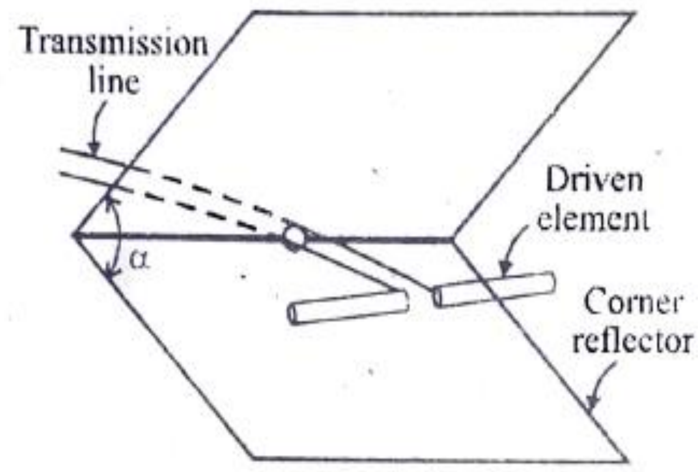


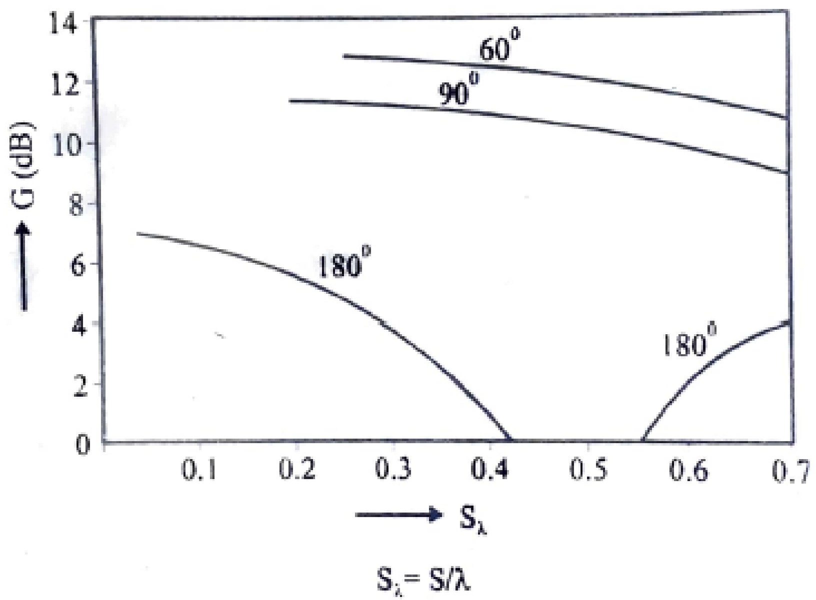
# Reflector type Antennas contd.

## 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°



# Reflector type Antennas contd.

## Field Pattern

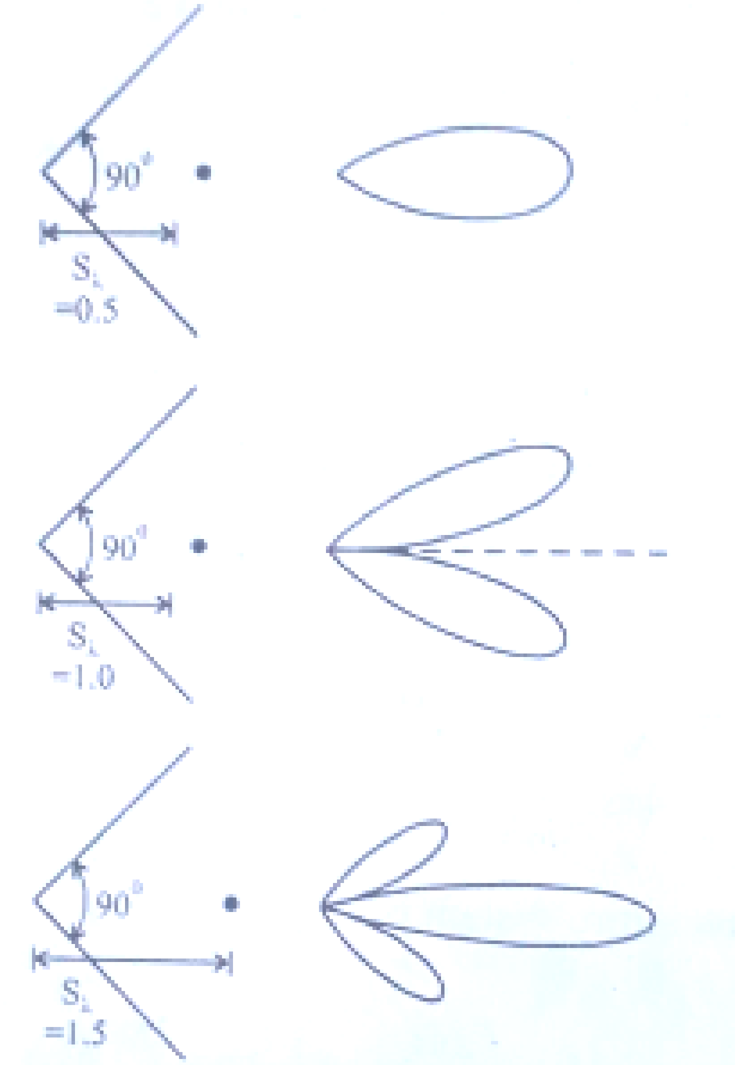
- pattern is function of the spacing 'S' for a fixed value of $\alpha$

