ANTENNA AND WAVE PROPAGATION
MODULE 4

Basic principle of beam steering

Beam steering is about changing the direction of the main lobe of a radiation pattern. In radio and radar systems, beam steering may be accomplished by switching the antenna elements or by changing the relative phases of the RF signals driving the elements.

Long-wire Antennas

Long wire antennas are formed by using a number of dipoles. The length of the wire in these type of antennas is n times $\lambda/2$

$L = n\ \lambda/2 L = n\ \lambda/2$

Where,

- L is the length of the antenna,
- n is the number of elements,
- λ is the wavelength

As 'n' increases, the directional properties also increase.

Long wire antennas are divided into two types namely − **Resonant Antennas** and **Non-resonant Antennas**.

Resonant Antennas

The resonant antennas are periodic in nature. They are also called as bi-**directional travelling wave antennas**, as the radiated wave moves in two directions, which means both incident and reflected waves occur here. In these antennas, the length of the antenna and frequency are proportional to each other. Resonant Antennas are those for which a sharp peak in the radiated power is intercepted by the antenna at certain frequency, to form a standing wave. The radiation pattern of the radiated wave is not matched with the load impedance in this type of antenna.
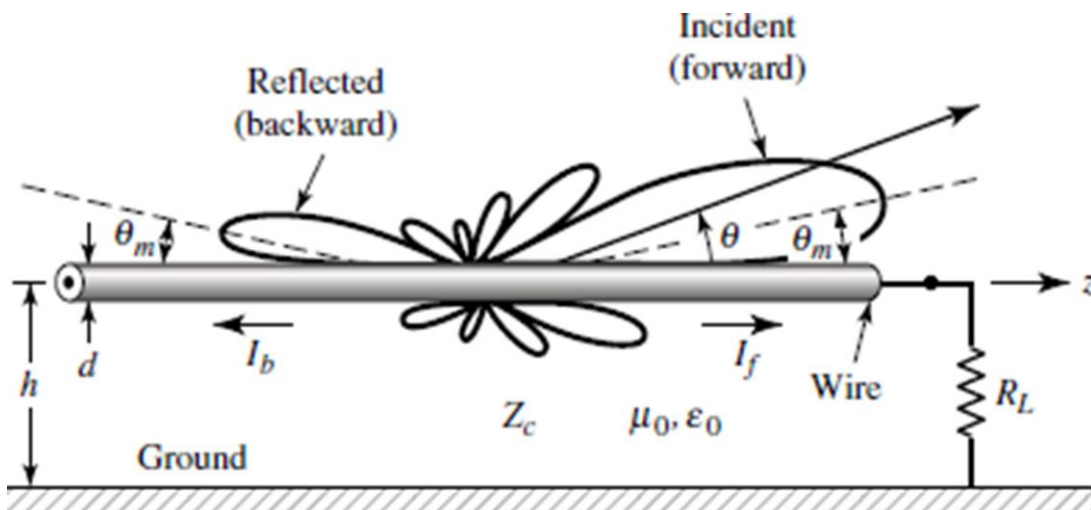
Non-resonant Antennas

Non-resonant Antennas are those for which resonant frequency does not occur. The wave moves in forward direction and hence do not form a standing wave. The radiation pattern of the radiated wave matches with the load impedance in the non-resonant antennas.

These non-resonant antennas are non-periodic in nature. They are also called as Unidirectional travelling wave antennas, as the radiated wave moves in forward direction only, which means that only incident wave is present. As the frequency increases, the length of the antenna decreases and vice versa. Hence, the frequency and length are inversely proportional to each other.

These long-wire antennas are the basic elements for the construction of V-shaped antennas or the Rhombic antennas.

V-Antenna

This antenna is formed by arranging the long wire in a V-shaped pattern. The end wires are called as legs. This antenna is a bi-directional resonant antenna.he frequency range of operation of V-antenna is around **3 to 30 MHz**. This antenna works in high frequency range.

