UNIT-I

Antenna Basics & Dipole antennas

Introduction: Antenna is an important device which has become an integral part of our day to day life . we find antenna everywhere ,at home ,work places ,on cars,vehicles, aircraft,ships,and not only that we carry antenna along with us in our mobiles. There are number of types of antennas but all operate with the basic principles of electromagnetics. First radio antenna was assembled in 1886 by Heinrich Hertz. He developed a circuit resembling a radio system with end loaded dipoles as a transmitting antenna while resonant square loop antenna as a receiving antenna operating at one meter wavelength. The laboratory work done by Hertz was further completed by Guglielmo Marconi. He demonstrated world communication of signal over long distances in 1901. Now a days ,antennas are the most essential communication link for aircraft and ships. Antennas are our electronic eyes and ears on the world. They are our links with space. The radiation is produced by accelerated or decelerated charges.

Basic Definitions of Antenna:

1. An antenna is a metallic device in the form of either wire or rod used for radiating or receiving radio waves .
2. According to The *IEEE Standard Definitions of Terms for Antennas* defines the antenna or aerial as "a means for radiating or receiving radio waves."
3. An *antenna* may be defined as the structure associated with the region of transition between a guided wave and a free-space wave, or vice versa.
4. An antenna can also be defined as transducer which converts electrical current into EM waves.
5. An antenna can also be defined as an impedance matching device between transmission line and free space and vice-versa.

Antenna as a transition device:

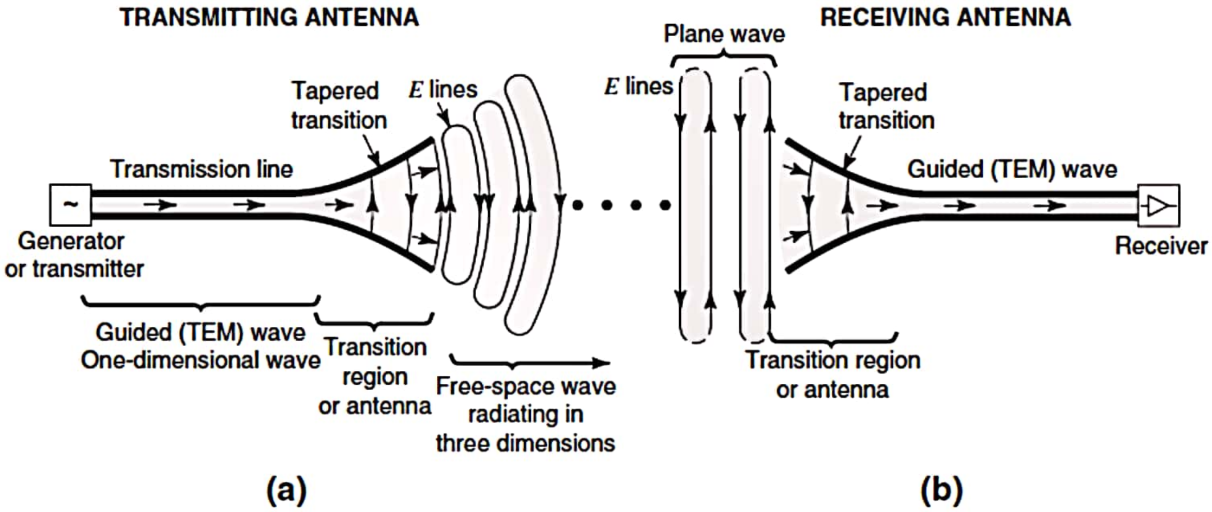


Fig.(a) transmitting antenna and (*b*) receiving antenna.

The two wire transmission line in fig is connected to a transmitter or generator. Along the uniform part of the line , the energy is guided as a plane TEM wave with little loss. The spacing between wires is assumed to be a small fraction of a wavelength. Further on the transmission line opens out in tapered region. As separation approaches the order of the wave length or more ,the wave tends to be radiated so that open out transmission line acts like an antenna which launches a free space wave. The currents on the transmission line flow out on the antenna and end there but the fields associated with them keep on going.

The transmitting antenna in Fig. 1*a* is a region of transition from a guided wave on a transmission line to a free-space wave. The receiving antenna (Fig. 1*b*) is a region of transition from a space wave to a guided wave on a transmission line. Thus, ***an antenna is a transition device, or transducer, between a guided wave and a free-space wave, or vice-versa.*** The antenna is a device which interfaces a circuit and space.

RADIATION MECHANISM:

Regardless of antenna type, all involve the same basic principle that radiation is produced by accelerated (or decelerated) charge. The *basic equation of radiation* may be expressed simply as

$\boxed{\dot{I}L = Q\dot{v}}$ Basic radiation equation

where

$\dot{I}$ = time-changing current, A s^{-1}

L = length of current element, m

Q = charge, C

$\dot{v}$= time change of velocity which equals the acceleration of the charge, m s^{-2}

L = length of current element, m

It simply states that *to create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge*. The phenomenon of transmitting energy into the free space in the form of electromagnetic fields is called as radiation.

