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UNIT: I

ANTENNA BASICS

1.1 HISTORY OF AN ANTENNAS:

Professor Heinrich Hertz of Germany's Technical Institute in Karlsruhe is credited with creating the first radio antennas. In 1886, Heinrich Hertz used a resonant half-wave receiving loop and an end-loaded half-wave dipole antenna to transmit electromagnetic waves with a wavelength of 8 m.

While Hertz deserves credit as the "father" of the radio, his invention remained a laboratory curiosity until 20-year-old Guglielmo Marconi of Bologna, Italy, improved upon it by adding tuning circuits, large antenna and ground systems for longer wavelengths, and the ability to send signals over great distances. When he received signals in St. John's, Newfoundland, from a station he built at Poldhu, Cornwall, England, in the middle of December 1901, he shocked the globe. The square, conical antenna was built by Guglielmo Marconi near Poldhu, England, in 1905 to transmit signals over the Atlantic Ocean at wavelengths of thousands of metres.To illustrate fig.1 below.

At the turn of the 20th century, Marconi's wireless technology was one of the few inventions to catch the public's imagination. Centimetre wavelengths gained popularity, and the whole radio spectrum was made available for widespread use with the invention of radar during World War II.

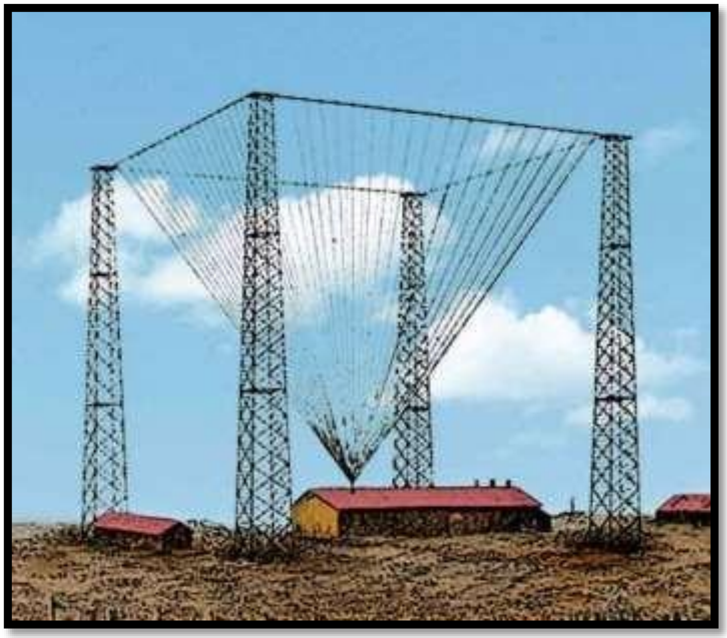

Fig 1.1: Square or conical antenna

Ref: http://simplyknowledge.com/uploads/script/gugliemo/guglielmo-marconi-failed-img.jpg

Antenna-covered communication satellites numbering in the thousands orbit the planet at low, medium, and geostationary altitudes. The geostationary satellites circle the planet like Saturn's rings.Whether day or night, cloudy or clear, your portable Global Positioning Satellite (GPS) receiver will always be accurate within a few centimetres. Radio sources at billions of light-year distances may be seen with the help of the Very Large Array (VLA), which consists of 27 steerable parabolic dish antennas, each 25 m in diameter, operating at centimetre wavelengths. The National Radio Astronomy Observatory in nearby Socorro is home to the array. In 1980, New Mexico was a brand new state. As seen in image (1.2.) below,

Fig 1.2: steerable parabolic dish antenna

Ref: [https://www.researchgate.net/profile/Wayne-Orchiston-2/publication/258658517/figure/fig6/AS:668568777682951@1536410626133/The-prefabricated-18-m-parabolic-antenna-courtesy-ATNF-Historic-Photographic-Archive.png]

The probes we have sent out into space, equipped with arrays of antennas, have visited planets in the solar system and beyond, responding to our commands and sending back photographs and data at centimetre wavelengths, even though it may take over 5 hours for the signals to travel in one direction. Signals from objects more than 10 billion light-years away have taken our radio telescope antennas operating at millimetre to kilometre wavelengths more than a thousand years to reach Earth. One of the 24 GPS satellites in its 20,000 km Medium Earth Orbit (MEO) uses a helix-shaped antenna array to relay location data to ground stations.

In 1985, these satellites could pinpoint your location (latitude, longitude, and elevation) within a metre, thanks to their = 20 cm accuracy. To illustrate fig (1.3) below.

Fig 1.3: A helix-shaped antenna array

Ref: https://cdn.britannica.com/13/73213-004-03CFCE74.jpg

The antennae in the top picture allow connections to be made throughout the whole landscape, including the valleys and mountains. Obviously, this method would be less labour-intensive than installing new wires everywhere. A mobile phone with a half-wave antenna operates at λ = 30 cm and allows you to communicate with anybody and everyone. All planes and ships need antennas so they can talk to each other. Cell phone antennas and other wireless device antennas allow us to stay in constant contact with the world around us.

Fig 1.4: Cell Phone tower

Ref: https://etimg.etb2bimg.com/thumb/msid-83950091,imgsize-128732,width-1200,height-628,overlay-ettelecom/radiation-from-cell-phone-towers-causes-no-harm-dot-official.jpg

The demand for antennas is expected to skyrocket as humankind increasingly ventures into space. Connectivity to and from the universe's many locations will depend on antennas. Antenna technology is headed towards the stars.

Fig 1.5: Hand-held cell phone with half-wave antenna

Ref: https://blog.solidsignal.com/wp-content/uploads/2019/01/08Motorola-DynaTAC-8000X-1983_large.jpg

1.2 INTRODUCTION:

An antenna is the connection point between a guided wave and the free-space environment. One of its most crucial features is an antenna's directional property, or its capacity to focus radiated power in a specific direction or choose a preferred approach for receiving energy.

Whether an antenna is being used as a transmitter or a receiver, its directional feature is always described in terms of a pattern. The antenna's input impedance must be matched to the characteristic impedance of the transmission line for an efficient interface between the free-space wave and the guided wave in the feed transmission line.

There are two basic types of antenna characteristics:

- Radiation characteristics, which define how the antenna emits or receives energy from space,
- Input characteristics, which characterise the antenna's performance while gazing at its terminals.

The input characteristics are input impedance, bandwidth, reflection coefficient, voltage standing wave ratio, etc. At the same time, the parameters include the radiation pattern, gain, directivity, effective aperture, polarisation, etc.Infinitesimal current element radiators were introduced in the previous chapter, and they serve as a helpful example since they are used to illustrate antenna properties. The reciprocity theorem establishes parity between an antenna's transmission and reception abilities. The link budget of a wireless system is then derived using these parameters, and some of the antenna-related challenges in wireless system design are explained.

1.2 BASIC ANTENNA PARAMETERS:

An antenna is often made up of metal conductors (called "elements") that are electrically linked to the radio equipment they serve. The role of an antenna is to transfer a signal from a conductor into a form that may travel freely over space, such as an electromagnetic wave. Their name comes from the Latin word for the long, thin feelers that many insects possess, "antennae." In wireless communication systems, a transmitting antenna sends out electromagnetic waves carrying information while a receiving antenna picks up some of that energy. To transmit or receive radio waves, you need an antenna device. An antenna may also be seen as a link between open air and a directing mechanism (such as a transmission line or waveguide).

The term "antenna" describes a solid metallic structure, whereas "aerial" describes a wire antenna. With that background, in this first lesson, let's look at several typical forms of antennas today.

1.2.1 TYPES OF MEASUREMENTS:

FUNDAMENTAL DIMENSIONS:

Fundamental dimensions include length, mass, time, electric current, temperature, and luminous intensity. Distance, mass, time, electricity, heat, and light would be represented by the letters L, M, T, I, T, and I, respectively.

SECONDARY DIMENSIONS:

A dimensional quantity whose value may be calculated using the square root of the primary dimension of length (l2).Using the unit, a dimension may be stated quantitatively as a standard or reference.A metre is a unit expressing the length dimension, while the kilogramme represents the mass measurement.

1.3 ANTENNA PARAMETERS:

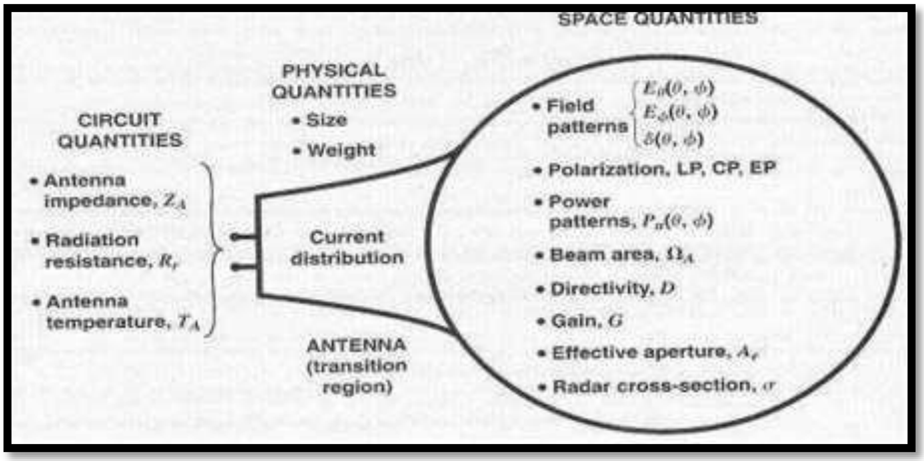

Fig 1.6: Schematic diagram of basic parameters

Ref:https://mrcet.com/downloads/digital_notes/ECE/III%20Year/ANTENNA%20AND%20WAVE%20PROPAGATIONS.pdf

An antenna's dual nature designates it as a circuit device on one frequency band and a space device on the other. The antenna's dual properties are in a simplified schematic form in Figure.1.6. Half-wave (HERTZ) and quarter-wave (MARCONI) antennas are common types of transmitting antennas.

Hertz antennas are often mounted in the air at a considerable height from the ground to maximise their range. Marconi antennas are designed to function with one end grounded and are often installed at a right angle to the ground or a grounding surface. Some of the most sophisticated antenna systems today have their roots in the simpler Hertz antenna, commonly known as a dipole. Operating frequencies over 2 MHz are typically handled by Hertz antennas, whereas Marconi antennas usually run frequencies below 2 MHz. Reciprocity, directivity, gain, and polarisation are the four fundamental features of every antenna, regardless of size or form factor.

A RADIATOR THAT EMITS IN ALL DIRECTIONS (OR ISOTROPIC):

There is a noticeable disparity in the antenna's outgoing signal strength between different directions. As a point of comparison, we use a made-up antenna type, an isotropic radiator, which emits equally in all directions. When it comes to transmitting or receiving electromagnetic waves, a directional antenna is superior to others in specific directions.

1.3.2 TYPICAL RADIATION PATTERN:

The radiation pattern of an antenna describes the relative distribution of radiated power as a function of direction in space (that is, as a function of and). It is usual to practise displaying the radiation pattern as a flat cross-section instead of a 3D surface. The E-plane and the H-plane both provide crucial perspectives.

The maximum value of the radiated field and electric field reside in the plane of the section, which is why this image is known as the E-plane pattern. The same holds when taking a segment perpendicular to the highest radiation direction and H field. Figure 1.7 displays a typical plot of the radiation pattern.

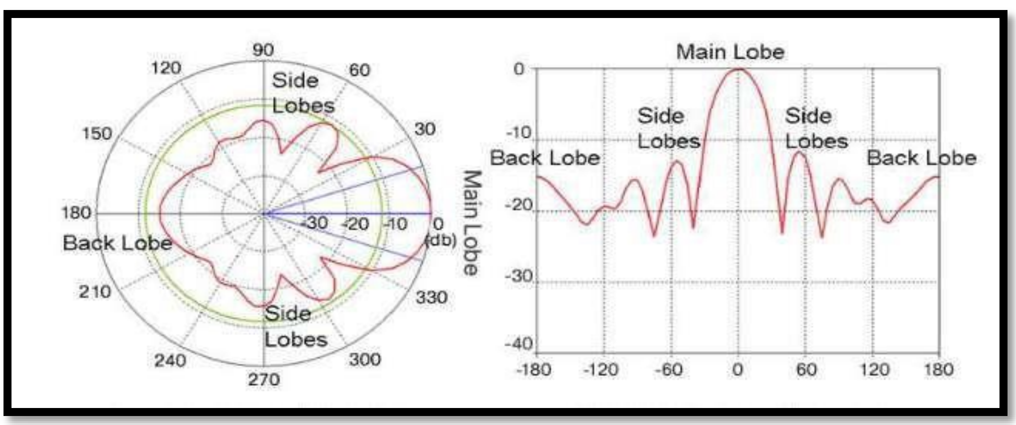

Fig 1.7: Radiation Pattern

Ref: https://www.industrialnetworking.com/pdf/Antenna-Patterns.pdf

Maximum radiation is directed in the direction of the central lobe. However, there may be more than one significant lobe in specific antennas. Minor lobes are any lobes except the main one. Radiation in the direction of interest may also be represented by smaller lobes, which should be reduced as much as possible.The half power beam width (HPBW) is the angle between the two sites where the power dissipated per unit area is precisely half its most incredible value.

RECIPROCITY (In terms of picture representation):

It is the capability of broadcasting and receiving using a single antenna. Its electrical properties remain the same whether the antenna is used for transmission or reception. If an antenna is good at sending a given frequency, it will also be good at receiving that frequency. Figure 1.8 depicts this (view A).