Construction & Working of V-Antennas

Two long wires are connected in the form of a horizontal **V**,fed at the apex as shown in fig
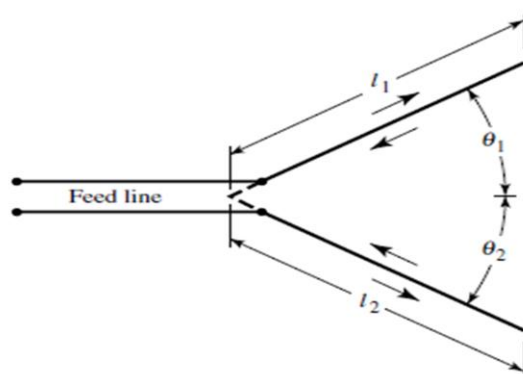
(a) *V* antenna

If the angle between the two sides of the **V** is twice the angle that the cone of maximum radiation of each wire makes with its axis, then the two cones will add up in the direction of the line bisecting the apex angle of **V,** and produce a maximum lobe of radiation.The two long wires are excited with 180˚ out of phase. As the length of these wires increases, the gain and directivity also increases.

The **gain** achieved by V-antenna is higher than normal single long wire antenna. The gain in this V-formation is **nearly twice** compared to the single long wire antenna, which has a length equal to the legs of V-antenna. If wide range of radiation is to be achieved, the apex angle should have an average value between higher and lower frequencies in terms of the number of $\lambda/2$ in each leg.

The radiation pattern of a V-antenna **can be unidirectional or bidirectional** .The radiation obtained on each transmission line is added to obtain the resultant radiation pattern.
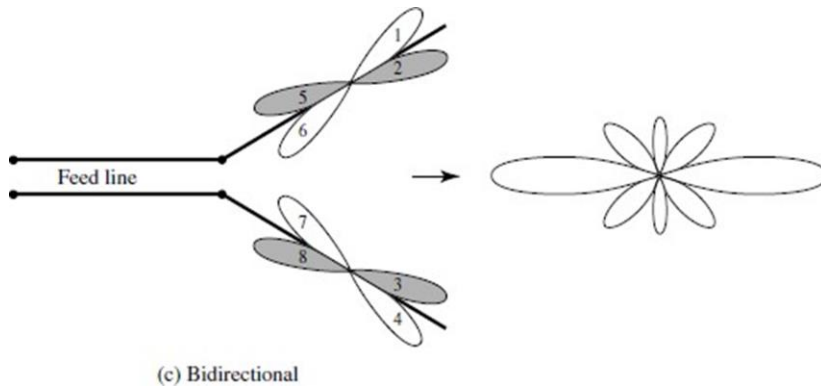
(c) Bidirectional

To achieve the unidirectional characteristics, the   wires of the V antenna must be nonresonant .This   can   be   accomplished by   minimizing   or   liminating reflections from the ends of the wire. One way of terminating the V antenna will be to attach a load, usually a resistor equal in value to the characteristic impedance of the leg.
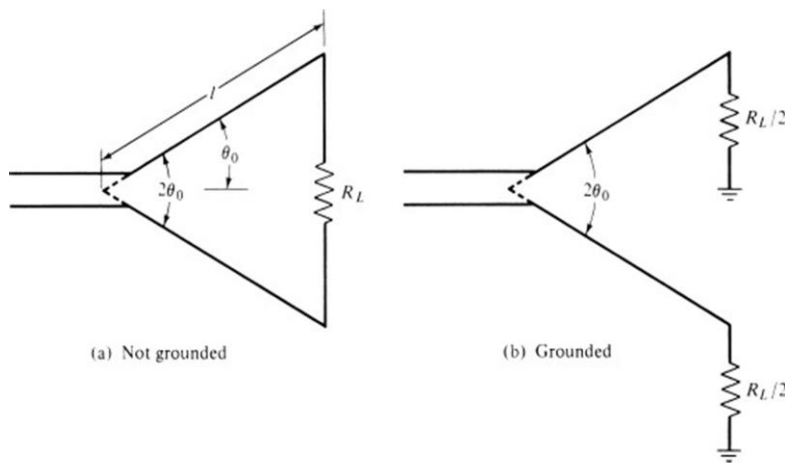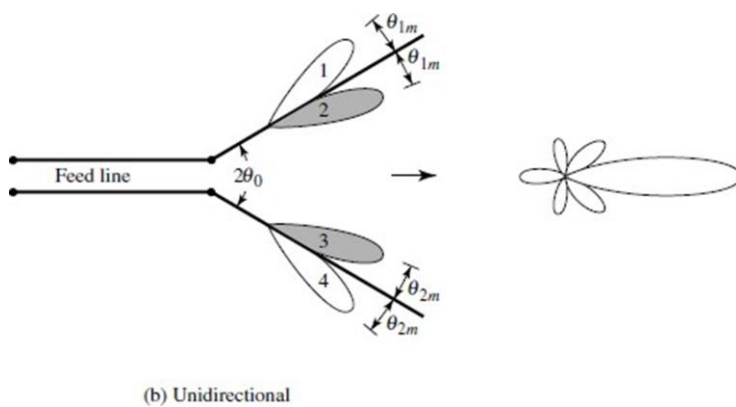