1. If a charge is not moving, current is not created and there is no radiation.
2. If charge is moving with a uniform velocity: (a). There is no radiation if the wire is straight, and infinite in extent.(b.) There is radiation if the wire is curved, bent, discontinuous, terminated, or truncated, as shown in Figure
3. If charge is oscillating in a time hormonic-motion, it radiates even if the wire is straight.

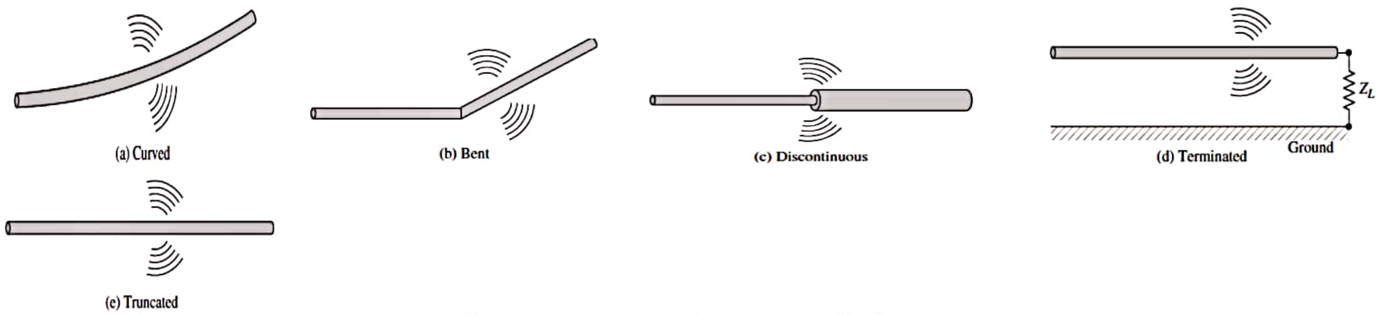


Fig Wire configurations for radiation.

Types of antennas:

1. Wire antennas(Dipole,loop and helical antennas)
2. Aperture antennas(Horn antenna)
3. Microstrip Antennas
4. Array antennas(Yagi-Uda array)
5. Lens antennas
6. Reflector antennas(parabolic reflector)

Isotropic Radiator: An *isotropic* radiator is defined as "a hypothetical lossless antenna having equal radiation in all directions". It is also called isotropic source. As it radiates uniformly in all directions, it is also called omnidirectional radiator or unipole. Basically isotropic radiator is a lossless ideal radiator or antenna. Generally all the practical antennas are compared with the characteristics of the isotropic radiator. The isotropic antenna or radiator is used as reference antenna. Practically all antennas show directional properties i.e. directivity property. That means none of the antennas radiate energy uniformly in all directions. Hence practically isotropic radiator cannot exist.

Consider that an isotropic radiator is placed at the centre of sphere of radius r. Then all the power radiated by the isotropic radiator passes over the surface area of the sphere given by $4\pi r^2$. The average power density Pavg at any point the surface of the sphere is defined as "power radiated per unit area in any direction". The total power radiated by the isotropic radiator is given by $P_{rad} = \iint P_{avg} \cdot dS = P_{avg}(4\pi r^2)$

$$P_{avg} = \frac{P_r}{4\pi r^2}$$

Where P_{rad}= total power radiated in watts

P_{avg}=Average power density

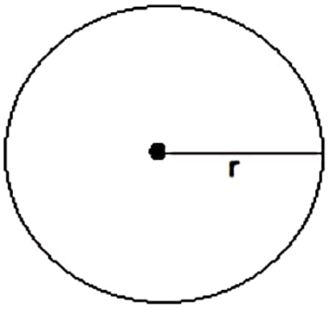


Fig. Isotropic Radiator

Note: 1. A *directional* antenna is one "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others.

2. Omnidirectional antenna is defined as the antenna having an essentially nondirectional pattern in a given plane (e.g., in azimuth) and a directional pattern in any orthogonal plane (in elevation). An *omnidirectional* pattern is then a special type of a *directional* pattern

Basic Antenna parameters: To describe the performance of an antenna, definitions of various parameters are necessary. They are given by the following

1. Radiation pattern (a).Field radiation pattern (2). Power pattern
2. Radiation Intensity
3. Directivity and gain
4. Antenna beam width
5. Antenna bandwidth
6. Antenna beam area
7. Resolution
8. Antenna impedance
9. Effective height
10. Effective length
11. Antenna apertures
12. Antenna temperature
13. Antenna polarizations

Radiation pattern:

The radiation patterns are the graphical representation of the three dimensional variations of field or power as a function of the spherical coordinates θ and ϕ. The pattern has its main lobe (maximum radiation) in the z direction ($\theta = 0$) with minor lobes (side and back) in other directions.