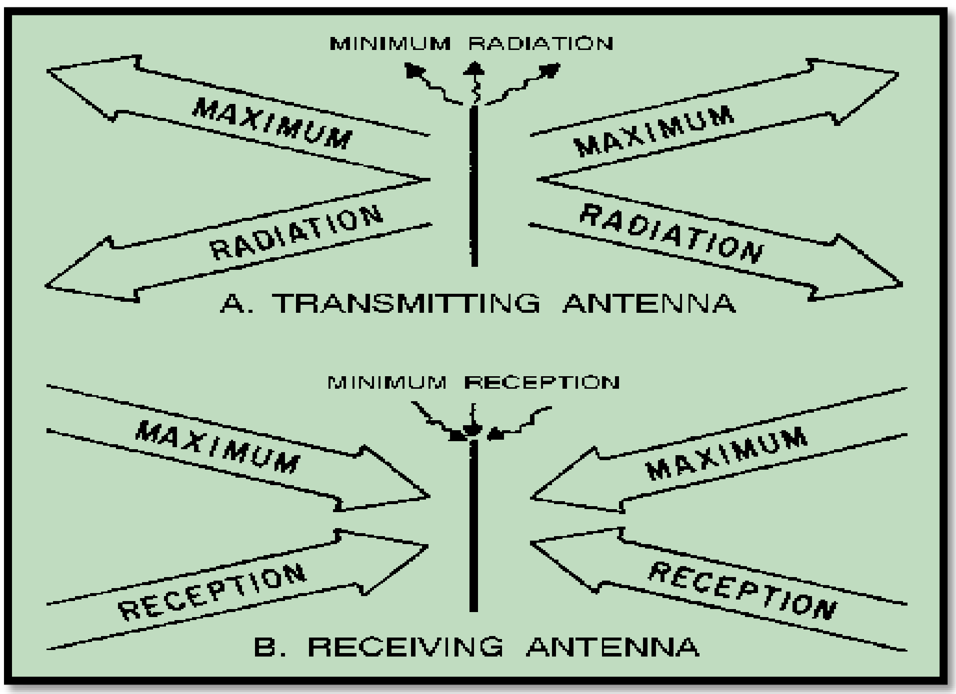

Fig 1.8: Reciprocity of Antenna

Ref: http://www.tpub.com/neets/book10/NTX4-7.GIF

Maximal radiation from a transmitting antenna occurs perpendicular to its axis. The best reception occurs perpendicular to the antenna's axis when the same antenna is used to pick up a signal (view B).

1.3.3 RADIATION BEAMS AND SHAPES:

Some characteristics are used to categorise the real form of the radiation patterns. Radiation patterns often exhibit many peaks and minima of E-field magnitudes when plotted on the E-plane (Cartesian coordinates y and x, or polar with r and). Here's a crude version of diagram 1.9 to illustrate.

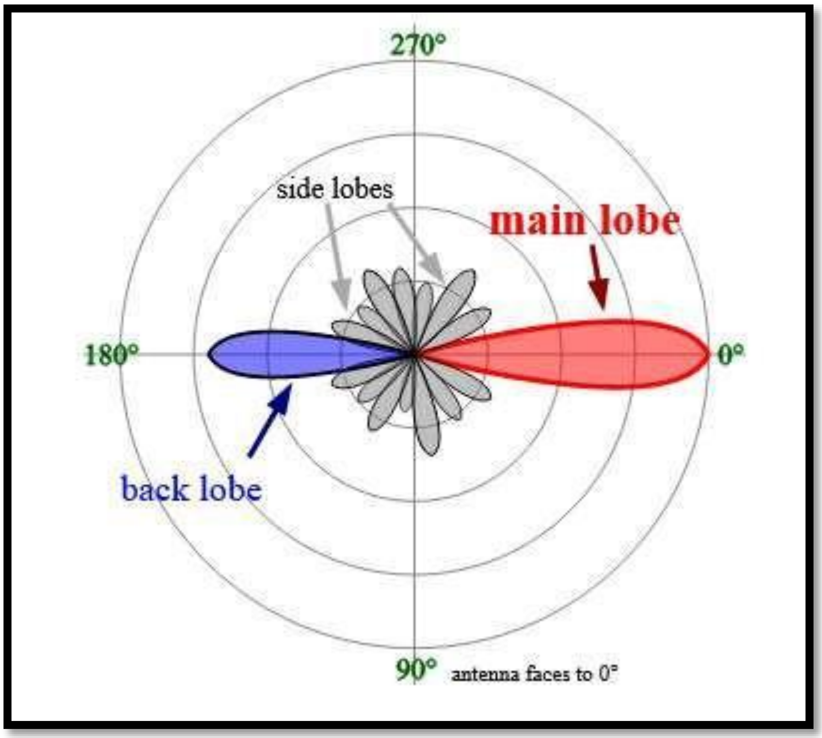

Fig 1.9: E – Field magnitude

Ref: https://rf5.github.io/2019/12/17/basic-antenna-parameters.html

Here we have a polar plot showing the size of the E-field in the E-plane for an antenna of modest complexity. A radiation lobe is the area of the radiation pattern or the magnitude of the E-field that is between two minima.

1.3.4 BEAM EFFICIENCY:

The ratio of the primary beam's area to the overall beam area radiated is what is meant by "beam efficiency," as defined by convention.The antenna's directivity determines the direction in which the emitted energy will go. An antenna's efficiency is highest in the direction in which it radiates the most power; energy is dissipated in the form of side lobes in other directions.

Beam efficiency is the ratio of radiated energy to losses, or how much power is really transmitted in the beam.

Expression Mathematical:

Effectiveness of a beam may be expressed mathematically as

$$\eta_B = \frac{\Omega_{MB}}{\Omega_A}$$

Where,

ηB = is the beam efficiency.

ΩMB = is beam area of the main beam.

ΩA = is total solid beam angle (beam area).

1.3.4 Directivity of antenna:

The degree to which an antenna's radiation pattern is focused in a certain direction is known as its directivity. Decibels (dB) are used to measure directional strength. More directivity indicates a more narrow and focused beam from the antenna.

If the beam's directivity is increased, its range will be expanded. An antenna with a directivity of 1 would be omnidirectional, radiating equally well in all directions (0 dB).

Antenna gain = Directivity of antenna × Antenna efficiency

Gain is the sum of efficiency and where your efforts are focused. The point at which antenna losses, such those caused by manufacturing flaws, surface coating losses, dielectric, resistance, VSWR, and so forth, are taken into consideration to calculate antenna efficiency.

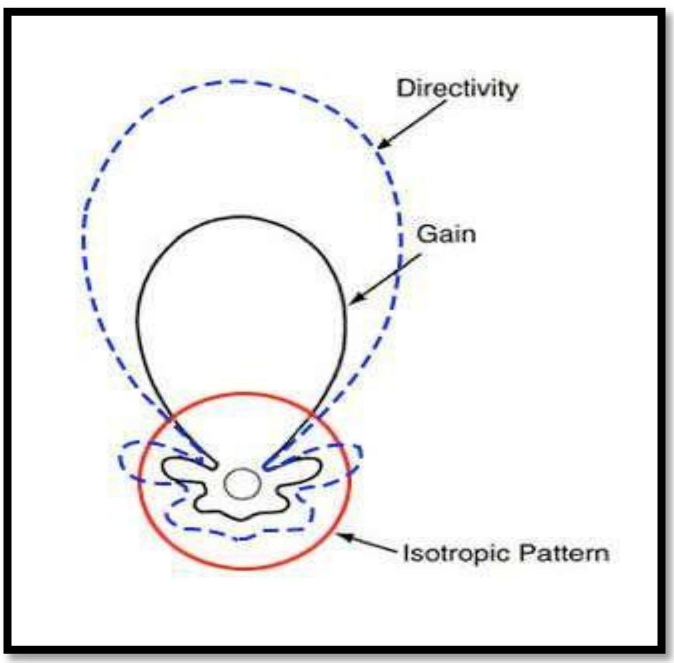

Fig 1.10: Directivity of Antenna

Ref: https://rf5.github.io/2019/12/17/basic-antenna-parameters.html

When it comes to antennas, excellent directivity isn't always preferable. For example, omnidirectional antennas are needed for numerous applications, including mobile devices.

Permanent installations, such as satellite TV, wireless backhaul, etc., need high-directivity antennas to send and receive data across greater distances and in a specific direction.

1.3.5 Gain:

Gain is a quantity which indicates the degree of directivity of the antenna's emission pattern. For this reason, a high-gain antenna will favour one direction over another while broadcasting. An antenna's gain also called its power gain, is defined as the ratio of the intensity (power per unit surface) emitted by the antenna in the direction of its highest output, at some distance in the air, to the intensity radiated at the same distance by a hypothetical isotropic antenna.

$$\textbf{GAIN} = \frac{\text{Intensity radiated by the antenna in the direction of MA. out at an orbitrary distance}}{\text{Intensity radiated at the same distance by a hypothetical isotropic antenna}}$$

As we said previously, specific antennas are pretty directional. The energy they emit is more concentrated in specific directions than others. The ratio of the power sent in these directions to the energy transmitted if the antenna were oriented otherwise.

Antenna GAIN was not directional. One consistent characteristic of an antenna is its gain. What function (transmitting or receiving) the antenna is being put to. The intensity of radiation and how it varies is described by its directivity function. The intensity profile is characterised by the directivity function D (θ, ϕ).

Definition of the directivity function,

$$\mathbf{D\ (\theta, \phi)} = \frac{\text{ower radiated per unit solid angle}}{\text{Average power radiated per unit solid angle}}$$

The term "directivity" refers to the most significant value of the "directivity function." The concept of directivity function is defined as the total radiated power.

An antenna's gain is defined similarly, except that it uses the input power to the antenna as a reference rather than the output power. As a result, the antenna does not completely radiate the supplied power.

$$P_r = \eta \, P_{in}.$$

Where, η is the radiation efficiency of the antenna.

The gain of the antenna is defined as,

$$\mathbf{G\ (\theta, \phi) = 4\pi} \frac{\text{ower radiated per unit solid angle}}{\text{Input power}}$$

The maximum gain function is termed as gain of the antenna,

$$\mathbf{G\ (\theta, \phi) = \eta\ D\ (\theta, \phi)}$$

Another metric that considers the gain is the adequate isotropic radiated power (EIRP), calculated by multiplying the input power by the highest growth.There is no discernible difference in performance between an antenna with a gain of 100 and 1 W of input power and one with a payment of 50 and 2 W of input power.

1.3.6 Antenna Apertures:

The term "antenna aperture" refers to the region surrounding an antenna from which it draws its power. An antenna's effective aperture, or "capture area," is a circular patch of space immediately around the antenna. The available voltage and the strength of the electromagnetic field around the antenna are two of the main parameters.A single-directional signal's intensity determines how large an antenna's aperture may be. Gain increases with bigger apertures and decreases with smaller ones.There are a few approaches to quantifying antenna aperture efficiency, one of which is by comparing the apertures of different antennas. An expert may quantify an antenna's aperture by measuring its gain and power in watts and then using mathematical formulas to describe those values.

The apertures of more giant antennas are often larger than those of their smaller counterparts. However, an antenna's size and effective aperture are not always proportional to one another. Small antennas with aperture sizes comparable to physically larger systems are now possible because of advances in antenna shape, antenna type, polarisation, power, and other design features.

When picking up an antenna, the aperture size is simply one factor. In addition to frequency, bandwidth, impedance, and beam width are all important. The aperture is crucial even with very tiny radio antennas like the aperture-linked micro strip antenna.It has the flexibility to be either square or round, and its multi-layered design incorporates parts for constructing the antenna aperture. Aperture calculations for tiny antennas may be done in advance using computer-aided design tools.

Smaller antennas, like those used in mobile phones, GPS devices, and wireless networks, allow the aperture to be adjusted. It's also used as a factor in determining the adequate strength of a signal. This may be calculated by multiplying the wattage by the antenna's effective area facing the incoming electromagnetic wave.

In general, waves that travel in the opposite direction as the transmitted power are essential to maintaining the antenna's aperture. The aperture size of an antenna tells its users how effectively it can pick up signals, how much space it has around it to absorb them, and whether or not it is suited for a specific task.

EFFECTIVE APERTURE:

The term "aperture" refers to an antenna's opening through which energy is transmitted or received. The easiest way to teach the idea of apertures is to think about a receiving antenna. Fig. 1.11 shows a rectangular Horn used as a receiving antenna in a uniform plane wave environment.

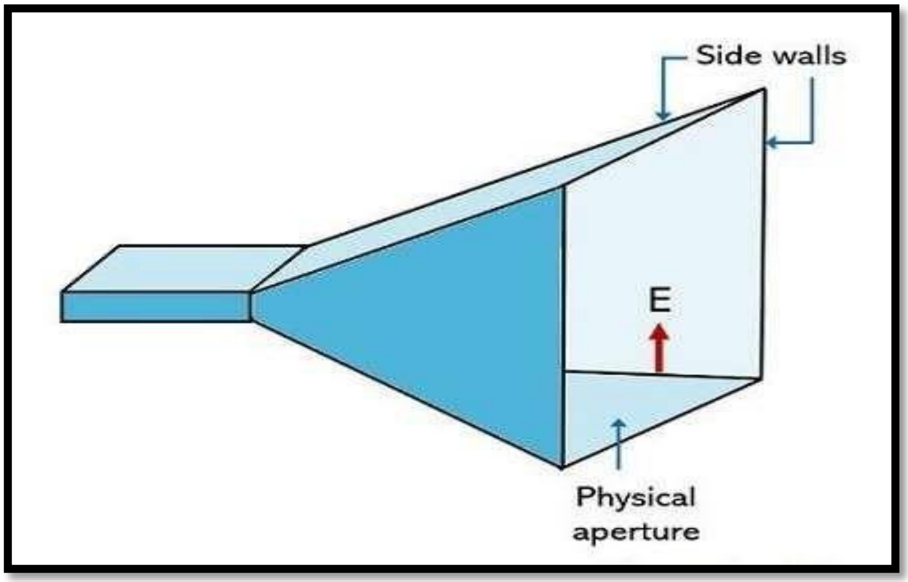

Fig 1.11: Aperture of an Antenna

Ref: https://electronicsdesk.com/wp-content/uploads/2020/07/horn-antenna-aperture.jpg

Let us assume that the plane wave's pointing vector, or power density, is S watts/sq. m, its area, or physical aperture, is Ap sq. m. The horn must capture all of the wave's energy over its whole physical aperture Ap.