(a) Not grounded

(b) Grounded

Figure 10.9 Terminated V antennas.

(b) Unidirectional

The directivity is further increased by adding the array of V-antennas.

Advantages of V-antenna

- Construction is simple
- High gain
- Low manufacturing cost

Disadvantages of V-antenna

- Standing waves are formed
- The minor lobes occurred are also strong
- Used only for fixed frequency operations

Applications of V-antenna

- Used for commercial purposes
- Used in radio communications

Inverted V antenna

The operating frequency of V antenna is limited. This can be modified by using another antenna, which is a non-resonant antenna or a travelling wave antenna. A travelling wave antenna produces no standing wave.The frequency range of operation of an inverted vee antenna (or V-antenna) is around **3 to 30 MHz**. This antenna works in high frequency range.

Construction & Working of Inverted V-Antenna

The maximum radiation for an inverted V-antenna is at its center. The antenna is placed in the shape of an inverted V, with its two transmission lines or legs bent towards the ground making 120° or 90° angle between them. The center of the antenna should not be higher than $\lambda/4$.The angle made by one of the legs with the axis of the antenna, is known as the **tilt angle** and is denoted by **θ**.
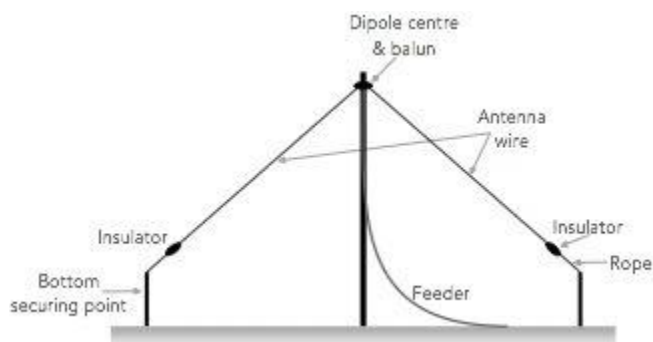
The radiation pattern of inverted V-antenna is **uni-directional pattern**, as no standing waves are formed here.

Advantages of inverted V-antenna

- Occupies less horizontal place

- No standing waves are formed

- High gain

Disadvantages of inverted V-antenna

- It has considerable undesired minor lobes

- Minor lobes create horizontally polarized waves

Applications of inverted V-antenna

- Used in tuned circuit applications

- Used in radio communications

- Used in commercial applications

Rhombic antenna

Rhombic Antenna is a combination of two V-antennas. It is an equilateral parallelogram shaped antenna. Generally, it has two opposite acute angles. The tilt angle, θ is approximately equal to 90° minus the angle of major lobe. Rhombic antenna works under the principle of travelling wave radiator. It is arranged in the form of a rhombus or diamond shape and suspended horizontally above the surface of the earth.The frequency range of operation of a Rhombic antenna is around **3MHz to 300MHz**. This antenna works in **HF** and **VHF** ranges.