To completely specify the radiation pattern with respect to field intensity and polarization requires three patterns:

1. The θ component of the electric field as a function of the angles θ and ϕ or $E_\theta(\theta,\phi)$ (V m−1)
2. The φ component of the electric field as a function of the angles θ and ϕ or $E_\phi(\theta,\phi)$ (V m−1).
3. The phases of these fields as a function of the angles θ and ϕ or δθ (θ, φ) and δφ(θ, φ) (rad or deg).

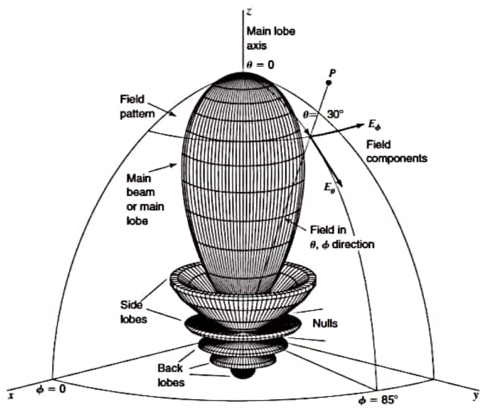


Fig Three-dimensional field pattern of a directional antenna with maximum radiation in z-direction at θ = 0◦.

To represent the radiation pattern in two dimensionally two plane cuts are required. Two such cuts at right angles, called the *principal plane patterns* (as in the *xz* and xy planes) may be required but if the pattern is symmetrical around the *z* axis, one cut is sufficient.

<u>Note:</u> For a linearly polarized antenna, performance is often described in terms of its principal E and H plane patterns.

1. The E-plane is defined as "the plane containing the electric-field vector and the direction of maximum radiation," . the x-z plane (elevation plane; ϕ = 0) is the principal E-plane
2. The H-plane is defined as "the plane containing the magnetic-field vector and the direction of maximum radiation." the x-y plane (azimuthal plane; $\theta = \pi/2$) is the principal H-plane.

The power pattern can be represented two dimensionally as shown below.

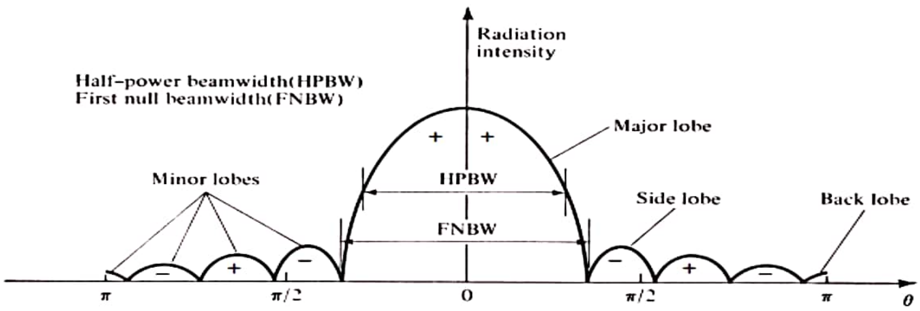


Fig . Linear plot of power pattern and its associated lobes and beamwidths.

<u>Field pattern</u> : The field patterns are the graphical representation of the three dimensional variations of fields as a function of the spherical coordinates **θ** and $\boldsymbol{\phi}$ **.**

Normalized field pattern: The normalized field pattern or relative field pattern is defined as the ratio of the field components to its maximum value. There are no units for the normalized field pattern.

$$\boxed{\textit{Normalized field pattern} = E_\theta(\theta,\phi)_n = \frac{E_\theta(\theta,\phi)}{E_\theta(\theta,\phi)_{\max}} \qquad \text{(dimensionless)}}$$

The half-power level occurs at those angles θ and φ for which $E\theta\ (\theta,\ \varphi)n = 1/\sqrt{2}=0.707$

Power pattern: The radiation patterns are the graphical representation of the three dimensional variations of power as a function of the spherical coordinates **θ** and **φ.**
Normalized power pattern: The normalized power pattern or relative power pattern is defined as the ratio of the power per unit area to its maximum value. There are no units for the normalized power pattern.

$$\boxed{\textbf{Normalized power pattern } = \mathbf{P}_{\boldsymbol{n}}(\boldsymbol{\theta},\emptyset) = \frac{\mathbf{P_d}(\boldsymbol{\theta},\emptyset)}{\mathbf{P}_{\boldsymbol{d}}(\boldsymbol{\theta},\emptyset)_{\boldsymbol{max}}} \quad \text{(dimensionalless)}}$$