The source of the absorbed power is

$$\mathbf{P = S}\ A_p = \mathbf{(}E^2\mathbf{/Z)}\ A_p\mathbf{Watts}$$

Where,

S is pointing impedance of medium,

Z is intrinsic impedance of medium,

E is rms value of electric field.

However, due to the requirement that E at the side walls is equal to zero, the field response of the horn is not constant throughout A_p.

The horn's $A_p$is more significant than its effective Aperture A_e

Aperture efficiency is defined as ϵ ap = $\frac{A_p}{A_e}$

The effective antenna aperture is the ratio between the power available at the antenna's terminals and the power flux density of a plane wave incident upon the polarisation-matched antenna. The direction of the most significant radiation is assumed if no movement is given.

The ratio of received power to incoming power density characterizes an antenna's "effective aperture," or "A_e." Aperture effectiveness is measured as the average power density generated at a single spot divided by the power received in the load.

$$A_e = \frac{P\ recieved}{P\ average}$$

P_R May be thought of as the antenna's received power.

The maximum effective aperture, represented by A_{em} is achieved when the received power is maximised, since this is the most usable region from which energy may be extracted by the antenna. So, let's figure out how much of an aperture a Hertzian dipole has to have in order to convert incoming waves into usable voltage at the load.

The antenna's induced voltage is calculated as

Voc = E dL

Where, |E| is the magnitude of Electric Field Intensity produced at the receiving. Point and dL is the length of the Hertzian dipole.

The maximum effective aperture is given by

$$A_{em} = \frac{Max.Power\ recieved}{Average\ Power\ Density}$$

$$A_{em} = dL^2 \eta_0 / 4 R_{rad}$$

Maximum directivity may be used to determine the equivalent aperture of a lossless antenna as

$$A_{em} = (\lambda^2/4\pi) D_o$$

1.4 DIFFERENT TYPES OF ANTENNA APERTURES:-

There are three main categories for these antennas: slot antennas, horn antennas, and microstrip slot antennas.

1.4.1 Waveguide Antenna:

Once one end of a waveguide antenna is energised and opened, the antenna may be used to radiate energy. The waveguide emits more radiation inside than a simple two-wire transmission line. Since the working frequency of a waveguide antenna is between 300MHz and 300GHz, it may be used for both ultrahigh- and extremely-high-frequency (UHF and EHF) signals.

Fig 1.12: Waveguide Antenna

Ref: https://www.elprocus.com/aperture-antenna/

This waveguide with a through termination acts as an antenna, albeit with minimal efficiency (only a tiny fraction of the energy is radiated, while the rest is reflected inside the open circuit). As a result of diffraction in the waveguide's vicinity, the emitted radiation is weak and has no particular directionality.

1.4.2 SLOT ANTENNA:

Simply cutting a slit outside the surface, they are attached to create a slot Antenna. These antennas typically operate between 300 MHz and 24 GHz. They are instrumental in navigation radar as an array supplied via a waveguide.

Fig 1.13: Slot Antenna

Ref: https://www.elprocus.com/aperture-antenna/

According to Babinet's optics concept, which this antenna uses to function, a slot antenna appears when a conducting plane of a certain size and form is perforated at a specific location. The fields produced by a slot antenna are similar to those produced by a dipole antenna, with the components of areas switched around. The polarization of a slot antenna is linear. Both radar navigation and arrays fed by a waveguide employ slot antennas.

1.4.3 MICROSTRIP SLOT ANTENNA:

This kind of antenna is also known as a practical slot antenna due to its straightforward design. A micro strip feed is used primarily to transmit electromagnetic waves from the slot above.

This antenna allows for improved separation between the feed and the tested material.

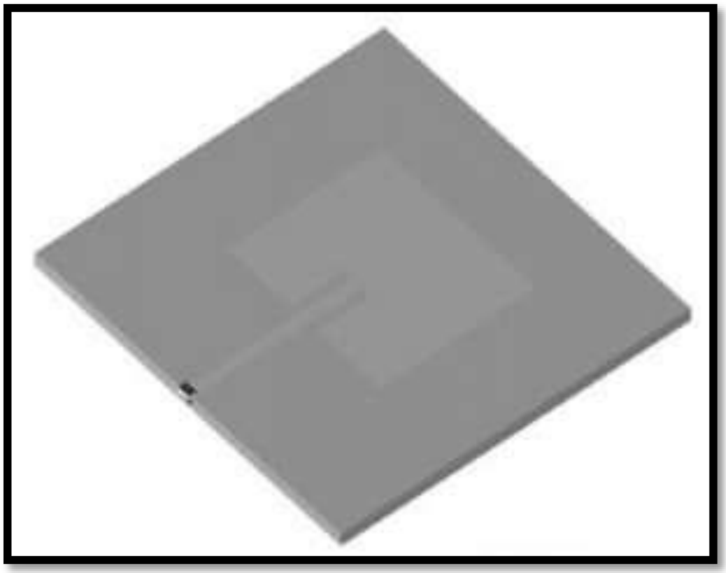

Fig1.14: Micro strip Slot Antenna

Ref: https://www.elprocus.com/wp-content/uploads/Microstrip-Slot-Antenna-300x234.jpg

This low-profile antenna has several advantages over similar antennas, including cheap cost, low weight, and ease of usage with the associated electronics. The 2.45 GHz resonance frequency, 0.47 wavelength, and 2.35 2.55 GHz bandwidth of these antennas is impressive.Because of their cheap manufacturing cost and simple form, these antennas find widespread usage in spacecraft, satellite communication, mobile communication, aviation, and missile applications.

1.4.4 HORN ANTENNA:

For radio waves to be focused into a narrow beam, horn antennas typically use a metal waveguide shaped like a flaring horn. At frequencies greater than 300 MHz, these antennas are used in the microwave and UHF bands.

These antennas provide a high gain of 10–20dB, and even 25dB, with a directed emission pattern. This antenna has a large input impedance bandwidth. Therefore, its impedance will shift gradually throughout an extensive frequency range.

Fig 1.15: Horn Antenna

Ref: https://www.elprocus.com/wp-content/uploads/Horn-Antenna-300x188.jpg

The gain of a horn antenna grows as its operating frequency rises. The physical size of these antennas is constant and thus experiences less loss. As a result, the directivity and the gain are almost identical. These antennas have been used in outer space. These antennas' large bandwidth, absence of resonant parts, and operation across a wide frequency range are just a few advantages. If you want to learn more about Horn Antenna, go here.

1.4.5 RADIATION PATTERN OF APERTURE ANTENNA:

Poor radiation efficiency and a lack of pattern discrimination characterise waveguide-type aperture antennas.

This is portrayed as a non-directive radiation pattern because the radiation comes from it in all directions but does not have a specific order. This radiation pattern diagram shows an omnidirectional or non-directional design from above.

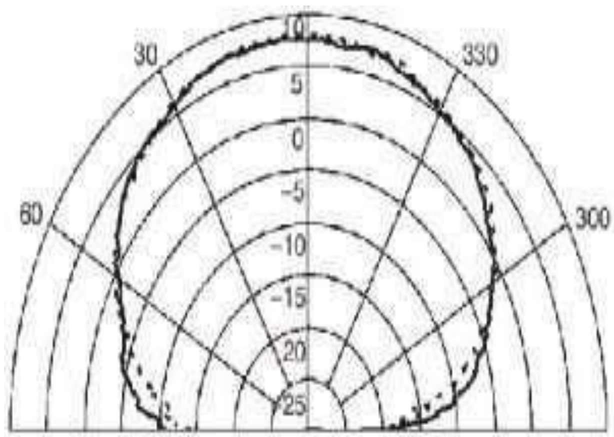

Fig1.16: Radiation pattern.

Ref: https://www.elprocus.com/wp-content/uploads/Radiation-Pattern-of-Aperture-Antenna-300x154.jpg

ADVANTAGES:

The following are some of the benefits of using an aperture antenna. More excellent irradiation compared to the conventional two-wire transmission line.

- Omni-directional radiation.
- Simple construction.
- Better performance.

DISADVANTAGES:

The following are some of the aperture antenna's many drawbacks.

- Poor radiation.
- VSWR increases.

APPLICATION OF AN APERTURE ANTENNA:

The following are examples of when aperture antennas have been helpful. Because of the unique geometric configurations that they are created around, they find the most widespread usage in space-based applications.

HERE ARE A FEW ADDITIONAL EXAMPLES OF APPLICATIONS:

- Microwave-based applications.
- Surface search radar applications.

All the information you need to know about aperture antennas, including how they function and what kinds there are, can be found here. These antennas provide a port for the transmission or reception of electromagnetic signals.Waveguides, horns, lenses, slots, and reflectors are all excellent examples of this kind of antenna. These antennas find their primary usage in aerospace and aviation.

1.5 EFFECTIVE HEIGHT:

An antenna's effective height is its length multiplied by the electric field in which it is submerged to calculate its output potential. One kind operates open circuit while the other operates into a matching load.

$$E\, h_e = V$$

For a tuned half-wave dipole, the open circuit effective height is:

$$h_e = \lambda/\pi$$

For a tuned half-wave dipole, the matched load effective height is:

$$h_e = \lambda/2\pi$$

Effective height is derivable from effective area:

$$A_e = G\lambda\hat{}2/4\pi$$

1.6 POLARIZATION:

The polarization of an antenna is loosely defined as the direction of the electromagnetic fields produced by the antenna as energy radiates away from it. These directional fields determine the order in which the point moves away from or is received by an antenna.

Polarization begins with the basics of EM waves. These waves consist of an electric field (E-field) and a magnetic field (H-field) travelling in a single direction. The E-field and H-field are perpendicular to each other and the direction along which the plane wave is propagating.

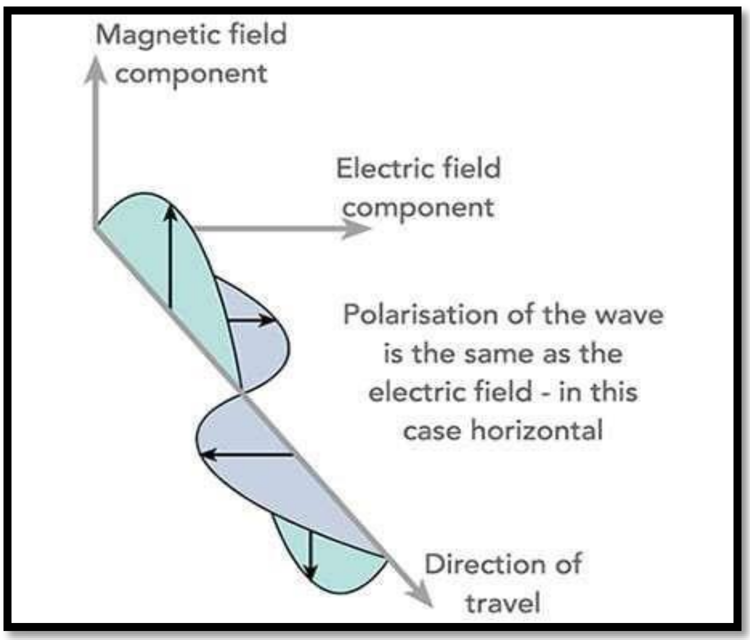

Fig1.17: Polarization

Ref: https://www.digikey.com/en/blog/antenna-polarization-what-it-is-and-why-it-matters

Polarization refers to the plane of the E-field from the perspective of looking at it from the transmitter of the signal: for horizontal polarization, the electric field will move sideways in a horizontal plane, while for vertical polarization, the electric field will oscillate up and down in a vertical plane.

Transmission and reception are optimised when the polarisation of both the sender and receiver antennas is aligned. Sure, "in space, no one can hear you scream," and vice versa. It's also true that there is no such thing as up or down in space.However, polarisation and antenna alignment remain essential factors in maximising signal energy transmission and collection.

1.6.1 THE LINEAR AND CIRCULAR DIRECTIONS

MULTIPLE POLARISATION STATES EXIST:

The two potential polarizations in standard linear polarisation are perpendicular to one another (Figure 1.18). Even if two antennas use the same frequency, one with horizontal polarisation won't "see" the signal coming from the other, and vice versa. When the polarizations are in phase with one another, maximum energy transfer occurs, allowing for full signal capture.Antennas may also be polarised in a non-linear fashion, known as slant polarization. It only makes sense on Earth, like fundamental horizontal and vertical polarization. When measured from a horizontal plane, 45 degrees is the angle of slant polarization. Linear polarisation encompasses this as well, although it often only describes horizontally or vertically polarised antennas.

Even with some attenuation, a signal broadcast (or received) by an angled antenna may be used with a vertically or horizontally polarised antenna. When the polarization of one or both antennas is unknown or is subject to change, a slant-polarized antenna may be a practical solution.