- $S\lambda$ = 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

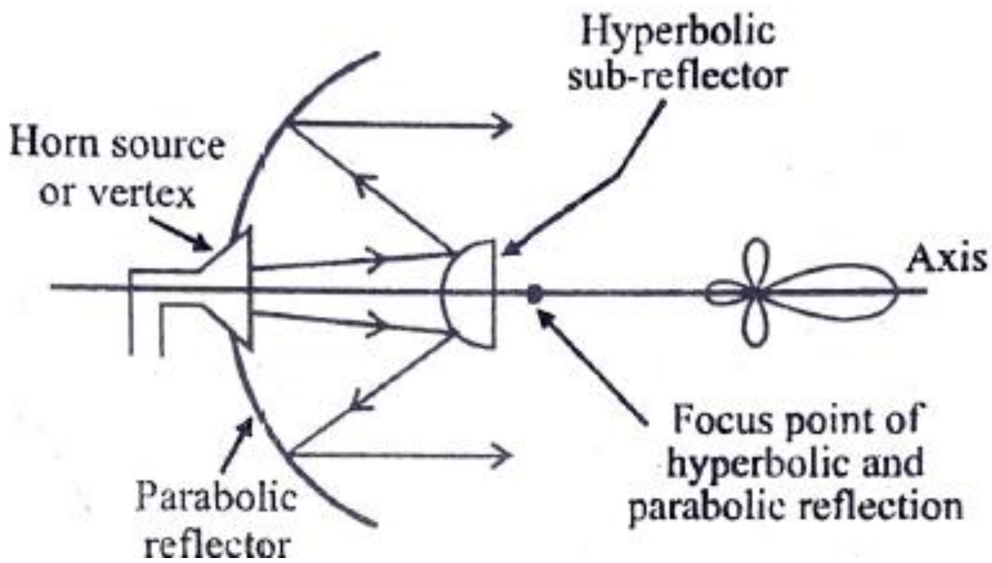
**Parabolic reflectors are based on :**

- **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)**

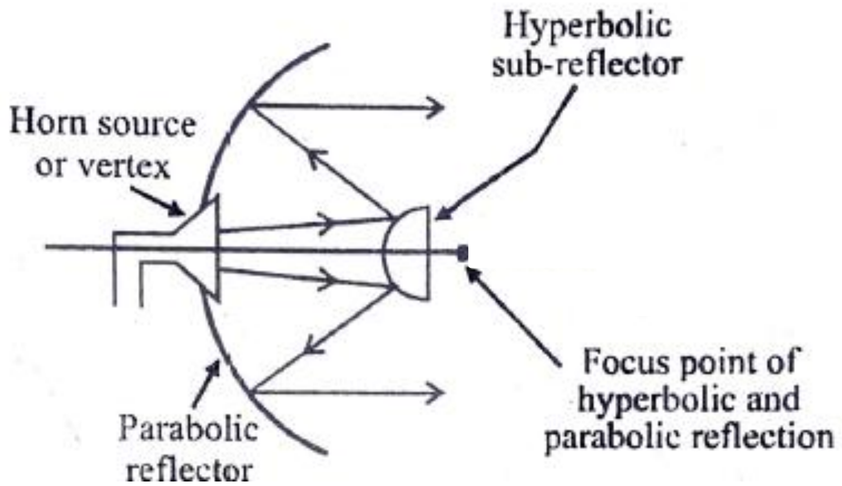
# Reflector type Antennas (Dish Antenna) contd.

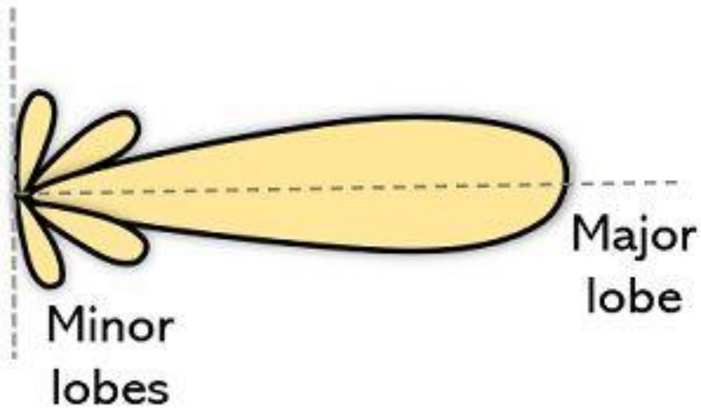
## Parabolic Reflector – geometrical relation