The decibel level is given by $\quad dB = 10log_{10}(P_n(\theta,\phi)$

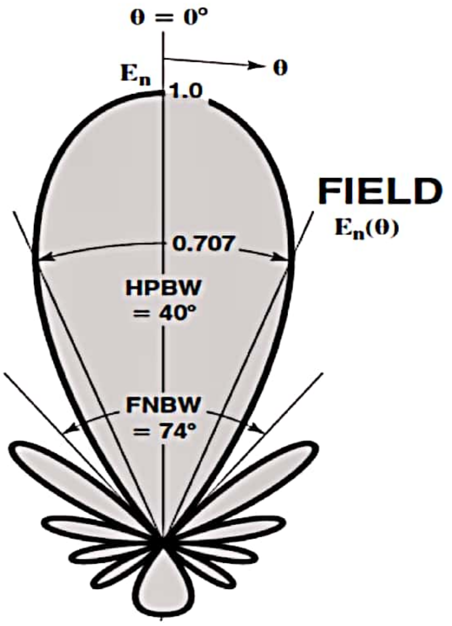
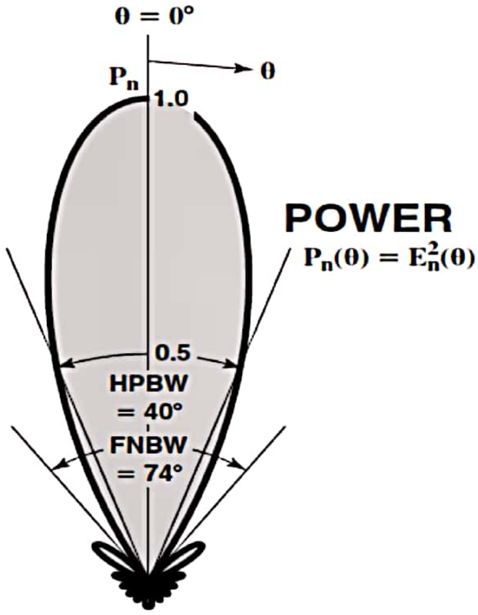


Fig (a) Normalized Field pattern



(b).Normalized power pattern

Note:1. Various parts of a radiation pattern are referred to as *lobes*, which may be subclassified into *major* or *main, minor, side*, and *back* lobes.

2. A *major lobe* (also called main beam) is defined as "the radiation lobe containing the direction of maximum radiation."

3.A *minor lobe* is any lobe except a major lobe and A *side lobe* is "a radiation lobe in any direction other than the intended lobe.

4.A *back lobe* is "a radiation lobe whose axis makes an angle of approximately 180◦ with respect to the beam of an antenna."

Antenna Beam width: The beam width is defined as the angular width in degrees between the two points on the major lobe of the radiation pattern. It is the measure of directivity of the antenna
Half power beam width (HPBW): The HPBW is defined as the angular width in degrees between the two half power points on the major lobe of the radiation pattern.
First null beam width (FNBW): The FNBW is defined as the angular width in degrees between the two null points on the major lobe of the radiation pattern.

Front to Back ratio(FBR):

$$\boldsymbol{FBR} = \frac{\textbf{Power radiated in the desired direction}}{\textbf{power radiated in opposite direction}}$$

Radian and Steradian : The radian is the measure of the plane angle while the Steradian is the measure of a solid angle.
Radian: One *radian* is defined as the plane angle with its vertex at the center of a circle of radius *r* that is subtended by an arc whose length is *r*. Since the circumference of a circle of radius *r* is $C = 2\pi r$, there are 2π rad $(2\pi r/r)$ in a full circle.

Steradian: One *steradian* is defined as the solid angle with its vertex at the center of a sphere of radius *r* that is subtended by a spherical surface area equal to that of a square with each side of length *r*. Since the area of a sphere of radius *r* is $S = 4\pi r^2$, there are 4π sr $(4\pi r^2/r^2)$ in a closed sphere.
The infinitesimal area *dA* on the surface of a sphere of radius *r*, shown in Figure 2.1, is given by
$dS = r^2 \sin\theta d\theta d\phi$ (m^2)
Therefore, the element of solid angle $d\Omega$ of a sphere can be written as
$d\Omega = {}^{dS}/_{r^2} = \sin\theta \, d\theta d\phi$ (sr)

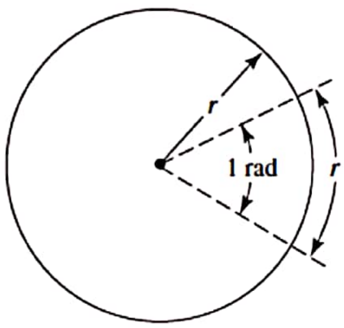
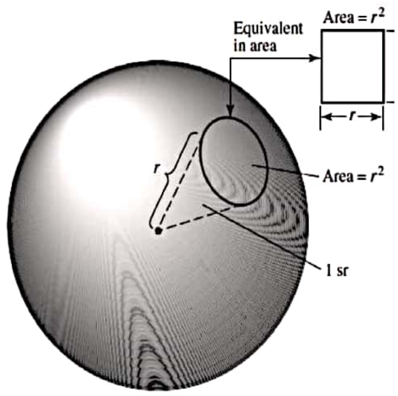


Fig .(a) Radian



(b)Steradian

Beam Area or beam solid angle **(Ω_A):** The beam area or *beam solid angle* or Ω_A of an antenna is given by the integral of the normalized power pattern over a sphere (4π sr)

$$\Omega_A = \int_{\phi=0}^{\phi=2\pi} \int_{\theta=0}^{\theta=\pi} P_n(\theta, \phi) \sin\theta \, d\theta \, d\phi$$

$$\boxed{\Omega_A = \iint_{4\pi} P_n(\theta, \phi) \, d\Omega \qquad \text{(sr)} \qquad \textit{Beam area}}$$