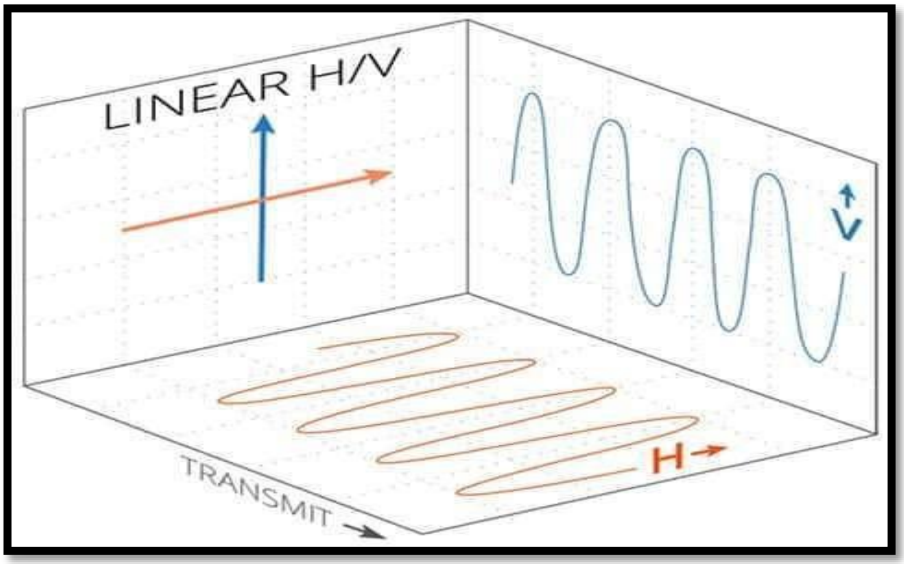

Fig 1.18: Linear polarization offers a choice of two polarizations at right angles to each other.

Ref: https://www.digikey.com/en/blog/antenna-polarization-what-it-is-and-why-it-matters

1.6.2 CIRCULAR POLARIZATION

More moving parts are involved in circular polarisation (CP) than linear polarisation. In this setting, the E-field vector's polarisation rotates as the signal travels.

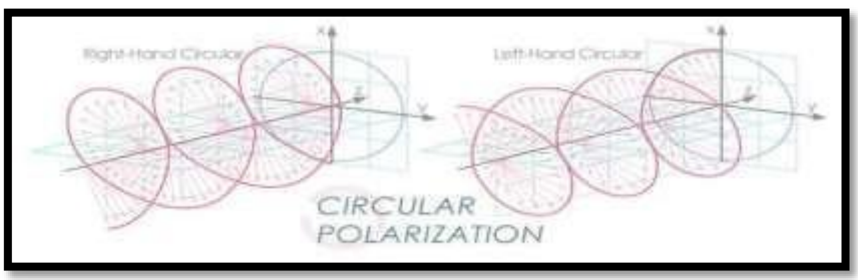

Fig 1.19: Circular polarization

Ref: https://www.digikey.com/en/blog/antenna-polarization-what-it-is-and-why-it-matters

Right-hand circular polarisation (RHCP) refers to polarization that rotates to the right as seen from the transmitter; left-hand circular polarisation (LHCP) refers to a polarization that spins to the left (Figure 1.19).Two out-of-phase orthogonal waves make up a CP signal. There are three prerequisites for its emergence. Two orthogonal components, 90 degrees out of phase and identical amplitude, are required for the E-field. Using a helical antenna to generate CP is a straightforward option.

1.6.3 ELLIPTICAL POLARIZATION:

CP has a variant called elliptical polarisation (EP). If you take two linearly polarised waves, such as CP waves, and then multiply them together, you get an elliptically polarised wave. The elliptically polarised wave results from the superposition of two linearly polarised waves of unequal amplitude perpendicular to one another. The polarization loss factor describes the degree to which antennas' polarizations are out of phase with one another (PLF). The parameter measured in decibels (dB) depends on the polarisation angle difference between the sender and receiver antennas.Depending on the orientation of the antennas, PLF may be anywhere from 0 dB (no loss) in the case of perfectly aligned antennas to 0 dB (infinite loss) in the case of entirely orthogonal antennas.

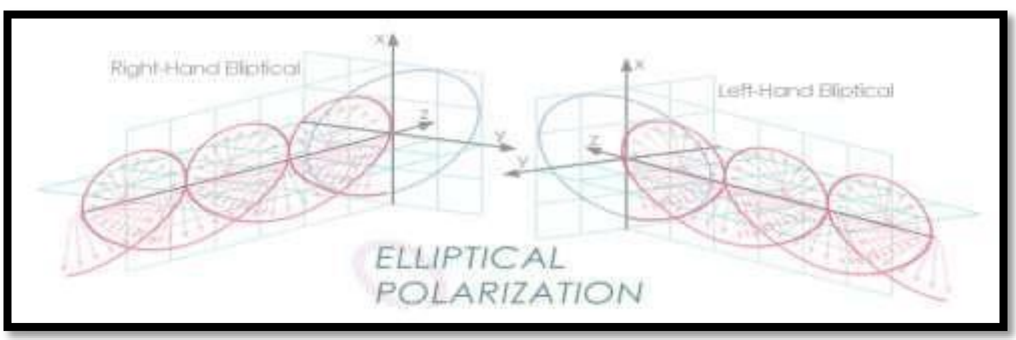

Fig: 1.20: Elliptical polarization

Ref: https://jemengineering.com/blog-intro-to-antenna-polarization/

However, in reality, the polarisation alignment (or misalignment) is not perfect due to factors like the mechanical location of the antenna, user activities, channel distortion, multipath reflections, and other events that create some angular twisting of the broadcast EM field.The initial "leakage" of 10-30 dB between orthogonal polarizations may be enough to prevent the target signal from being recovered. On the flip side, even if two antennas are perfectly aligned and polarised, the presence of a PLF of 10-20 dB or more might make it difficult to recover the original signal.

Thus, both PLF and accidental cross-polarization might weaken or perhaps wholly cancel out the signal of interest.

1.7 ANTENNA IMPEDANCE:

It is the voltage or current ratio across an antenna system terminal that defines its impedance and is connected to the electric and magnetic fields. An important characteristic of every antenna system is its impedance.

Antennas are often fed using transmission lines. The impedance of the location where the transmission line will be attached must also be known. An antenna may perform two distinct functions: sending and receiving signals.

However, knowing the impedance is essential for transmitting the greatest possible power or receiving the sent power.

1.7.1 THE IMPEDANCE OF THE ANTENNA:

The Antenna integrates the electric and magnetic fields to produce voltage and current control the electrical device. Therefore, the field-to-circuit transition concerning impedance must be appropriately evaluated to have the necessary field and circuit numbers.The impedance of an antenna depends on its operating frequency, feeding mechanism, geometrical orientation, and the impacts of nearby objects.

An antenna's impedance, measured in electric and magnetic fields, is the electric field's relative strength relative to the magnetic field at a set of discrete locations.

The antenna impedance may be determined using one of many approaches, including:

- Boundary value method,
- Poynting vector method and
- Transmission line method

However, impedance is often calculated using the boundary value approach. I am applying boundary conditions that stand in for the lack of the tangential electric field component at the conducting surface, yields the impedance in the boundary technique. This means that the impedance (the resistance to current flow) is directly proportional to the applied (emf).

In contrast, the Poynting vector approach integrates the power density across a closed surface (often, a sphere with a huge radius R, where R is higher than or equal to 2L2/, where L denotes the maximum dimension of the Antenna that is evaluated).

The biconical Antenna is the most amenable to the transmission line approach since it assumes the Antenna is a transmission line. Consequently, when the actual radiated power flow is computed using any of the techniques above, self and mutual impedances may be established by employing fundamental relations.

1.7.2 SELF-IMPEDANCE:

At the point where the Antenna will be linked to the transmission line, the impedance is crucial. Because the Antenna's input terminal is linked to the transmission line, the Antenna's input impedance describes the resistance the radio signal encounters.

Since the Antenna is fed at this location, the term "feed point impedance" is sometimes used. For the same reason that the transmission line containing the RF power that drives the Antenna is linked there, this is also known as the driving point impedance.

As we've previously established, whether the device is a transmitter or a receiver, the transmission line must be designed to provide as much power as possible from the transmitter to the Antenna or to collect as much energy as possible from the Antenna and deliver it to the receiver.

As a result, the terminal impedance is crucial. The impedance of the antenna in the two-terminal network concerning the transmission line is shown in the following figure:

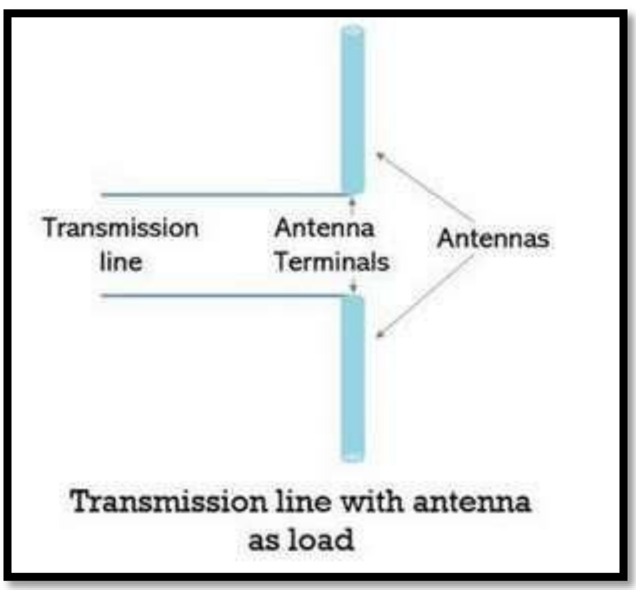

Fig 1.21: The impedance by the antenna to the transmission line using the two-terminal network.

Ref: https://electronicsdesk.com/wp-content/uploads/2020/09/transmission-line-with-antenna-as-load1-286x300.jpg

Here the entire system is replaced by equivalent impedance ZL as shown below:

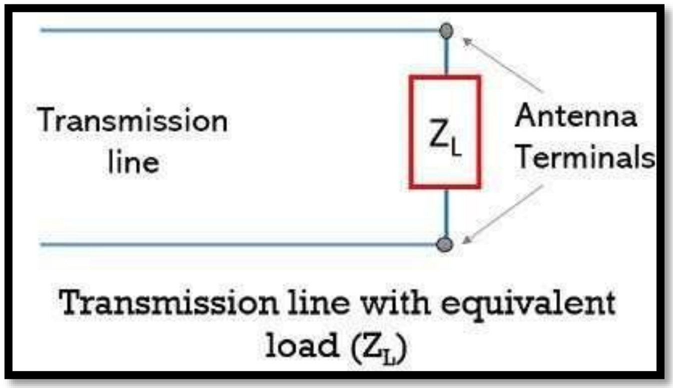

Fig 1.22: Transmission line with equivalent load

Ref: https://electronicsdesk.com/wp-content/uploads/2020/09/transmission-line-with-equivalent-load-300x167.jpg

Thus, the terminal impedance (ZL) will be equal to the antenna's self-impedance (Z11) if no heat loss is involved and it is located away from the ground and other objects.Self-impedance will be expressed as:

$$Z_{11} = R_{11} + jX_{11}$$

Self-impedance is a complicated number, with the fundamental component being radiation resistance or self-resistance and the imaginary member being self-reactance. The terminal impedance will change with the same setup depending on what is around. This is because a mutual inductance will be produced due to a current flowing through adjacent active parts.Since no external components are present, the antenna's input impedance is known as its self-impedance. To add to this, the antenna's self-impedance is always positive. The antenna's broadcast and receive capabilities are also equivalent.

MUTUAL IMPEDANCE:

When one circuit is open and the other is closed, the mutual impedance of the circuit is defined as the negative ratio of the voltage produced in the first circuit to the current flowing in the second circuit.

Let's have a look at the connected circuit configuration below:

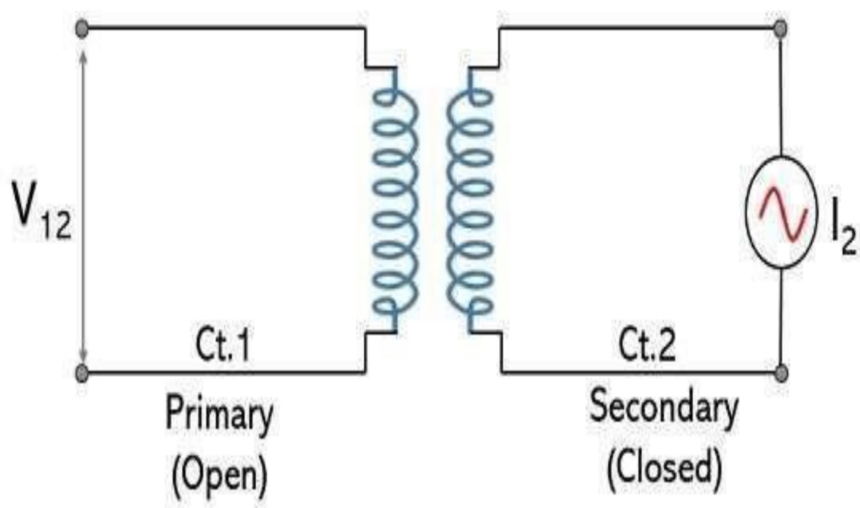

Fig1.23: Coupled circuit

Ref: https://electronicsdesk.com/antenna-impedance.html

The resulting mutual impedance may be expressed as:

$$Z_{12} = -\frac{V_{12}}{I_2}$$

Because of the current in closed-loop circuit 2, a voltage is induced in circuit 1 (primary, open) (secondary, closed).Now, consider the reverse condition as shown below:

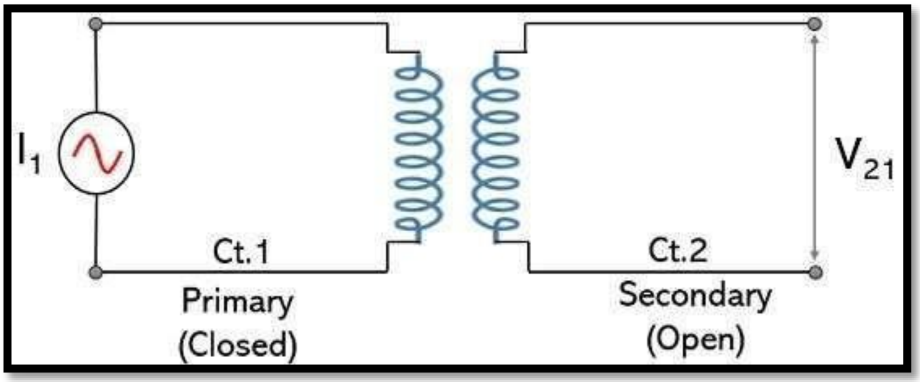

Fig 1.24: Reverse condition circuit

Ref: https://electronicsdesk.com/antenna-impedance.html

In this case, a voltage is induced in circuit 2 due to the current flow in circuit 1. For this purpose, circuit 1 will be the primary closed circuit, while circuit 2 will be the secondary open circuit.