Construction of Rhombic Antenna

Rhombic antenna can be regarded as two V-shaped antennas connected end-to-end to form obtuse angles. Due to its simplicity and ease of construction, it has many uses −

- In HF transmission and reception

- Commercial point-to-point communication

The construction of the rhombic antenna is in the form a rhombus, as shown in the figure.
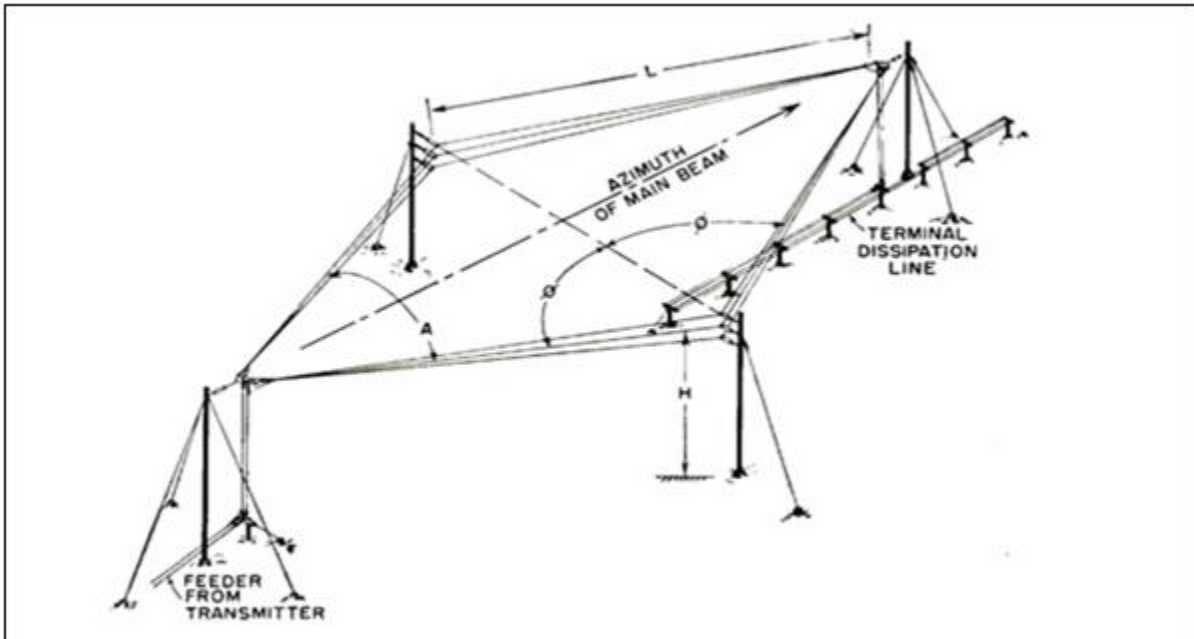
The two sides of rhombus are considered as the conductors of a two-wire transmission line. When this system is properly designed, there is a concentration of radiation along the main axis of radiation. In practice, half of the power is dissipated in the terminating resistance of the antenna. The rest of the power is radiated. The wasted power contributes to the minor lobes.

The maximum gain from a rhombic antenna is along the direction of the main axis, which passes through the feed point to terminate in free space. The polarization obtained from a horizontal rhombic antenna is in the plane of rhombus, which is horizontal.

The radiation pattern of the rhombic antenna is shown in the following figure. The resultant pattern is the cumulative effect of the radiation at all four legs of the antenna. This pattern is **uni-directional**, while it can be made bi-directional by removing the terminating resistance.

By properly selecting the tilt angle, the mbic antenna will give additive effect of radiation pattern of each long wire antenna

The radiation mechanism basically depends on two factors:

- Tilt angle (φ)
- Height above the ground
- Due to ground effect, the maximum radiation is elevated about an angel (β)