UNIT-III

VHF,UHF And Microwave Antenna-II

Micro strip Antennas- Introduction, features, advantages and limitations, Rectangular patch antennas- Geometry and parameters, characteristics of Micro strip antennas, Impact of different parameters on characteristics, reflector antennas - Introduction, Flat sheet and corner reflectors, parabola reflectors- geometry, pattern characteristics, Feed Methods, Reflector Types -Related Features, Lens Antennas - Geometry of Non-metallic Dielectric Lenses, Zoning , Tolerances, Applications, Illustrative Problems.

Micro strip Antennas:

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure

The patch is generally made of conducting material such as copper or gold and can take any possible shape.

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure

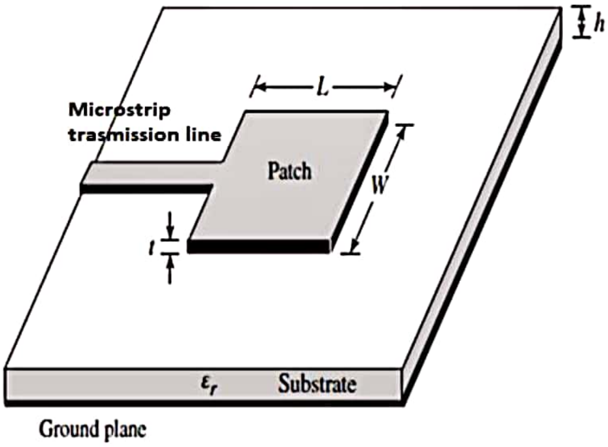


Fig. Microstrip antennas.

Advantages:

The principal advantages are given below:

• Light weight, smaller size and low volume.
• Low profile planar configuration which can be easily made conformal to host surface.
• Low fabrication cost, hence can be manufactured in large quantities.
• Supports both, linear as well as circular polarization.
• Can be easily integrated with microwave integrated circuits (MICs).
• Capable of dual and triple frequency operations.
• Mechanically robust when mounted on rigid surfaces.
• With the microstrip antennas it is easy to form large arrays with half-wavelength or lesser spacing.

Limitations:

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas.
Some of their major disadvantages are given below:

• Narrow bandwidth
• Low efficiency
• Low Gain
• Extraneous radiation from feeds and junctions
• Poor end fire radiator except tapered slot antennas
• Low power handling capacity.
• Surface wave excitation
• The size of a microstrip antenna is inversely proportional to its frequency. At lower frequencies the size of antenna becomes large.
• The design complexity gets enhanced due to their smaller size.

Applications:

- Wireless applications
- Mobile phones and Pagers
- Radars
- Satellite communication
- Radio altimeter
- The telemetry and communication antennas on missiles
- Feed elements in complex antennas
- Satellite navigation receiver
- Biomedical radiator

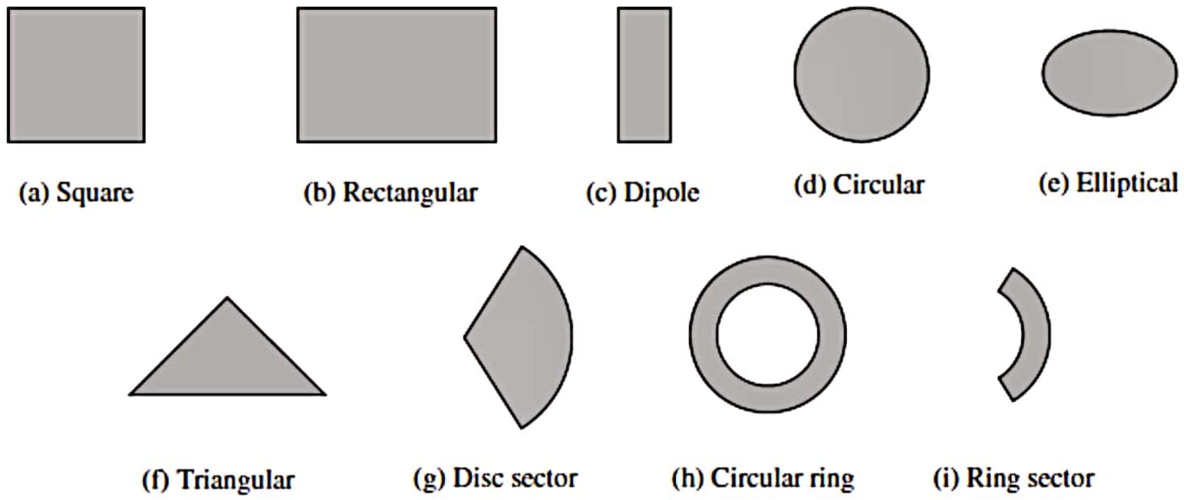
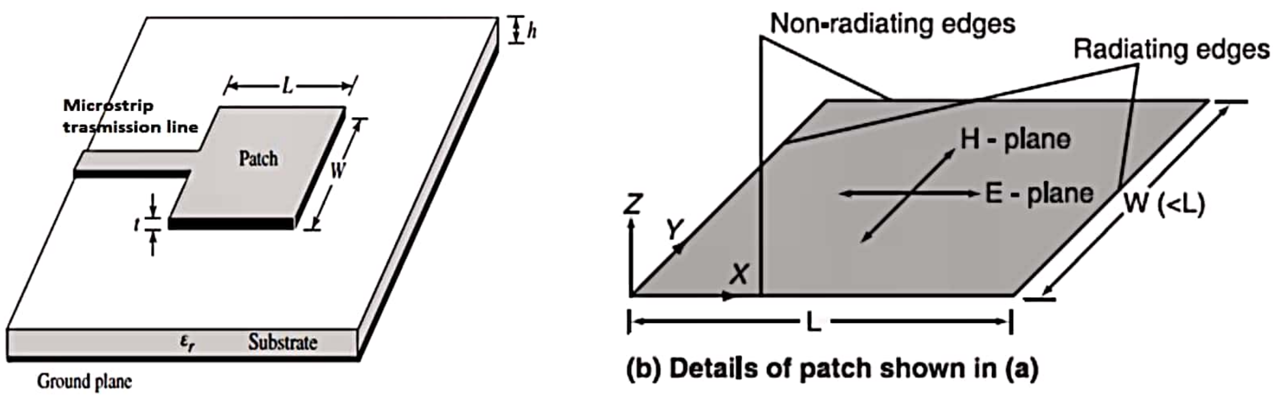