In this case, the mutual impedance will be:

$$Z_{21} = -\frac{V_{21}}{I_1}$$

The reciprocity theorem states that the two mutual impedances are equivalent.

$$Z_{12} = -\frac{V_{12}}{I_2} = Z_{21} = -\frac{V_{21}}{I_1} = Z_m$$

$$Z_m = \frac{V_{12}}{I_2} = \frac{V_{21}}{I_1}$$

Zm may be computed using V12 and I2 or V21 and I1.

Therefore, several antennas may be connected to create an antenna array, like coupled circuits. In contrast, the input impedance of an antenna array is dependent not only on the self-impedance of a single antenna but also on the mutual impedance of the other antennas.

1.8 FRONT–TO-BACK RATIO:

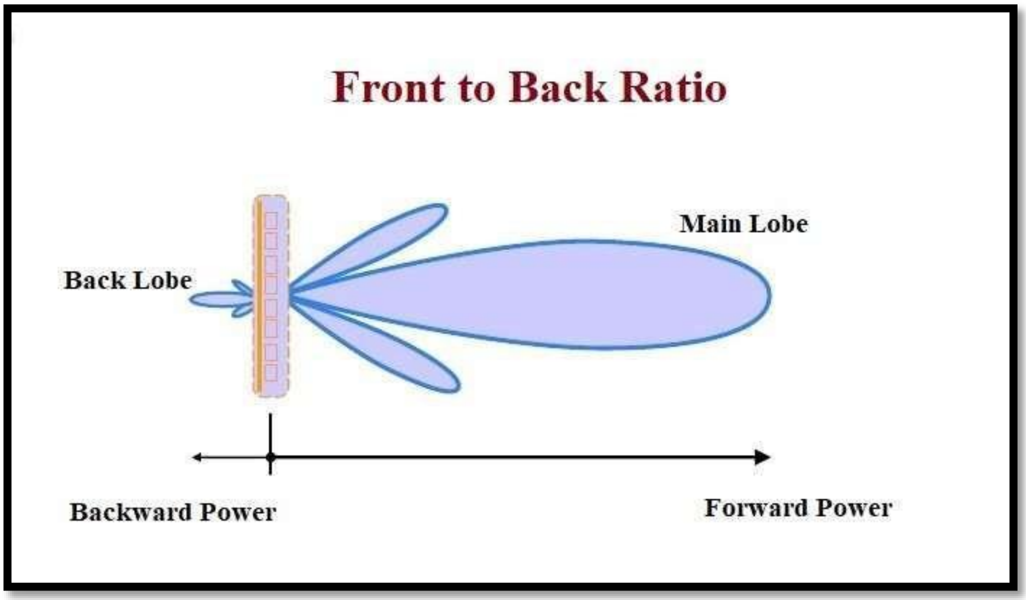

Fig 1.25: Front to back ratio

Ref: https://www.everythingrf.com/community/what-is-front-to-back-ratio-in-an-antenna

An antenna's F/B Ratio describes the proportion of its total radiated power directed toward the front or significant radiation lobe against that directed toward the back or secondary radiation lobe (180 degrees from the main beam).

$$\text{Front to Back ratio} = \frac{Fordward\ Power\ (F)}{Backward\ Power\ (B)}$$

This Ratio, often denoted in decibels (dB), provides information on the strength of backward radiation. In cases when backwards interference or coverage must be limited, this value is crucial.

1.9 ANTENNA THEOREMS:

It is possible to utilise the same antenna to send and receive signals. While doing so, we can wonder whether the antenna's characteristics change if we switch its mode of operation. Thankfully, it isn't anything we have to worry about. It is known as the property of reciprocity that antenna characteristic are fixed.

1.9.1 PROPERTIES UNDER RECIPROCITY:

To illustrate this phenomenon of reciprocity, consider the following characteristics of both the sending and receiving antennas:

- Equality of Directional patterns.
- Equality of Directivities.
- Equality of Effective lengths.
- Equality of Antenna impedances.

So, let's check out the results of the application.

EQUALITY OF DIRECTIONAL PATTERNS:

If antenna2 transmits and antenna1 receives, then the radiation pattern of antenna2 is identical to the radiation pattern of antenna1.

EQUALITY OF DIRECTIVITIES:

In the scenario when the value of directivity is the same for both the transmitting and receiving antennas, that is, when the directivities are computed from either the transmitting or receiving antenna's power, then the two instances are equivalent.

EQUALITY OF EFFECTIVE LENGTHS:

Both the transmitting and receiving antennas have the same maximum practical aperture value.With this method, the sending and receiving antennas' length remains constant regardless of the wavelength.

EQUALITY IN ANTENNA IMPEDANCES:

A successful transmission occurs when the antenna's output and input impedance is the same. Whether the same antenna is used as a transmitter or a receiver, it will retain these characteristics in either mode of operation. The principle of mutual benefit is therefore maintained.

1.10 DIPOLE ANTENNAS BASIC MAXWELL'S EQUATIONS:

MAXWELL'S EQUATIONS:

Maxwell's equations describe the behaviour of electromagnetic fields, which is a set of equations. The corresponding formulae may derive the electric and magnetic fields from their respective charge and current densities.

Differential form	Integral form
$\nabla \cdot \vec{D} = \rho$	$\oint_S \vec{D} \cdot d\vec{S} = \int_V \rho \, dV$
$\nabla \cdot \vec{B} = 0$	$\oint_S \vec{B} \cdot d\vec{S} = 0$
$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	$\oint_C \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \int_S \vec{B} \cdot d\vec{S}$
$\nabla \times \vec{H} = \vec{J} + \frac{\vec{D}}{\partial t}$	$\oint_C \vec{H} \cdot d\vec{l} = \int_S \vec{J} \cdot d\vec{S} + \frac{\partial}{\partial t} \int_S \vec{D} \cdot d\vec{S}$

The equations of Maxwell may be found in both differential and integral versions. When given in the integral form, Maxwell's equations are easier to grasp for their physical importance.

$$\oint_S \vec{D} \cdot d\vec{S} = \int_V \rho \, dV$$

The flux of the displacement electric field through a *closed surface* equals the total electric charge enclosed in the corresponding volume space.This is also called the Gauss law for electricity. Consider a point charge +q in a three-dimensional space. Assuming a symmetric field around the charge and at a distance r from the order, the surface area of the sphere is $4\pi r^2$.

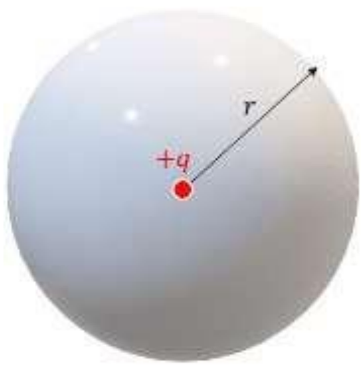

Fig 1.26: Illustration of Coulomb's law using Maxwell's equation

Ref: https://www.gaussianwaves.com/2021/09/from-maxwells-equations-to-antenna-array-part-1/

$$\oint_S \vec{B} \cdot d\vec{S} = 0$$

Put another way, the magnetic field's flow across an open area is zero. Put another way, the sum of the magnetic field that "flows into" and "flows out of" a closed surface is zero.

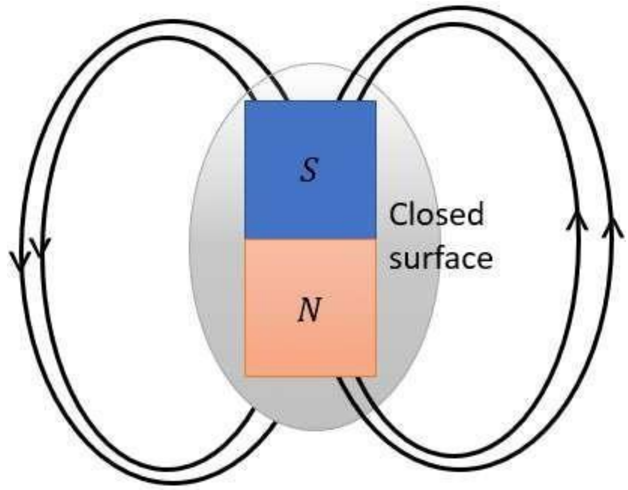

Fig 1.27: Gauss law for magnetic field

This means that the magnetic flux lines are neither generated nor consumed but exist as closed field lines that span indefinite distances. For magnetic fields, this is known as Gauss's law.

$$\oint_C \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t}\int_S \vec{B} \cdot d\vec{S}$$

Electromotive force is defined as the work done by a moving electric charge on a closed loop conductor (emf). So, the induced emf in a circuit may be found on the left side of the. Thus, Faraday's (and Len's) law of magnetic induction is the third equation of Maxwell's field.

$$\oint_C \vec{E} \cdot d\vec{l} = emf = -\frac{\partial}{\partial t}\int_S \vec{B} \cdot d\vec{S} = -\frac{\partial \Phi}{\partial t}$$

The rate of change of magnetic flux across a circuit is exactly proportional to the emf produced in the circuit.

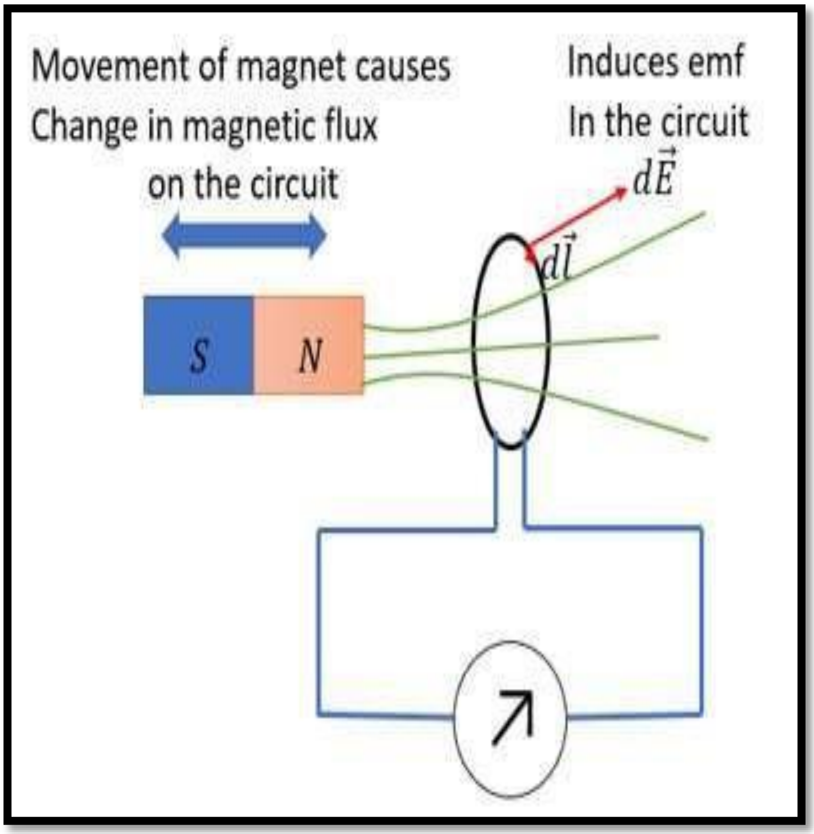

Fig 1.27: Faraday's law for magnetic induction

Ref: https://www.gaussianwaves.com/gaussianwaves/wp-content/uploads/2021/09/Faradays-law-for-magnetic-induction-emf-change-of-magnetic-flux.png

$$\int_S \vec{J} \cdot d\vec{S} + \frac{\partial}{\partial t}\int_S \vec{D} \cdot d\vec{S} = \oint_C \vec{H} \cdot d\vec{l}$$

As the name implies, a circulating magnetic field is one in which a magnetising area is constantly redirected along a closed circular channel. The quantity of electric current (denoted by the symbol "J") is the density of the current flowing through a surface that spans the curved route.The rate of change of displacement current across any surface along that curved route is what this number represents. Maxwell's generalisation of Ampere's rule states that there are two methods to create magnetic fields: with electric current or with varying electric flux. According to the equation, a circulating magnetic field is generated at the boundaries of a surface by an electric current or a change in electric flux across the surface.