A. INDIVIDUAL RADIATION PATTERNS

B. RESULTANT RADIATION PATTERNS

Vertical patter
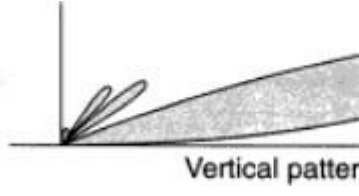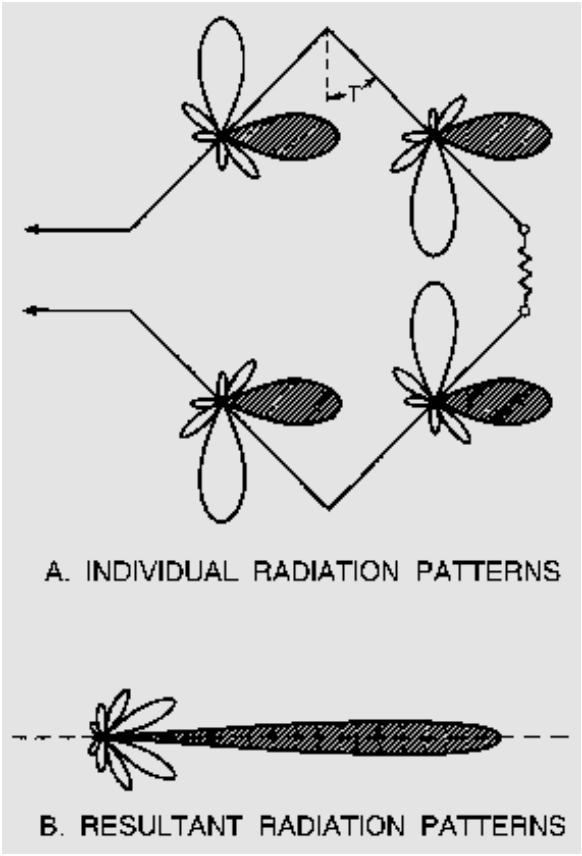
Design equations of Rhombic antenna

$$E = \frac{2\cos\phi\left[\sin\left(\frac{2\pi h}{\lambda}\sin\beta\right)\right]\left\{\sin\left(\frac{\pi L}{\lambda}\right)[1-\cos\beta\sin\phi]\right\}^2}{(1-\cos\beta\sin\phi)}$$

ϕ = tilt angle = $(90 - \beta)$

β = angle of elevation

h = height above ground

L = length of the leg in λ

λ = wavelength

- From this equation, we can deduce the condition to get the maximum power direction with respect to height h and length of line L

$$h = \frac{\lambda}{4\sin\beta} \quad m$$

And the length L is given by,

$$L = \frac{0.37\,\lambda}{\sin^2\beta}$$

Finally,

$$\phi = 90 - \beta$$

The main disadvantage of rhombic antenna is that the portions of the radiation, which do not combine with the main lobe, result in considerable side lobes having both horizontal and vertical polarization.

Advantages of Rhombic antenna

- Input impedance and radiation pattern are relatively constant
- Multiple rhombic antennas can be connected
- Simple and effective transmission

Disadvantages of Rhombic antenna

- Wastage of power in terminating resistor
- Requirement of large space
- Redued transmission efficiency

Applications of Rhombic antenna

- Used in HF communications
- Used in Long distance sky wave propagations
- Used in point-to-point communications
-

Horn Antenna

A **Waveguide** is capable of radiating energy when excited at one end and opened at the other end. The radiation in wave guide is greater than a two-wire transmission line.

Frequency Range

The operational frequency range of a wave guide is around **300MHz to 300GHz**. This antenna works in **UHF** and **EHF** frequency ranges. The following image shows a waveguide.
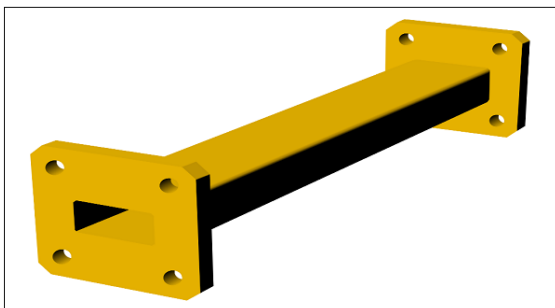
This waveguide with terminated end, acts as an antenna. But only a small portion of the energy is radiated while a large portion of it gets reflected back in the open circuit. It means **VSWR** (voltage standing wave ratio, discussed in basic parameters chapter) value increases. The diffraction around the waveguide provides poor radiation and non-directive radiation pattern.

The radiation of waveguide antenna is poor and the pattern is non-directive, which means omni-directional. An **omni-directional** pattern is the one which has no certain directivity but radiates in all directions, hence it is called as **non-directive radiation pattern**.

To improve the radiation efficiency and directivity of the beam, the wave guide should be provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation. So that all the energy in the forward direction gets radiated. This can be termed as **Flaring**. Now, this can be done using a horn antenna.