Fig . Representative shapes of microstrip patch elements.

<u>Rectangular Microstrip Antennas:</u>

The rectangular shape is the simplest and most widely used configuration for fabrication of microstrip antennas. The basic structure of the rectangular microstrip antenna is shown in figure (a). The length L causes resonance at its half-wavelength frequency.

The two ends of the length 'L' are called radiating edges and other two are called non-radiating edges. The radiating edges produce single polarized waves and non-radiating edges produce cross polarization.



(a) Rectangular microstrip antenna

Fig.1 Basic structure of a rectangular microstrip antenna.

The field variations of the rectangular patch antenna for both sinusoidal and uniform variations are given below.

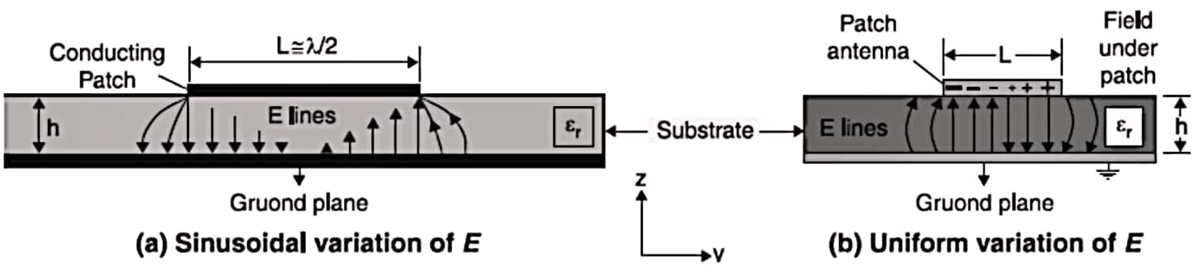


Fig 2. Patch antenna with *E* field distribution.

Due to the half wave length of the patch, the fields under the L-edges are of opposite polarity and when the fields curved out and finally propagates out into the direction normal to the substrate and the radiation from the two sides are added up because the fields are in phase (both facing left).
The radiation intensity goes on decreasing as fields move away from the edges and cancel due to out of phase.

For effective radiation from a microstrip antenna

1. The structure needs to be a half-wavelength resonator (L=λ/2)
2. The dielectric substrate should be sufficiently thicker and with low dielectric constant
3. The height of the substrate needs to be a fraction of the wavelength.

Let us consider the microstrip antenna fed by a microstrip transmission line as shown in fig. The microstrip or patch antenna, microstrip transmission line and the ground plane are made of a high-conductivity metal. The patch is of length *L*, width *W*, and sitting on top of a dielectric substrate of thickness *h* with permittivity ε_r.

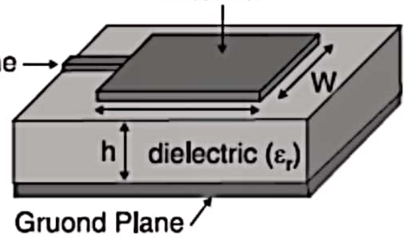


Fig.3.Geometry of a microstrip patch antenna.