- **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

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

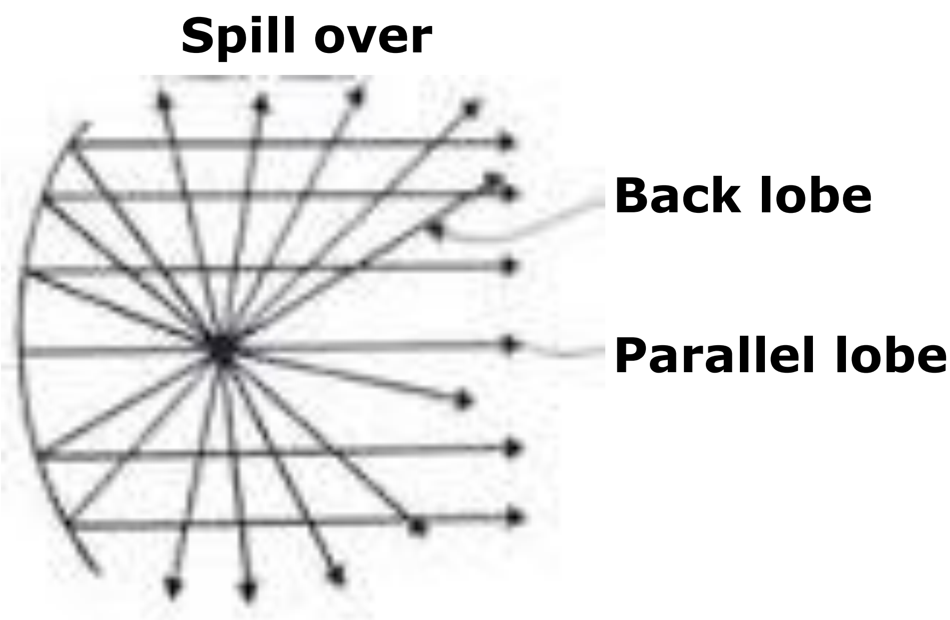
$$D_\lambda = \frac{D}{\lambda} \qquad D \rightarrow diameter\ of\ aperture\ in\ meters$$

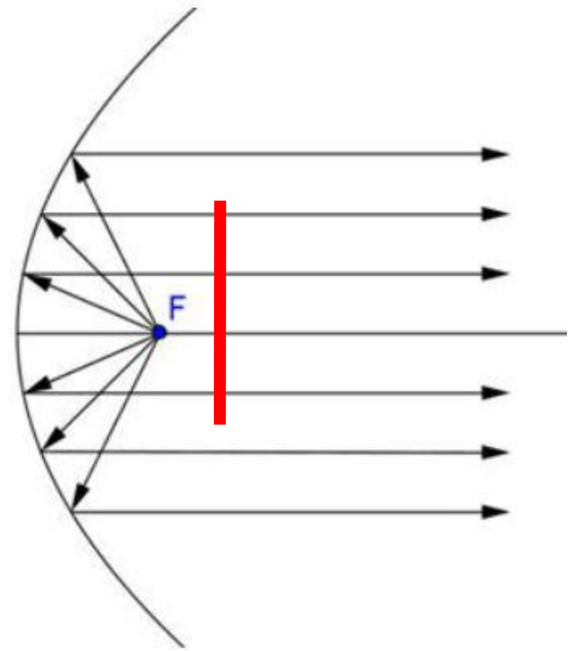
$$L_\lambda = \frac{L}{\lambda} \qquad L \rightarrow Length\ of\ aperture$$

# Reflector type Antennas (Dish Antenna) contd.

## Feeding techniques for parabolic antenna

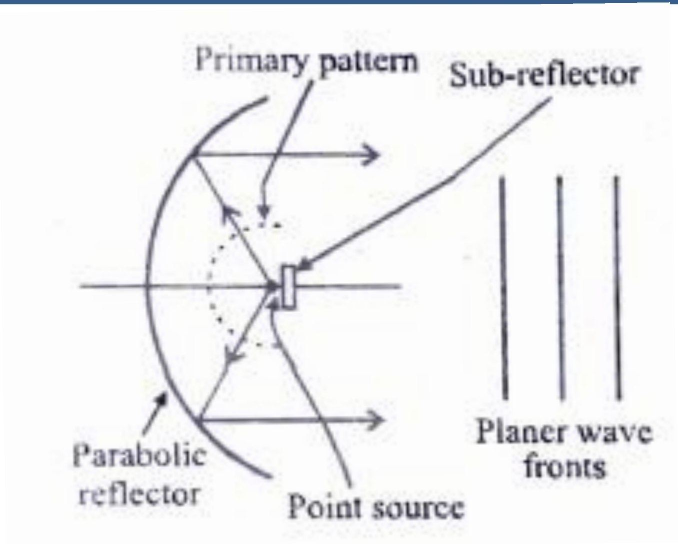
▪ feed system should direct all of its energy substantially against the reflecting surface



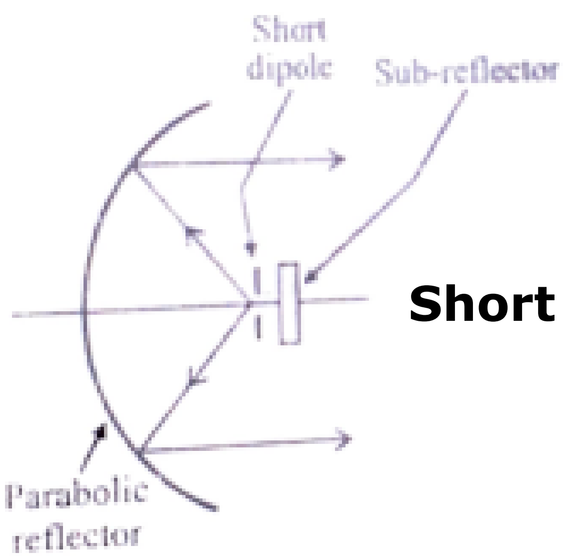




▪ Loss of power (gain) can be prevented by properly shaping the aperture and using sub reflector