The operational frequency range of a horn antenna is around **300MHz to 30GHz**. This antenna works in **UHF** and **SHF** frequency ranges.

Construction & Working of Horn Antenna

The energy of the beam when slowly transform into radiation, the losses are reduced and the focussing of the beam improves. A **Horn antenna** may be considered as a **flared out wave guide**, by which the directivity is improved and the diffraction is reduced.
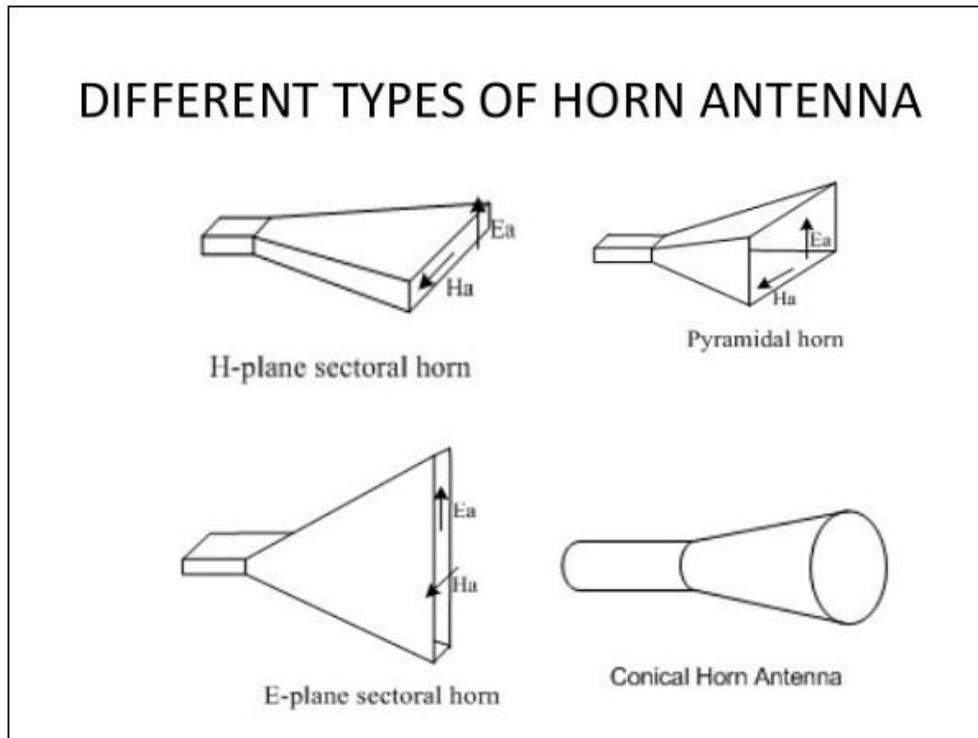
The above figures show the types of horn configurations.

Sectoral horn

This type of horn antenna, flares out in only one direction. Flaring in the direction of Electric vector produces the **sectorial E-plane horn**. Similarly, flaring in the direction of Magnetic vector, produces the **sectorial H-plane horn**.

Pyramidal horn

This type of horn antenna has flaring on both sides. If flaring is done on both the E & H walls of a rectangular waveguide, then **pyramidal horn antenna** is produced. This antenna has the shape of a truncated pyramid.

Conical horn

When the walls of a circular wave guide are flared, it is known as a **conical horn**. This is a logical termination of a circular wave guide.

Flaring helps to match the antenna impedance with the free space impedance for better radiation. It avoids standing wave ratio and provides greater directivity and narrower beam width. The flared wave guide can be technically termed as **Electromagnetic Horn Radiator**.

Flare angle, **Φ** of the horn antenna is an important factor to be considered. If this is too small, then the resulting wave will be spherical instead of plane and the radiated beam will not be directive. Hence, the flare angle should have an optimum value and is closely related to its length.