The frequency of operation of the patch antenna is determined by the length *L* and is given by

$$f_c \cong \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0\varepsilon_r\mu_0}}$$

According to the recent inventions the frequency of operation will also depends on the width 'w' and the relation is given by,

$$f_{r,nm} = \frac{c}{2\sqrt{\varepsilon_{r,eff}}}\left[\left\{\frac{n}{L+2\Delta L}\right\}^2 + \left\{\frac{m}{W+2\Delta W}\right\}^2\right]^{1/2}$$

The expression for dominant mode (n=1 and m=0) is given by.

$$f_{r,nm} = \frac{c}{2(L+2\Delta L)\sqrt{\varepsilon_{r,eff}}}$$

In the above equations, ΔL and ΔW are the incremental length and width which account for the fringing of field at the respective edges.
The width 'w' is an important parameter because it controls the input impedance of the antenna. When the width is increased the input impedance of the antenna will decrease. The width of the patch also controls the radiation pattern of the antenna.
The normalized pattern of the antenna can be obtained by plotting the fields E_θ and E_ϕ which is approximately given as

$$\mathbf{E}_\theta = \frac{\sin[(\beta\omega\sin\theta\sin\phi)/2]}{[(\beta\omega\sin\theta\sin\phi)/2]}\cos[(\beta L/2)\sin\theta\cos\phi]\cos\phi$$

$$\mathbf{E}_\phi = -\frac{\sin[(\beta\omega\sin\theta\sin\phi)/2]}{[(\beta\omega\sin\theta\sin\phi)/2]}\cos[(\beta L/2)\sin\theta\cos\phi]\sin\phi$$

The net magnitude of electric field at any point is a function of θ and ϕ and is given by

$$E(\theta,\phi) = \sqrt{(E_\theta^2 + E_\phi^2)}$$

6. TRAVELLING WAVE TUBES

A TWT amplifier circuit uses a helix slow wave structure. The goal of TWT is to slow down the RF wave, which propagates at the speed of light (C) to a phase velocity close to the velocity of electron beam. The mechanism that reduces RF wave phase velocity in a TWT wave is a slow wave structure, also called as periodic delay line.

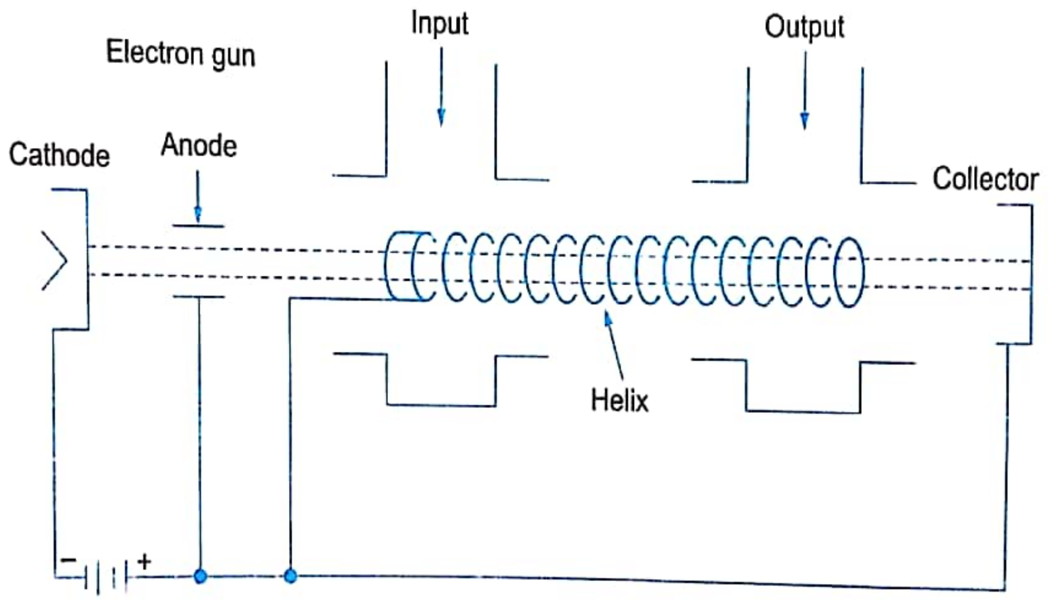
Constructional Details:

- In this helical slow wave structure used.
- Helix TWT consists of an electron gun and a slow wave structure
- A magnetic focusing field is provided to prevent the beam from spreading and to guide it through the centre of the long axial helix.

Operational Details:

- The signal to be amplified is applied to the end of the helix adjacent to the electron gun.
- The applied signal propagates around the turns of the helix and produces an electric field at the center of the helix.

The amplified signal appears at the output or at other end of the helix under appropriate operating conditions.



7. CROSS FIELD TUBES

In crossed field devices, both the d.c magnetic and electric fields are perpendicular to each other. In the RF interaction process of crossed – field tubes, the D.C magnetic field plays a absolute role. The electrons emitted by the cathode in a crossed-filed tube accelerated by electric field and gain velocity. The bending of the path by the magnetic field depends upon the velocity of electrons.