# Reflector type Antennas (Dish Antenna) contd.

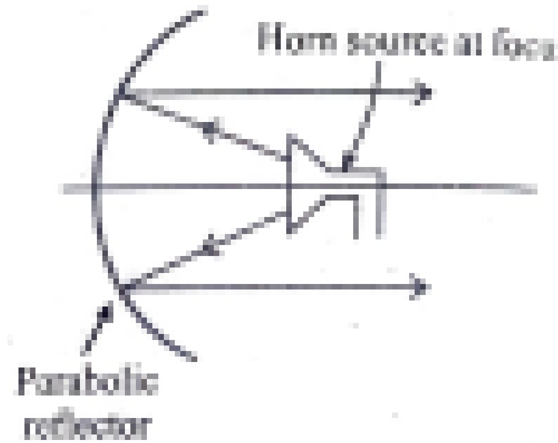


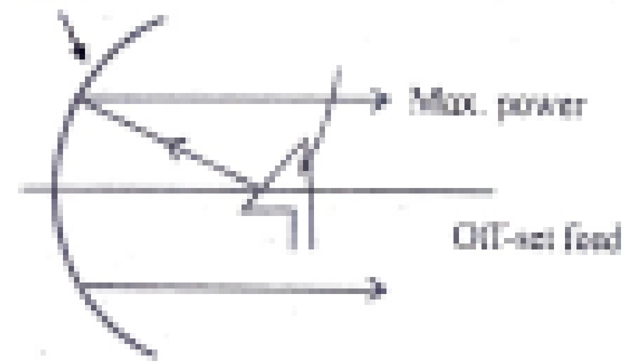

**Point source feed**




**Short dipole feed**

**Horn feed**

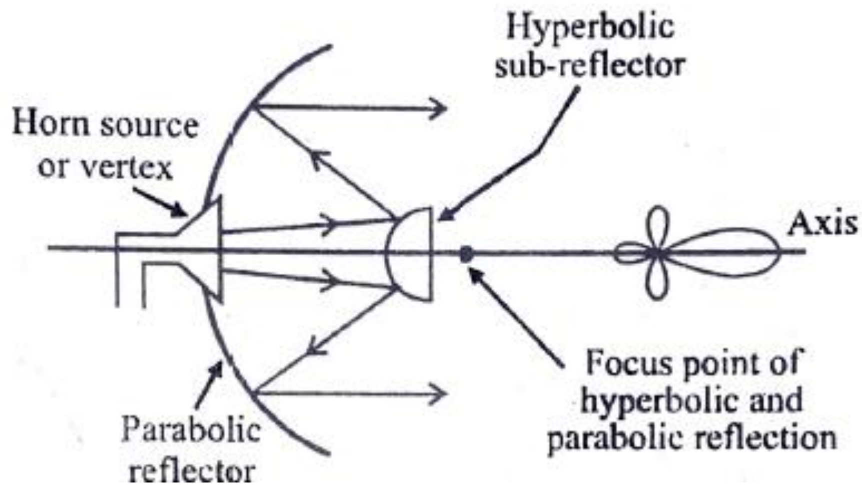


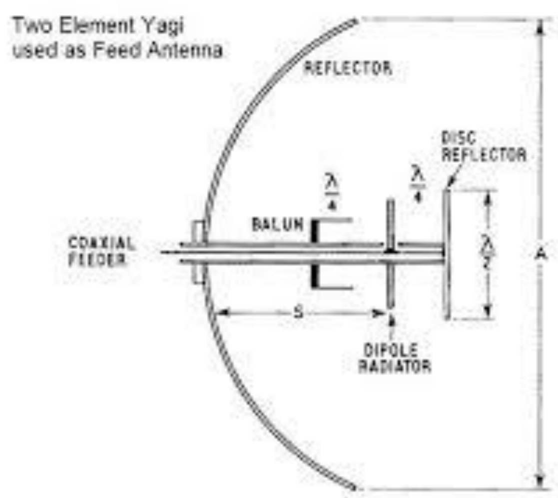

**Horn feed (offset reflector)**

# Reflector type Antennas (Dish Antenna) contd.

**Cassegrain feed**

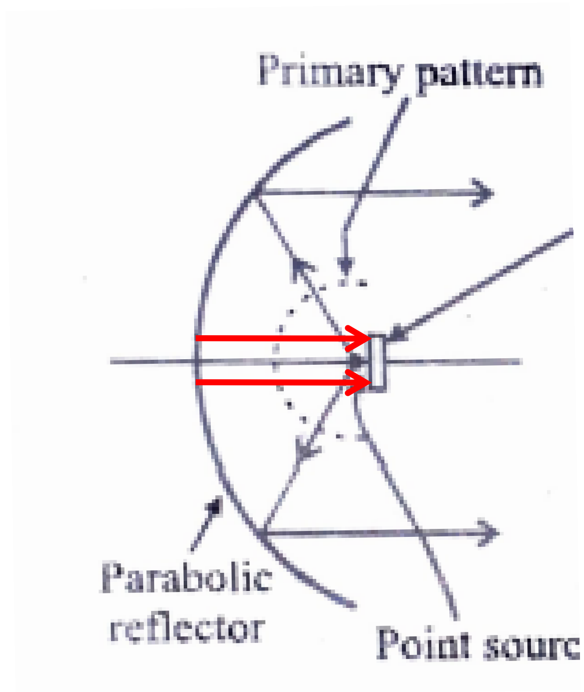



**Yagi antenna feed**



# 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.**

$$\lambda = \frac{C}{f} = \frac{3\times10^8}{1.43\times10^9} = 0.21m$$

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

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

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

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

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

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

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

$$Directivity = 9.87{D_\lambda}^2 = 9.87\times304.76^2 = 916712$$

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

$$\text{Power gain}, G = 6{D_\lambda}^2 = 6\times304.76^2 = 557271$$

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

# Problems

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

**Soln.**

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

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