1.11 RETARDED POTENTIAL-HELMHOLTZ THEOREM:

One of the first steps in learning about antenna radiation is to comprehend how radiation sources affect the movement of electromagnetic waves. The electric and magnetic potentials along the line of propagation provide the most accurate description of the behaviour of travelling waves.

$$\Phi(r) = \frac{1}{4\pi\epsilon} \int_V \frac{\rho(r')}{R} d^3r'$$
$$A(r) = \frac{\mu}{4\pi} \int_V \frac{J(r')}{R} d^3r'$$

Electric field E, charge density, current density J, electric potential, magnetic field B, and magnetic potential A are stable in the static condition. So, in the spherical coordinate system, they are functions of radial distance r, but not parts of time t. In a spherical coordinate system, the solution to Maxwell's equations has the following form in electric and magnetic potentials:

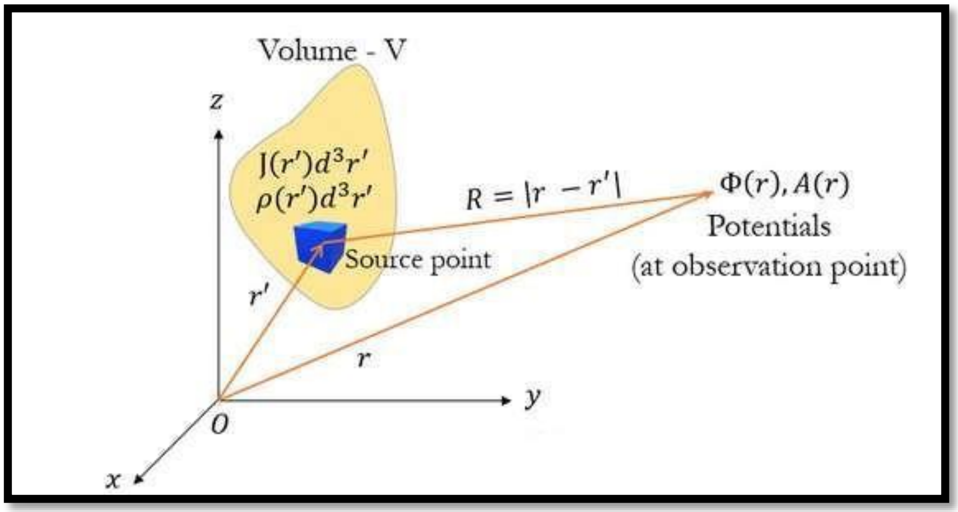

Fig 1.28: Potentials – solutions for Maxwell's equations for static case.

Ref: https://www.gaussianwaves.com/2021/10/retarded-potentials/

The symbol d3 r denotes the volume element at the point of origin', and the distance R between the source and the point at which the associated fields are seen is given by the symbol (r).

RETARDED POTENTIALS: THE NON-STATIC SITUATION:

Since time-varying electric charges generate electromagnetic radiation, we are interested in defining the potentials at a particular observation site for this non-static condition. Electric field E, charge density, current density J, electric potential Φ, magnetic field B, and magnetic potential A are non-static functions of radial position and time.

As for the potentials, the appropriate formulae are

$$\Phi(r,t) = \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r', t-\frac{R}{c})}{R} d^3r'$$

$$A(r,t) = \frac{\mu}{4\pi}\int_V \frac{J(r', t-\frac{R}{c})}{R} d^3r'$$

For a given source of electromagnetic radiation, the time elapsed between photon production and subsequent detection by an observer is provided by t = (R / c), where c is the speed of light. Because of the speed with which the electromagnetic field travels, potentials at the observation site (caused by the source's changing charge) are felt after a certain lag.

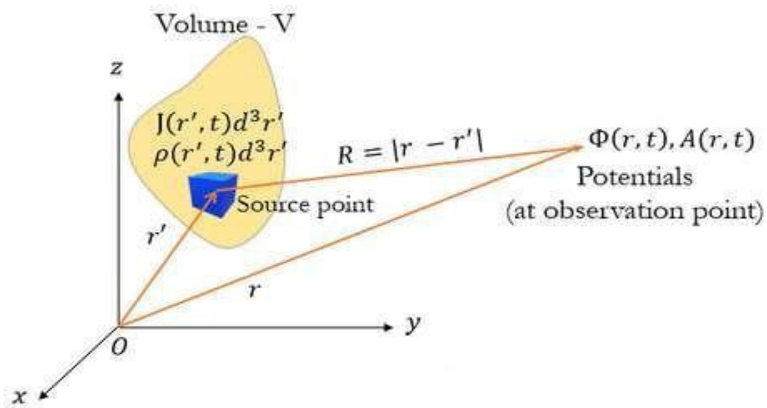

Fig1.29: Retarded potentials – solutions for Maxwell's equations for non-static case

Ref:https://www.gaussianwaves.com/gaussianwaves/wp-content/uploads/2021/10/retarded-potentials-for-non-static-case-solutions-for-Maxwells-equations.png

We refer to such potentials as retarded potentials and the delay in propagation as retarded time (t - R/c). As a result, we may state that the delayed potentials are associated with time-varying electromagnetic fields of a current or charge distribution.

SINUSOIDAL TIME DEPENDENCE OF RETARDED POTENTIALS:

The antenna elements (source) are fed sinusoidal waves in antenna theory. As a result, since all values at the source fluctuate sinusoidal in time, we can now describe the retarded potentials at the observation point.

For this reason, the shift feature of the Fourier transform may be used when the quantities are single-frequency sinusoidal waves.

$$
\begin{aligned}
\Phi(r,t) &= \Phi(r)e^{j\omega t} \\
\rho(r,t) &= \rho(r)e^{j\omega t} \\
A(r,t) &= A(r)e^{j\omega t} \\
J(r,t) &= J(r)e^{j\omega t}
\end{aligned}
$$

The potential (r,t) at the field observation site then becomes retarded as,

$$
\begin{aligned}
\Phi(r,t) &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r', t-\frac{R}{c})}{R} d^3r' \\
\Rightarrow \Phi(r)e^{j\omega t} &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r')e^{j\omega(t-\frac{R}{c})}}{R} d^3r' \\
\Rightarrow \Phi(r) &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r')e^{-j\omega\frac{R}{c}}}{R} d^3r' \\
\Rightarrow \Phi(r) &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r')e^{-j\frac{\omega}{c}R}}{R} d^3r' \\
\Rightarrow \Phi(r) &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r')e^{-jkR}}{R} d^3r'
\end{aligned}
$$

In a similar vein, we may calculate the retarded potential A(r,t). Given this, we can write out the equation for the retarded potentials of a sinusoidal wave of a single frequency:

$$
\boxed{
\begin{aligned}
\Phi(r) &= \frac{1}{4\pi\epsilon}\int_V \frac{\rho(r')e^{-jkR}}{R} d^3r' \\
A(r) &= \frac{\mu}{4\pi}\int_V \frac{J(r')e^{-jkR}}{R} d^3r'
\end{aligned}
}
$$

k = /c = 2 / is the free-space wavenumber in these equations.

1.12 RADIATION FROM SMALL ELECTRIC DIPOLE:

An easy-to-make antenna is a short dipole. It has an open circuit at one end and is powered by an alternating current source. This dipole acquired its name because of its length.The short dipole may function between around 3 KHz and 30 MHz in frequency. Most low-frequency receivers take advantage of this. As the dipoles are so short, the current in the wire is dI. This wire is often utilised between two capacitor plates when the minimal mutual coupling is required. The capacitor plates provide for consistent distribution of current. Thus, the current is not zero.For the capacitor plates, a simple conductor or wire stand-in will do. Since the distant fields of the capacitor plate antenna are approximately those of an infinitesimal dipole, the fields emitted by the radial currents tend to cancel each other out.

THE PATTERN OF RADIATION:

Half-wave dipoles are comparable to short dipoles and infinitesimal dipoles in their radiation patterns. If the dipole is vertical, the pattern will be round. The Radiation's two-dimensional distribution may be a "figure of eight" structure. The following diagram depicts the omnidirectional radiation pattern of a short dipole antenna.

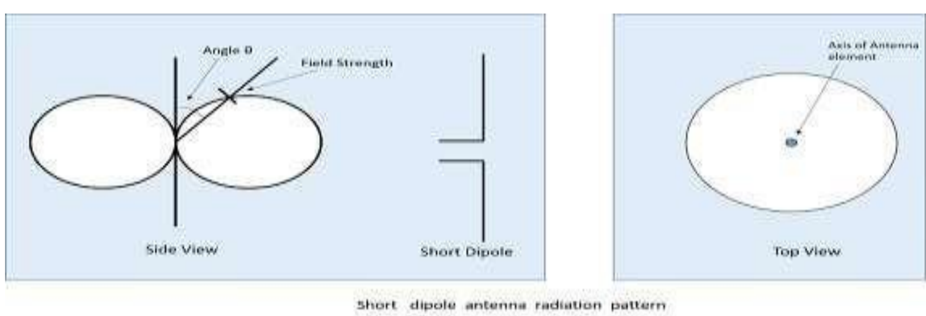

Fig 1.30: The radiation pattern of a short dipole antenna

Ref:https://www.tutorialspoint.com/antenna_theory/images/omni_directional_pattern.jpg

1.13 CURRENT DISTRIBUTIONS:

The total antenna current distribution curve is used in various computations, including impedance, resistance, radiation resistance, reactance, radiation pattern, and so on. After years of utilising the Pocklington current distribution formula as a foundation, the resulting antenna calculations are often so complex that only the most talented and committed mathematicians can make sense of them.While researching some elementary formulae for estimating the radiation resistance of a simple antenna, I noticed that the current distribution curves shown in every antenna book I had on hand were very similar to the curves presented for transmission line current into a mismatch.

Having looked at the transmission line curves and come to a result that does not match what is written in the books, it made sense to do the same thing with the current distribution in antennas.

RESONANT ANTENNAS:

An open-ended wire's current will flow, as shown in Fig.3.21 (a). At its open end, it is at zero, and at half-wavelength distances from the end, it goes through a series of minima. Except for a small region just around the minimum, when the phase shift occurs almost entirely, the current in the loops on each side of a current minimum is almost precisely 180° out of phase. The arrows represent the direction of current flow

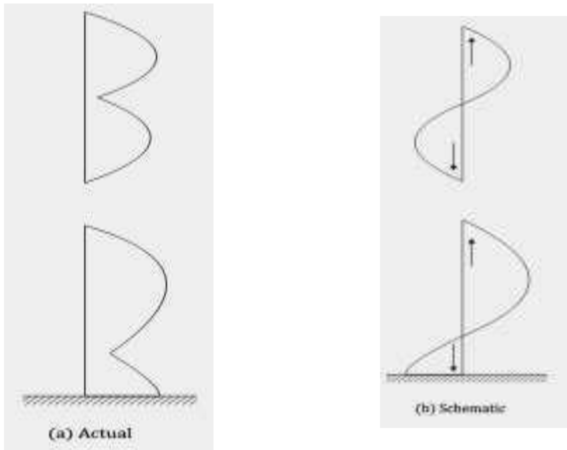

Fig1.31: Actual and schematic current distribution in resonant antennas.

Ref: https://chemandy.com/technical-articles/antenna/current/antenna-current-distribution-article1.htm

Because the current minimums are so tiny in comparison to the current maximums, the current distribution is often shown as in Fig 1.31(b), where the current at the minima is considered to be zero rather than just small, and the currents in neighbouring loops are regarded as 180° out of phase.

$$\text{current} = I_o \sin\left(\frac{2\pi x}{\lambda}\right) \sin \omega t$$

Where I_o = current at current maximum

X/λ = distance in wavelengths from the open end

$\omega = 2\pi$ x frequency

t = time

If the antenna performed precisely like a transmission line with no losses, the current distribution shown by the Equation would be the result. An antenna will permanently lose some power in the form of radiation. Hence it's impossible to achieve this condition precisely in reality.

1.14 FIELD COMPONENTS:

The near field and far field areas of the antenna are an essential issue to examine after the antenna characteristics mentioned in the preceding chapter. Close to the antenna, the radiation strength is different from what it is at a greater distance. This location is effective even though it is far from the antenna because the radiation intensity is still strong there.

NEAR FIELD:

Near-field refers to the region of electromagnetic space closest to the antenna. Despite having elements of radiation, its inductive action gives rise to an alternative name for the field: inductive field.

FAR FIELD:

The term "far-field" is used to describe the area of electromagnetic radiation that extends beyond the immediate vicinity of the antenna. High levels of radiation have an impact on this region, hence it is sometimes referred to by that name. This is the sole area where the antenna's directivity, radiation pattern, and other factors are taken into account.

FIELD STRUCTURE:

Field pattern refers to the quantitative description of the field distribution in terms of field intensity. Electric field, E (v/m), is the unit of measure for the radiated power from the antenna. This is why we refer to it as a field pattern. Patterns that can be measured in terms of power (W) are referred to as power patterns.

Radiated field or power will be shown graphically as a function of

- Spatial angles (θ, Ø) for far-field.
- Spatial angles (θ, Ø) and radial distance(r) for near-field.

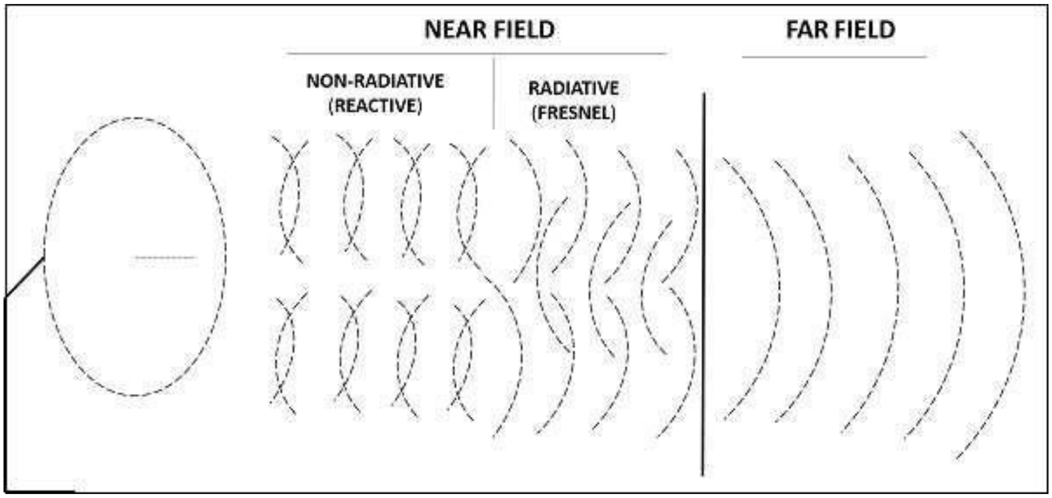

Fig1.32: The distribution of near and far field regions

Ref:https://www.tutorialspoint.com/antenna_theory/antenna_theory_near_and_far_fields.htm

THE FIELD PATTERN CAN BE CLASSIFIED AS FOLLOWS:

- There is both a reactive near-field zone and radiates near-field region.
- Far-field refers to the area far away from the source of the radiation.