The radiation pattern of a horn antenna is a Spherical Wave front. The following figure shows the **radiation pattern** of horn antenna. The wave radiates from the aperture, minimizing the diffraction of waves. The flaring keeps the beam focussed. The radiated beam has high directivity.
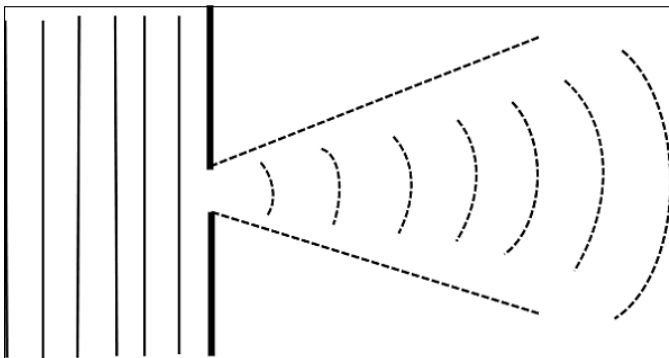
Design equations
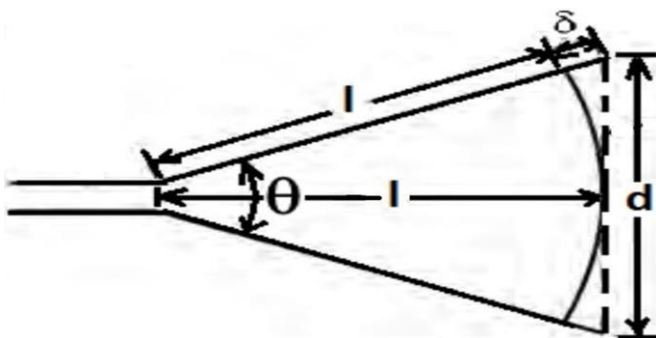
From the geometry of the fig,we have

$$\cos \theta = \frac{l}{l+\delta} \text{ and } \tan \theta = \frac{d}{2l}$$

$\theta = \tan^{-1}[\frac{d}{2l}] = \cos^{-1}[\frac{l}{l+\delta}]$ where δ = permissible phase angle variation

and $l = d^2/8\delta$

HPBW of optimum flared horn is

$$\theta E = 56\lambda/d$$

$$\theta H = 67\lambda/w$$

where θE and θH are HPBW in E and H directions.

- **Directivity** $D = 7.5\ d\ w/\lambda^2$
- **Power gain Gp** $= 4.5\ d\ w/\lambda^2$

Advantages of Horn antenna

- Small minor lobes are formed
- Impedance matching is good
- Greater directivity
- Narrower beam width
- Standing waves are avoided

Disadvantages of Horn antenna

- Designing of flare angle, decides the directivity
- Flare angle and length of the flare should not be very small

Applications of Horn antenna

- Used for astronomical studies
- Used in microwave applications

<u>Parabolic Reflectors</u>

arabolic reflectors are Microwave antennas..The frequency range used for the application of Parabolic reflector antennas is **above 1MHz**. These antennas are widely used for radio and wireless applications.

Principle of Operation

The standard definition of a parabola is - Locus of a point, which moves in such a way that its distance from the fixed point (called **focus**) plus its distance from a straight line (called **directrix**) is constant.

The following figure shows the geometry of parabolic reflector. The point **F** is the focus (feed is given) and **V** is the vertex. The line joining F and V is the axis of symmetry. PQ are the reflected rays where **L** represents the line directrix on which the reflected points lie (to say that they are being collinear). Hence, as per the above definition, the distance between F and L lie constant with respect to the waves being focussed.
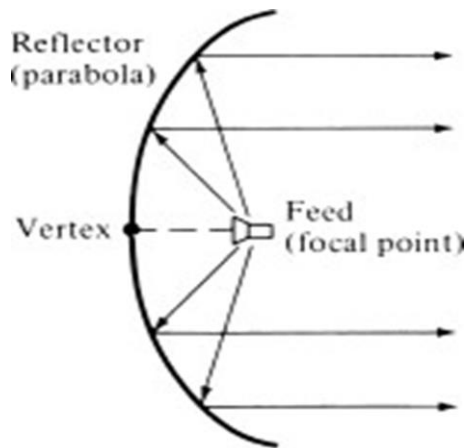
(c) Curved (front-fed)

The reflected wave forms a colllimated wave front, out of the parabolic shape. The ratio of focal length to aperture size (ie., f/D) known as **"f over D ratio"** is an important parameter of parabolic reflector. Its value varies from **0.25 to 0.50**.