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

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

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

# 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.**

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

$$\lambda = \frac{C}{f} = \frac{3\times10^8}{2\times10^9} = 0.15\,m \qquad Since\ area = 9m^2, L = W = 3m$$

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

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

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

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

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

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

$$Directivity = 12.6\,L_\lambda{}^2 = 12.6\times20^2 = 5040 \qquad Directivity, D_0 = \frac{4\pi}{\lambda^2}(L\times W)$$

$$\text{Power gain}, G = 7.7L_\lambda{}^2 = 7.7\times20^2 = 3080 \qquad \text{Power gain}, G = 7.7L_\lambda{}^2$$

# 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)**

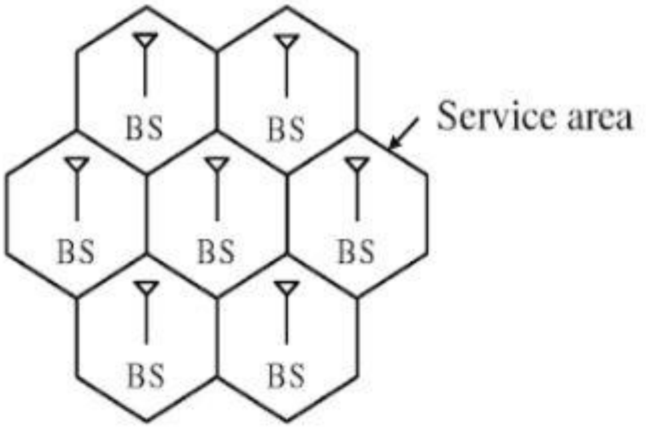
# Antennas for terrestrial mobile communication

- 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

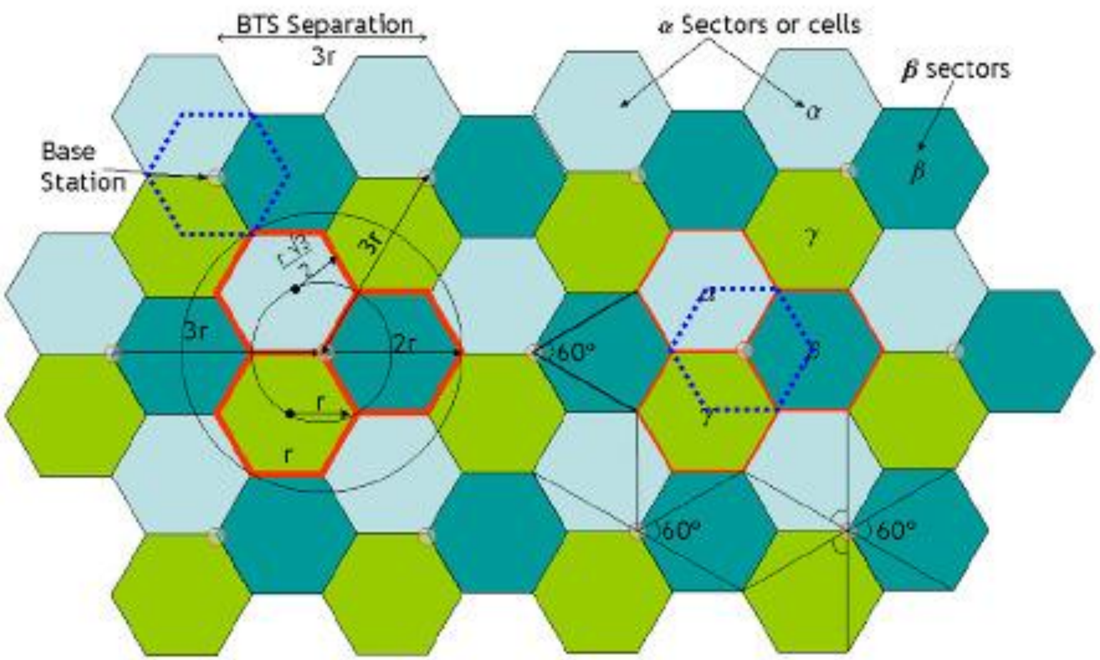
- base station antennas are used to direct the power to the area to be covered
- each cell has radius of about 1 to 15 kms
- each cell has a base station antenna