Magnetrons:

Magnetrons are High power oscillators. The magnetron has in built microwave oscillators in it, that operates differently from linear wave tubes, such as TWT and Klystron. Magnetron is of 3 types:

1. Negative resistance type.
2. Cyclotron frequency type.
3. Cylindrical type.

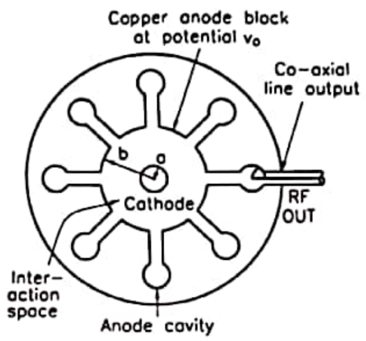
Cylindrical type Magnetrons: (Construction)

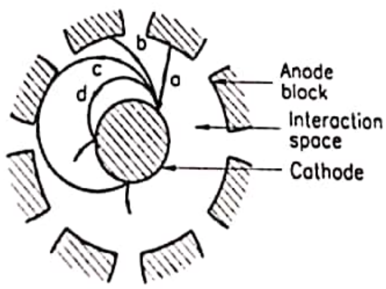
Cylindrical type magnetron consists of a cylindrical cathode of finite length and radius 'a' at the center surrounded by a cylindrical anode of radius 'b'. The anode has several re-entrant cavities which are equi-spaced around the circumference. These cavities are connected between anode and cathode by slots. The d.c voltage V_0 is applied between anode and cathode. The magnetic flux density B_0 is maintained in positive Z- direction by an electromagnet.

Depending on the relative strengths of the electric and magnetic fields the electrons emitted from the cathode and moving towards the anode will traverse the interaction space.

In the absence of a magnetic field (B=0), the electron travels straight from the cathode to the anode due to the radial electric field force acting on it (indicated by the trajectory 'a' in figure). If the magnetic field strength is increased (i.e., for the moderate value of B) it will exert a lateral force bending the path of the electron as shown by path 'b' in the figure. The radius of the path is given by R=mv/eB, which varies directly with electron velocity and inversely as the magnetic field strength.

If the strength of the magnetic field is made sufficiently high so as to prevent the electrons from reaching the anode (as shown by path 'c' in the figure) the anode current becomes zero. The magnetic field required to return electrons back to cathode just grazing the surface of the anode is called the critical magnetic field (Bc), the cutoff magnetic field. If the magnetic field is made larger than the critical field (B> Bc), the electron experiences a greater rotational force and may return back to cathode quite faster. All such electrons may cause back heating of the cathode. This can be avoided by switching off the heater supply after the commencement of oscillation. This is done to avoid fall in the emitting efficiency of the cathode.

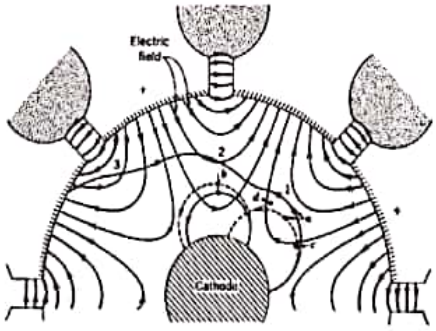




Pi-Mode:

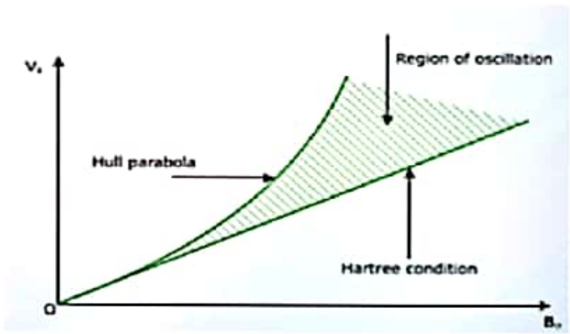
In this mode, the phase difference (ϕ) between two adjacent cavities is π and is called π-mode. In higher modes, this difference ϕ must be $<\pi$, but with the condition that $8\phi = 2n\pi$, i.e., the total phase shift in the complete circle must be multiple of 2π. The lines of forces and the path traversed by electrons in magnetron under π – mode is shown in figure. Oscillation in π – mode can occur at voltage between a critical level called Hartee potential and Hull potential.

$$V_{Ht} = \frac{2\pi f B}{N}(b^2 - a^2)$$



Where, V_{Ht} = Hartee potential in volts
B = Magnetic field flux density (Wb/m^2)
f = Oscillating frequency (Hz)
N = Number of cavity resonators
b = Anode radius (m)
a = Cathode radius (m)

The graph illustrates a plot of Hull cut off and Hartee Voltage Vs B_0.



Characteristics of Magnetron

1. Frequency range – Upto 10GHz
2. Efficiency – 40 to 70%
3. Power output – 800kW (Pulsed)

Applications of Magnetron

1. Magnetrons are widely used in radars with high o/p power.
2. In satellite and missiles for telemetry.
3. Industrial Heating.
4. Microwave ovens.