The law of reflection states that the angle of incidence and the angle of reflection are equal. This law when used along with a parabola, helps the beam focus. The shape of theparabola when used for the purpose of reflection of waves, exhibits some properties of the parabola, which are helpful for building an antenna, using the waves reflected.

Properties of Parabola

- All the waves originating from focus, reflects back to the parabolic axis. Hence, all the waves reaching the aperture are in phase.

- As the waves are in phase, the beam of radiation along the parabolic axis will be strong and concentrated.

Following these points, the parabolic reflectors help in producing **high directivity with narrower beam width.**

Construction & Working of a Parabolic Reflector

If a Parabolic Reflector antenna is used for transmitting a signal, the signal from the feed, comes out of a dipole or a horn antenna, to focus the wave on to the parabola. It means that, the waves come out of the focal point and strike the Paraboloidal reflector. This wave now gets reflected as **collimated wave front**, as discussed previously, to get transmitted.

The same antenna is used as a receiver. When the electromagnetic wave hits the shape of the parabola, the wave gets reflected onto the feed point. The dipole or the horn antenna, which acts as the receiver antenna at its feed, receives this signal, to convert it into electric signal and forwards it to the receiver circuitry.

The gain of the paraboloid is a function of aperture ratio **(D/λ)**. The Effective Radiated Power **(ERP)** of an antenna is the multiplication of the input power fed to the antenna and its power gain.

Usually a wave guide horn antenna is used as a feed radiator for the paraboloid reflector antenna. Along with this technique, we have another type of feed given to the paraboloid reflector antenna, called as Cassegrain feed.

Cassegrain Feed

Cassegrain is another type of feed given to the reflector antenna. In this type, the feed is located at the vertex of the paraboloid, unlike in the parabolic reflector. A convex shaped reflector, which acts as a hyperboloid is placed opposite to the feed of the antenna. It is also known as **secondary hyperboloid reflector** or **sub-reflector**. It is placed such that its one of the foci coincides with the focus of the paraboloid. Thus, the wave gets reflected twice.
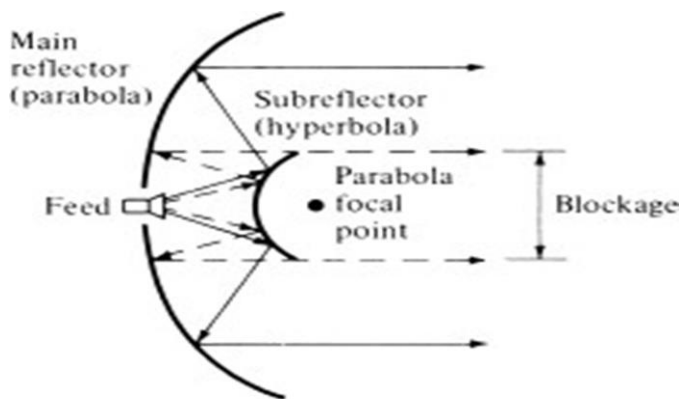
(d) Curved (Cassegrain feed)

The above figure shows the working model of cassegrain feed.

Working of a Cassegrain Antenna

When the antenna acts as a transmitting antenna, the energy from the feed radiates through a horn antenna onto the hyperboloid concave reflector, which again reflects back on to the parabolic reflector. The signal gets reflected into the space from there. Hence, wastage of power is controlled and the directivity gets improved.

When the same antenna is used for reception, the electromagnetic waves strike the reflector, gets reflected on to the concave hyperboloid and from there, it reaches to the feed. A wave guide horn antenna presents there to receive this signal and sends to the receiver circuitry for amplification.

Advantages of Parabolic reflector antenna

- Reduction of minor lobes
- Wastage of power is reduced
- Equivalent focal length is achieved
- Feed can be placed in any location, according to our convenience
- Adjustment of beam (narrowing or widening) is done by adjusting the reflecting surfaces

Disadvantages of a Parabolic reflector antenna

- Some of the power that gets reflected from the parabolic reflector is obstructed.

Applications of Parabolic reflector antenna

- used in wireless telecommunication systems.
- used in satellite communications.