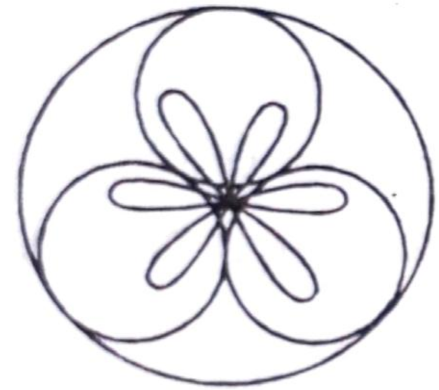

- In cellular system the power distribution is restricted to minimize the frequency reuse distance
- base station antenna should cover a large area irrespective directivity in horizontal plane
- vertical plane beam width is reduced to increase the directivity (to achieve 5 to 17dB)

# 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 (20$\lambda$ to 40$\lambda$)
    - polarization diversity between horizontal and vertical polarization is preferred for tilted mobiles under use

# Antennas for terrestrial mobile communication con.

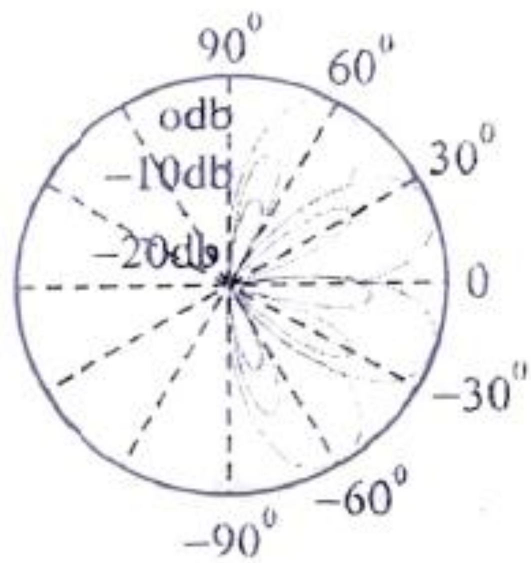
## Adaptive base station antennas

- 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

## Adaptive options

### (i) Switched beam antennas

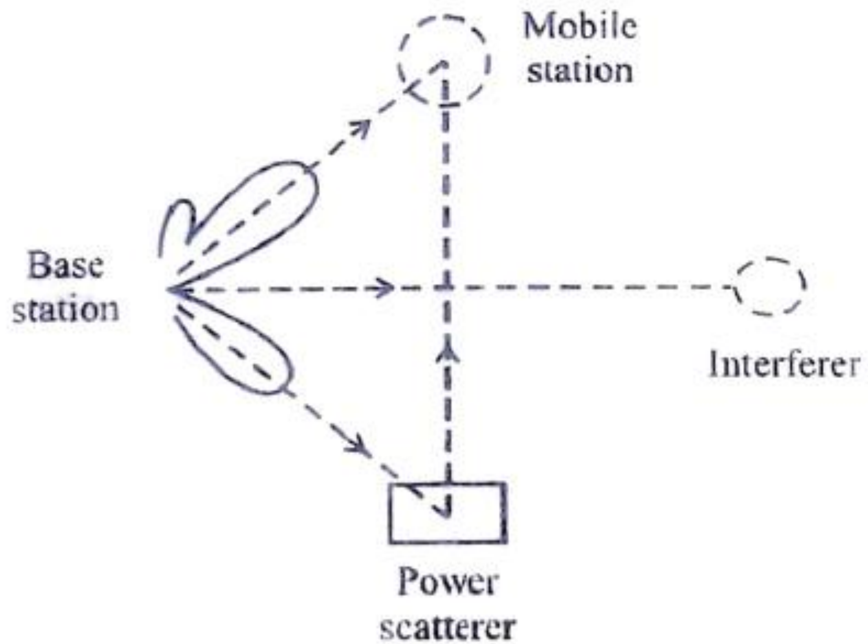
- **base station antenna has several selectable beams of which each covers a part of the cell area**
- **constructed based on butler matrix, which provides one beam per antenna element**
- **operation is very simple but limited adaptability**



# 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**

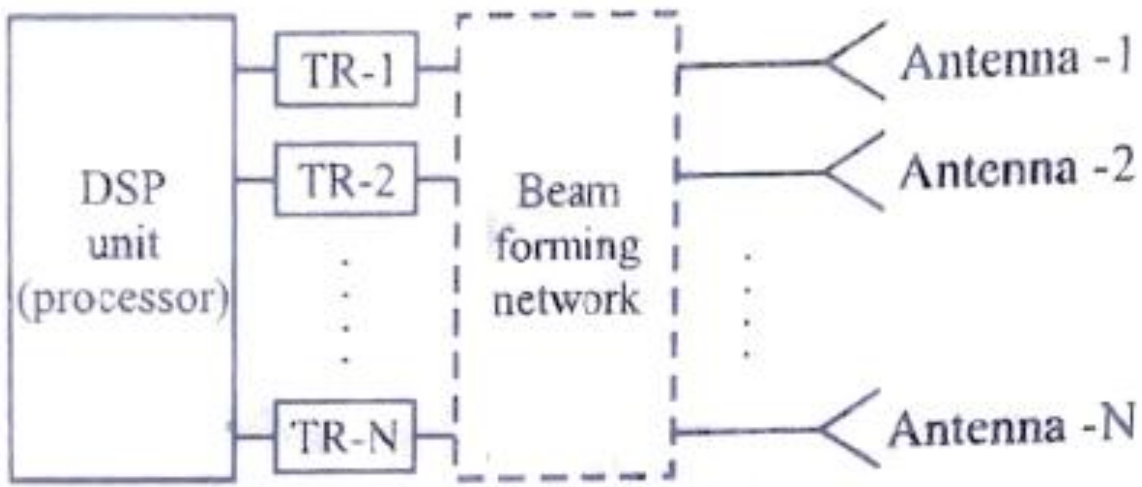



- **since number of antenna elements are limited, only few maxima and nulls can be realized simultaneously**