It is a near-reactive or non-radiates field since radiation does not dominate in this region close to the antenna. Since the radiation is most prominent in this proximity and the angular field distribution is distance-dependent, this area is known as the radiating near field or Fresnel's field. Its far-field area is adjacent. At these distances from the antenna, the field distribution does not change. This area exhibits the typical distribution of the radiation's effective pattern.

1.15 RADIATED POWER:

In radio frequency (RF) engineering, the total power emitted by an antenna to which a transmitter is attached is known as the Total Radiated Power (TRP). Antenna efficiency is intrinsically linked to the concept of Total Radiated Power. Pout, or Output Power, is shown in Figure 1.33 below.

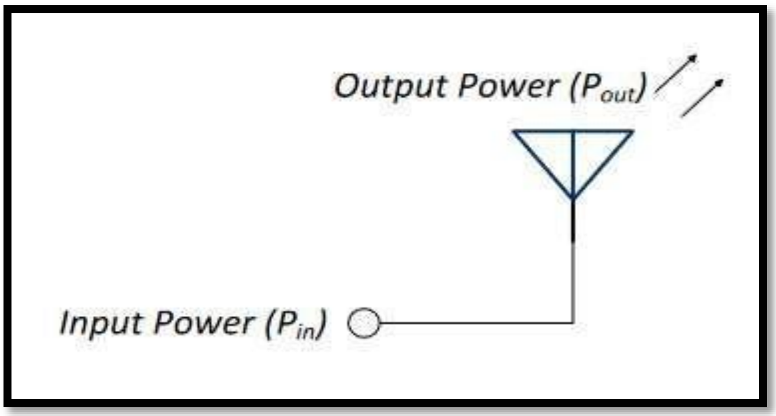

Fig 1.33: Input/output Definition.

Ref: https://www.taoglas.com/wp-content/uploads/pdf/Total-Radiated-Power-ED-16-004.A.pdf

Efficiency of an antenna is defined as the ratio of its output power to its input power. Watts (W), mill watts (mW), and the logarithms of W and mW are all valid units for expressing TRP (dBW and dBm). The effectiveness of an antenna may be measured in percentage or decibels (dB). CTIA Certification, a subset of CTIA—The Wireless Association, has thoroughly documented and standardised this measurement for cellular/mobile and WLAN transmitters. In the document Over-the-Air Certification Test Plan: Method of Measurement for Radiated RF Power and Receiver Performance, all of the nitty-gritty details of the measurement are laid out, including the necessary derivations and uncertainty estimates.

$$\eta_{antenna} = \frac{P_{out}}{P_{in}} = \frac{TRP}{P_{in}}$$

The Total Radiated Power of an antenna is determined in a special test facility called an anechoic chamber. An antenna receives power from the transmitter, which is energised in some way. When the antenna is activated, the energy is released into the environment.

The power is measured at a series of distinct spots that are spaced out in all directions from the antenna by the measuring device. Typically, this entails taking readings at regular intervals of between 5 and 30 degrees in both the vertical and horizontal axes. It is also common practise to measure power in both the vertical and horizontal planes.

TRP is totally dependent on two factors, input power and antenna efficiency, as was mentioned previously. The power output of a cellular device's transmitter (often a cellular module) is consistent, measurable, and well-controlled. Because of this, the engineer tasked with merging a cellular module and an antenna must rely on the antenna's efficiency to achieve a satisfying TRP.

1.16 RADIATION RESISTANCE:

When it comes to power transmission, the radiation resistance of a receiving antenna stands in for the resistance of the antenna itself as a (Thevenin equivalent) power source. An antenna's radiation resistance while receiving radio waves is the same as when emitting waves, according to electromagnetic reciprocity.

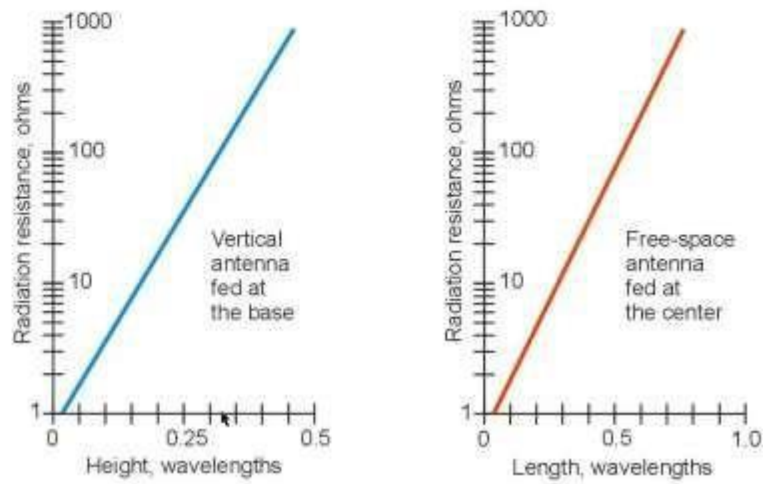

Fig 1.34: Radiation resistance of height, length wavelength.

Ref: https://i.ytimg.com/vi/p-tRk2e6rgM/maxresdefault.jpg

1.17 BEAM WIDTH:

Beam width is a crucial characteristic of an antenna's radiation pattern. The main lobe of an antenna is the primary radiation beam via which the antenna emits the most and most stable amount of energy.The aperture angle at which the majority of the power is emitted is known as the beam width. Half Power Beam Width (HPBW) and First Null Beam Width (FNBW) are two primary parameters to think about while determining the optimal beam width (FNBW).

HALF-POWER BEAM WIDTH:

The half power beam width is the "angular separation, in which the amplitude of the radiation pattern reduces by 50% (or -3dB) from the peak of the main beam," as defined by the standard. In other words, Beam width is the region across which the maximum amount of power is emitted.The half power beam width of an antenna is the angle where the effective radiated field power is more than 50 percent of the peak power.

INDICATION OF HPBW:

HPBW, or half power beam width, is the angle formed by a line from the radiation pattern's origin to the half power points on the primary lobe, on both sides. The following graphic might help clarify this.

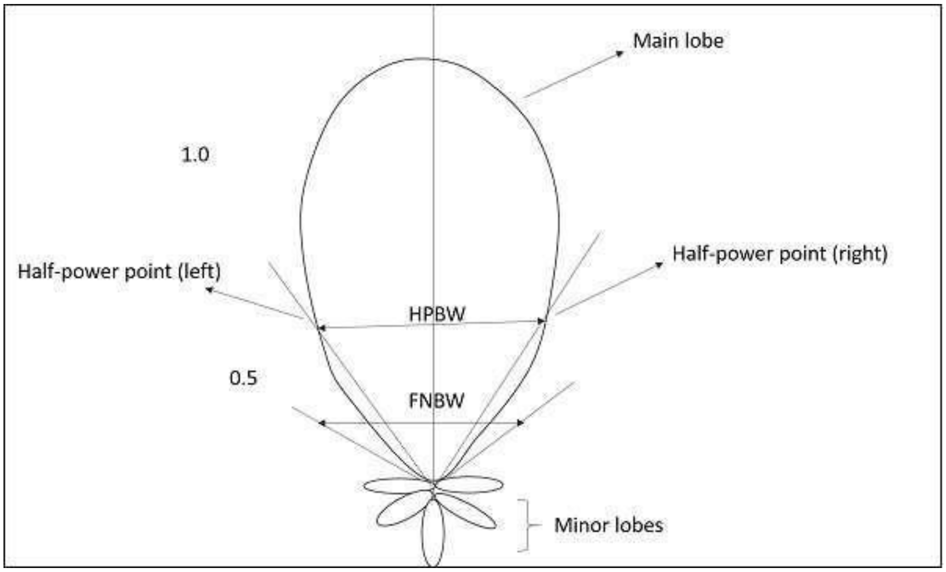

Fig 1.35: Half-power points on the major lobe and HPBW

Ref:https://www.tutorialspoint.com/antenna_theory/images/half_power_point.jpg

$$Half\ power\ Beam\ with = 70\lambda_{/D}$$

1.18 FIELDS FROM OSCILLATING DIPOLE:

Free-Space Electric Dipole Radiation. The electric dipole in oscillation is the primary generator of electromagnetic radiation.

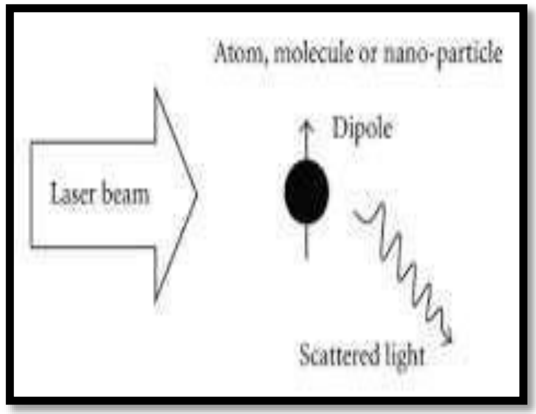

Fig1.36: Dipole of free space electric in radiation

Ref: https://static-02.hindawi.com/articles/isrn/volume2012/856748/figures/856748.fig.001.jpg

The electric dipole moment of a source with a locally-varying current density that oscillates with angular frequency looks like this, where it is the complex amplitude of the source's oscillations.

1.19 ILLUSTRATIVE PROBLEMS:

It is possible that yield and reliability issues may arise during the production of MOS integrated circuits due to a phenomena known as the antenna effect, or more formally plasma driven gate oxide degradation. Antenna regulations, which are often provided by factories, outline the proper procedures to follow in order to prevent this issue. An antenna infringement is a breach of certain norms. In this case, the term "antenna" may be a bit of a misnomer, since the issue is not with converting electromagnetic fields into/from electrical currents, but rather with the collection of charge. The term "antenna effect" gets thrown about every once in a while. Side view of a typical integrated circuit net is shown in Figure 1.37 (a).

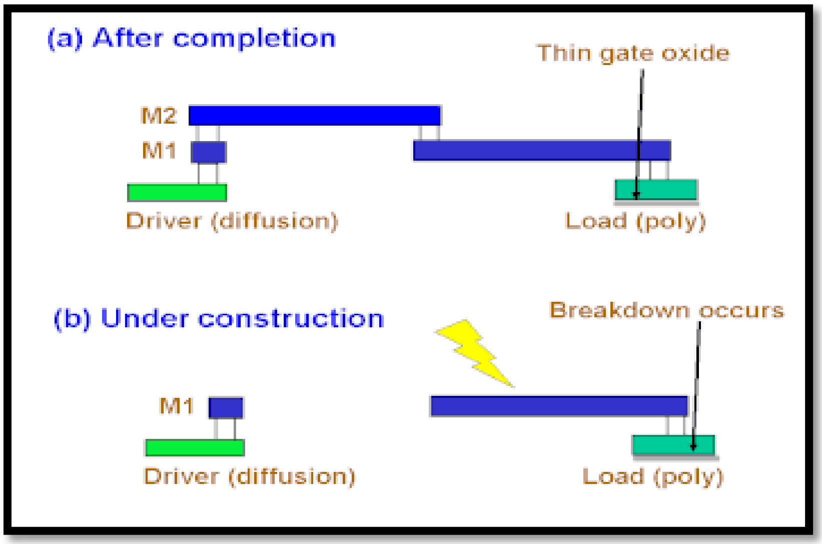

Fig 1.37: The cause of antenna effect. M1 and M2 are the first two metal interconnect layers.

Ref:https://upload.wikimedia.org/wikipedia/en/thumb/6/62/AntennaEffect.gif/350px-AntennaEffect.gif

At the very least one driver with source or drain diffusion (or implantation in more advanced technologies) and one receiver with a gate electrode over a thin gate dielectric will be present in each net (see Figure 1.38 for a detailed view of a MOS transistor).

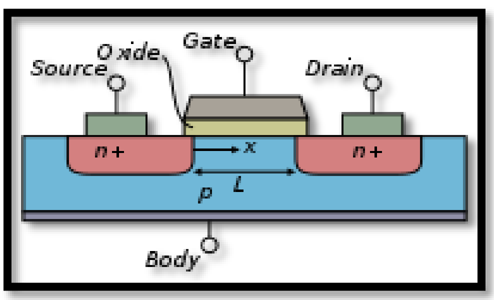

Fig 1.38: Source/drain implant and gate dielectric.

Ref: https://upload.wikimedia.org/wikipedia/commons/thumb/7/79/Lateral_mosfet.svg/195px-Lateral_mosfet.svg.png

The gate dielectric is just a few molecules thick, making its breakdown a major concern. To do this, the net must acquire a voltage somewhat greater than the chip's typical working voltage. (Given that silicon dioxide has traditionally been used as the gate dielectric, the term "gate oxide damage" or "gate oxide breakdown" is often used in the literature. Since 2007, several companies have started substituting other high- dielectric materials (which may or may not be oxides) for this oxide.

Every net has at least one source/drain implant linked to it, therefore this can't happen after the chip has been created. The diode formed by the source/drain implant fails at a lower breakdown voltage than the oxide (either by forward diode conduction or reverse breakdown).

The gate oxide is shielded in this way. Unfortunately, a diode may not be present during chip fabrication to safeguard the oxide. FIGURE 1.37(B) depicts the condition during the etching of metal 1.