# 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

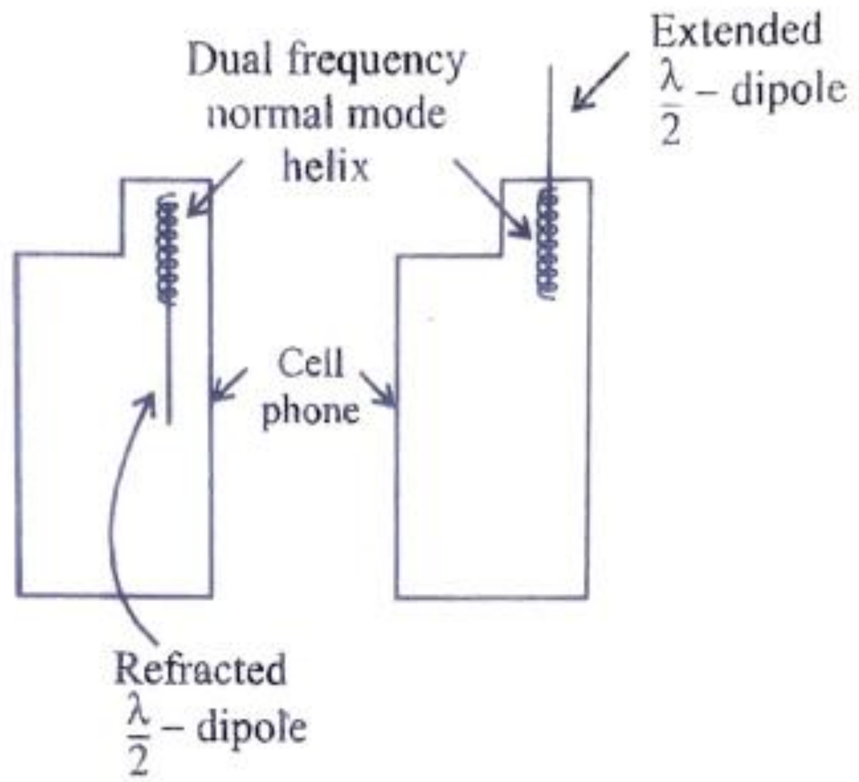
- retractable whip antenna of length

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

# Antennas for terrestrial mobile communication con.

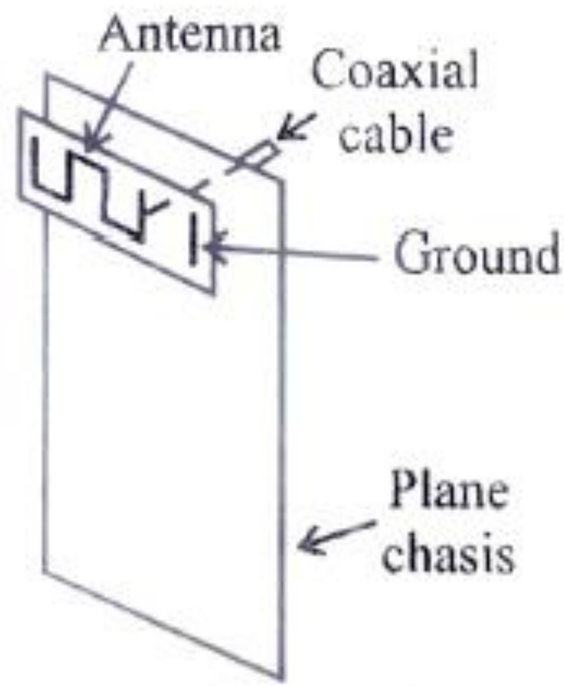
## (ii) Normal mode helical antenna

- **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

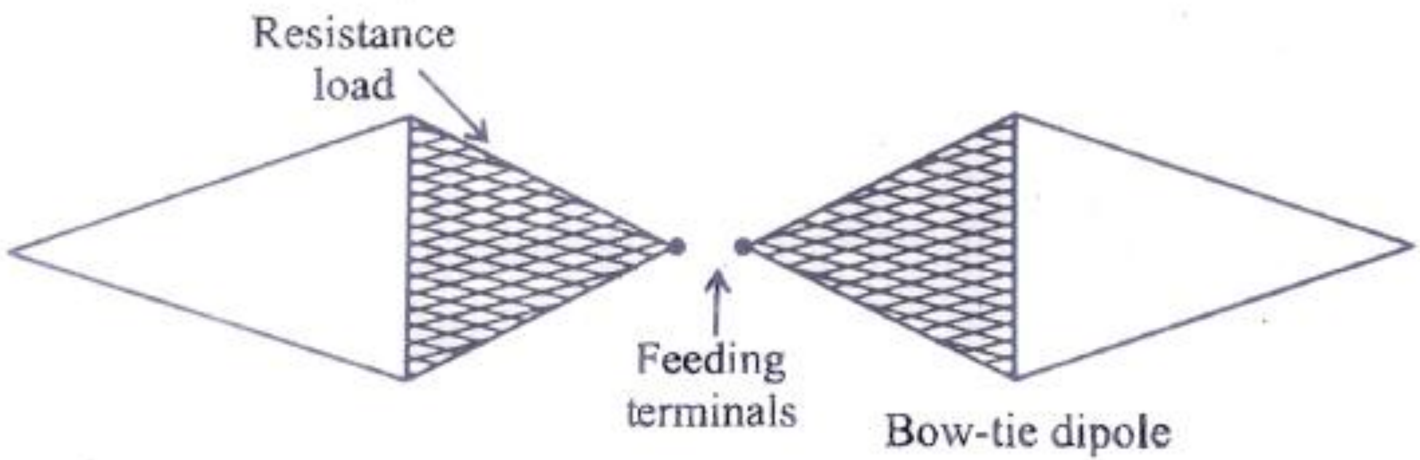
- in mobile station is difficult due to limited space

# 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

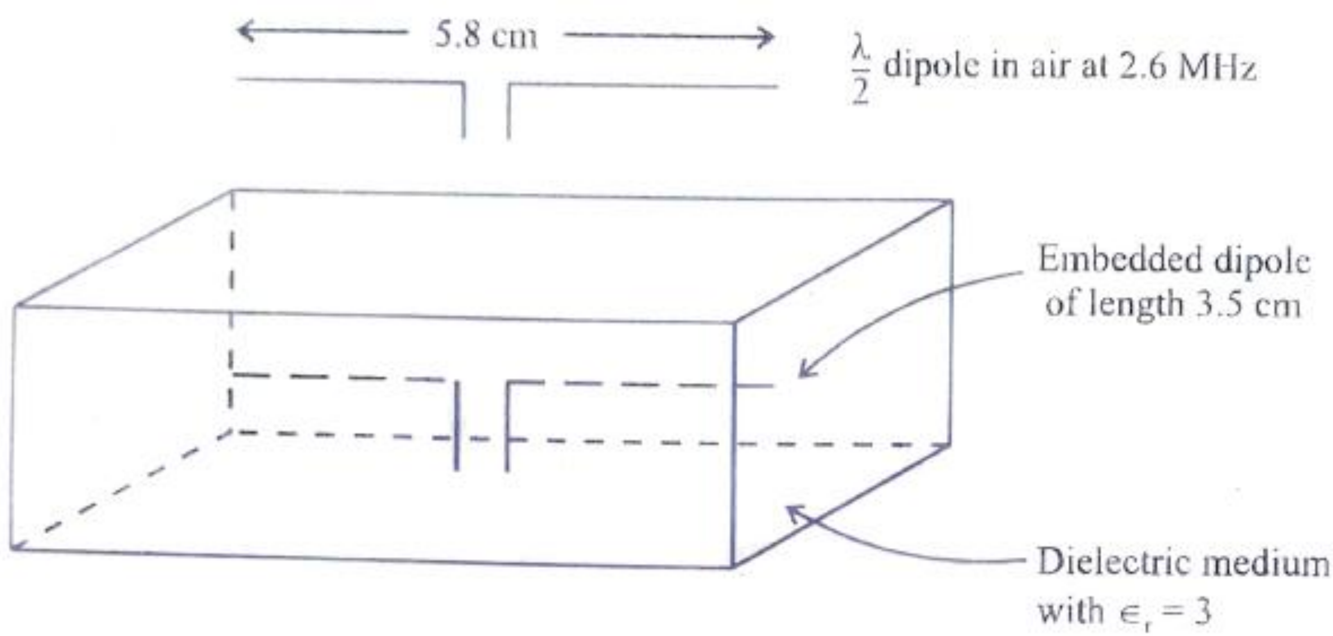
- modern trend in manufacturing electronic systems is to integrate everything on a common substrate
- embedded antenna is one such (embedded in dielectric medium)
  - suitable for mobile handsets
- embedded antenna is constructed embedding a $\lambda/2$ dipole on a dielectric substrate
- dimensions should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

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

- with $\epsilon_r$ 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**

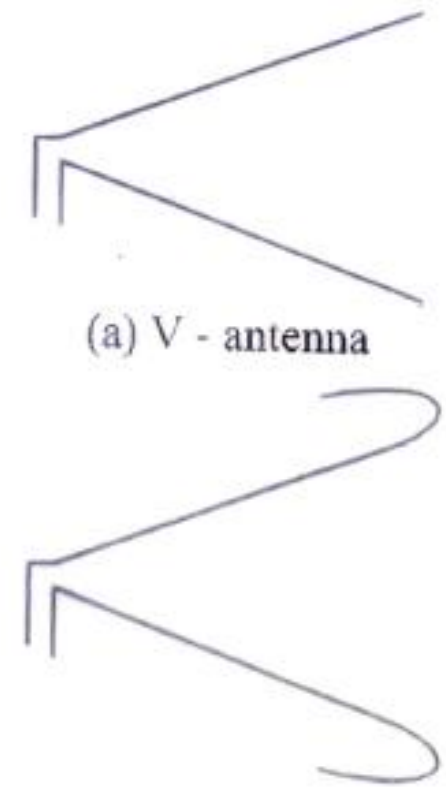


# Ultra wideband antennas for digital application

- 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**