In the absence of metal 2, the gate oxide lacks a diode connection. As a result, the gate oxide may be dissolved if a charge is supplied to the metal 1 form. In particular,

The condition shown may occur as a consequence of reactive-ion etching of the first metal layer: the metal on each net becomes isolated from the original global metal layer, and the plasma etching continues to impart charges to the individual metal particles.Power dissipation is hindered by leaky gate oxides, but the antenna effect is protected against. The accumulation of a charge sufficient to cause oxide breakdown may be prevented by a porous oxide.Since leakage increases exponentially with decreasing oxide thickness, while the breakdown voltage decreases only linearly, the startling conclusion follows that a very thin gate oxide is less vulnerable to damage than a thick gate oxide.

UNIT: II

VHF, UHF AND MICROWAVE ANTENNAS-I

2.1 LOOP ANTENNAS:

To improve reception, a loop antenna uses a circular configuration. Because of their portability, versatility, and low power consumption, loop antennas are often the most effective. While other elements may have a role, the performance of a loop antenna is primarily reliant on its design and installation. Signal quality and communication may be enhanced by using loop antennas to pinpoint hotspots with optimal signal intensity.

2.1.1 INTRODUCTION:

A loop antenna is an antenna that uses a coil wound in a single turn to transmit radio frequency signals. Phase coherence will be maintained by currents flowing through this loop antenna. Throughout the whole current-carrying loop, the magnetic field will be perpendicular. Copper or similar conductive metal is wound into a loop and both ends are linked to the same capacitor to create a loop antenna. The frequency changes in the opposite direction when the user modifies the capacitance of the loop antenna. The frequency rises when the capacitance of the loop is increased. However, the frequency drops as the user reduces the loop's capacitance. This occurs because a capacitor in the loop stores electrical energy and releases it at a later time.

That's why the longer the capacitor stores energy, the farther the radio waves from the antenna travel and the lower the frequency will be. Lower frequencies won't carry as far, but they'll be more powerful once they get there.

FREQUENCY RANGE:

Loop antennas may function at frequencies between 300 MHz and 3 GHz. This antenna is effective in the ultrahigh-frequency (UHF) spectrum.

2.1.2 SMALL LOOP:

As can be seen in Figure 2.1, the tiny loop antenna has the form of a loop. Seeing as how the antenna feed points would be connected in series with the loop, a little loop would essentially appear as a short circuit across the antenna feed. These antennas have a high inductive reactance and a low radiation resistance, making it challenging to match their impedance to a radio's (often 50 Ohms).

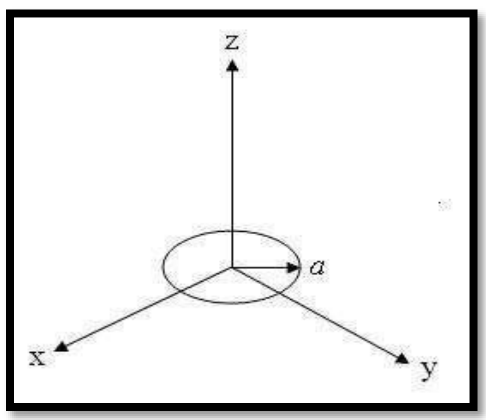

Fig2.1: Small loop Antenna.

Ref: https://www.antenna-theory.com/antennas/loop.jpg

Therefore, these antennas are often utilised as receive antennas, where the impedance mismatch loss may be handled somewhat more readily in certain systems. Given that the loop is electrically insignificant, the current inside it may be roughly estimated as being constant throughout the loop, therefore I= I_0

The fields from a small circular loop are given by

$$E_\phi = \frac{\eta k^2 a^2 I_0 e^{-jkr} \sin\theta}{4r}$$

$$H_\theta = \frac{-E_\phi}{\eta}$$

Radiation pattern for loop antenna describes the directional dependence of the radiation pattern, such that a tiny loop antenna's radiation pattern has the same power pattern as a short dipole. When compared to a short dipole antenna, the E-field of a tiny loop is horizontally polarised in the x-y plane, while the H-field is vertically polarised.

Small loop antennas are mainly of two types:

- Circular loop antennas
- Square loop antennas

The tiny loop antenna is commonly considered the "dual" of the dipole antenna because its fields would be similar to those of a small dipole if a magnetic current were running through it (instead of an electric current, as in a standard dipole). Magnetic current does not exist in reality, but the fields created by imagining such a current are similar to those produced by a tiny loop antenna.The impedance of a tiny loop is inductive, but that of a short dipole is capacitive (the imaginary component of the impedance is negative) (positive imaginary part). Increasing the number of turns in the loop improves its resistance to radiation and ohm loss.

The radiation resistance for tiny loops may be roughly calculated (in Ohms) if there are N turns of a small loop antenna, and each turn has a surface area of S (we don't need the loop to be circular at this point).

$$R_r = \left(\frac{177NS}{\lambda^2} \right)^2$$

The reactive portion of the impedance for a tiny loop may be calculated by measuring its inductance, which is shape-dependent. The reactive part of the impedance for a circular loop with radius and wire radius p is given by:

$$X = 2\pi f \mu a \left[\ln\left(\frac{8a}{p} \right) - 1.75 \right]$$

Uses for tiny loop antennas include field strength probes in wireless measurements, mobile pagers, and near-field communication antennas. The feed point of a loop antenna may be situated pretty much anywhere around the edge of the loop. Keep in mind that a banal may be required to ensure that the current distribution on the loop antenna is unaffected by the cable used to link the radio (transmitter or receiver) to the loop.

2.1.3 COMPARISON OF FAR FIELDS OF SMALL LOOP AND SHORT DIPOLE:

When positioned as in the following slide's example, the electrically tiny loop antenna acts as a secondary antenna to the electrically short dipole antenna. The far-field electric field of the small loop antenna is the same as the far-field magnetic field of the short dipole antenna, and the far-field magnetic field of the small loop antenna is the same as the far-field electric field of the short dipole antenna.

Since both the short dipole and the small loop antenna's radiated fields are dual quantities, the radiated power is equal for both antennas and their radiation patterns. That's because the highest radiation from the loop is emitted in the plane of the hitch itself.

The short dipole is most effective when its electric field is perpendicular to the wire when used as a receiver. Using the duality principle, we determine that the optimum orientation for the tiny loop is with the magnetic field perpendicular to the circle.Small loops have substantially lower radiation resistance than short dipoles. It is possible to identify pairs of equivalent and dual sources by comparing the far fields of the infinitesimally tiny dipole and the electrically small current loop with electric and magnetic currents. It is possible to identify pairs of equivalent and dual sources by comparing the far fields of the infinitesimally tiny dipole and the electrically small current loop with electric and magnetic currents.

Since the magnetic field of one is equal to the electric field of the other when the currents and dimensions are set suitably, the infinitesimally small electric and magnetic dipoles are characterised as dual sources.

Equally multifaceted are the tiny electric and magnetic current loops. Through this analysis, we also learn that the far-field polarisation for dual sources is orthogonal to that of the corresponding sources. The following table displays the far-field polarisations of each of the four sources in the maximum radiation (x-y) plane.

- Infinitesimal electric dipole → vertical polarisation
- Infinitesimal magnetic dipole → horizontal polarisation
- Small electric current loop → horizontal polarisation
- Small magnetic current loop → vertical polarisation

2.2 ARRAYS WITH PARASITIC ELEMENTS:

The antenna mentioned above arrays is used to enhance gain and directivity. Parasitic organisms are those that live off the energy or nutrients of other organisms. It is not independently updated. For this reason, we use components like this in arrays that boost radiation indirectly. Parasitic organisms are not directly linked to the feed and are not part of it.

Fig 2.2: Parasitic array antenna

Ref:https://www.tutorialspoint.com/antenna_theory/images/parasitic_element.jpg

An example of a parasitic array is shown above. Images of a mesh structure turn out to be nothing more than reflections. There is no wiring connecting these reflectors to anything. By making the beam more focused, they boost the signal's intensity.

CONSTRUCTION & WORKING OF PARASITIC ARRAY:

Let us look at the essential parts of a parasitic array and how they work.

All of the major components are:

- Driven element
- Parasitic elements
- Reflector
- Director
- Boom

DRIVEN ELEMENT

As a group, the antennas' radiation is more vital than it would be alone, although both modes of operation contribute to the overall radiation beam. None of the array's components has to be directly linked to the power source. A driven element is a dipole that is coupled to the feed.

PARASITIC ELEMENTS:

The additional components are not wired to the driving element or the feed. They are set up such that their inductive paths cross with those of the driving element. This is why they are categorised as parasitic components.

REFLECTOR:

When one parasitic element, 5 per cent longer than the driven element, is put near the driven element, it functions as a concave mirror. It redirects the radiation pattern's energy in the other direction.

DIRECTOR:

A parasitic element that is only 5% as long as the driving component from which it draws power would act like a convergent convex lens to maximise radiation in its direction. The term "director" describes this piece. There are more directors in place to improve direction.

BOOM:

A boom is a structure onto which all of these are mounted. It's an insulating framework made of materials other than metal, preventing components from shorting out to one another. All of these primary components are responsible for radiation production.

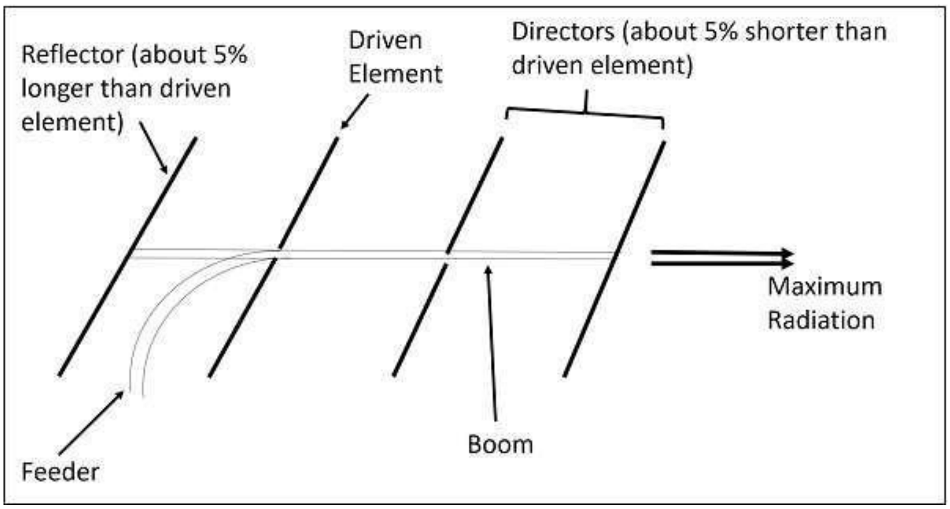

Fig 2.3: Parasitic array such as the driven element, the directors and the reflector.

Ref:https://www.tutorialspoint.com/antenna_theory/images/construction_parasitic_array.jpg

The arrays are used at frequencies ranging from 2MHz to several GHz. These are especially used to get high directivity, and better forward gain with a uni-directional. The most common example of this type of array is the Yagi-Uda antenna. Quad antenna may also be quoted as another example.

2.2.1 FOLDED DIPOLES & THEIR CHARACTERISTICS:

The dipole antenna, or aerial, in its most fundamental form, is very common. A variant of this, the folded dipole antenna, has certain benefits in certain setups, however. The folded dipole antenna, also known as a folded dipole aerial, is frequently used not only on its own but also as the driving element of other antennas like the Yagi antenna and others. Multiple benefits of folded dipoles may be used to enhance performance in a variety of contexts.

FOLDED DIPOLE ANTENNA BASICS:

The folded dipole antenna is essentially just a regular dipole with an extra conductor spliced into the middle. The resulting wire "loop" creates a DC-to-DC short circuit. Because of how its ends seem folded back, this kind of antenna is known as a folded dipole antenna. The diagram below outlines the fundamental structure of a folded dipole aerial.The folded dipole, like the standard dipole, is a balanced antenna that requires a balanced feeder.

In order to utilise an unbalanced feeder, a balun (an unbalanced to balanced transformer) must be used. More often than not, a folded dipole will be a half wave variant. One of the wires is centrally fed. This suggests it is being supplied by a source with a high current but a low voltage.

In other words, it is supplied at a low impedance location, similar to the conventional half-wave centre-fed dipole, although with a larger impedance. A common method for creating the folded dipole antenna's supplementary section is to use a wire or rod with the same diameter as the antenna's primary dipole. It's not always the case however.

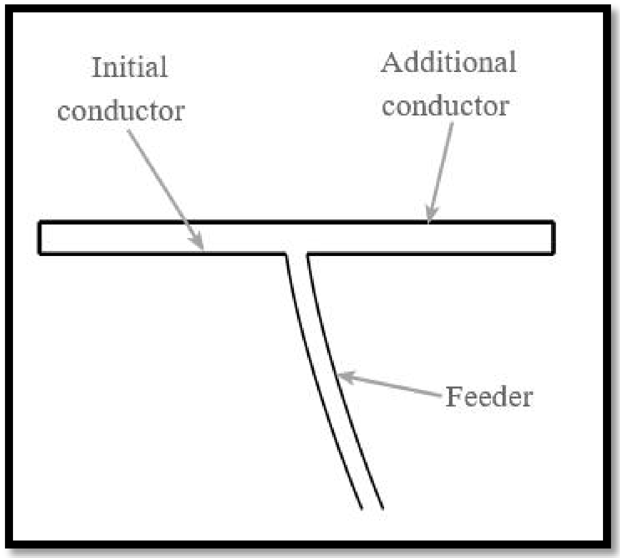

Fig 2.4: Basics folded dipole antenna.

Ref: https://www.electronics-notes.com/articles/antennas-propagation/dipole-antenna/folded-dipole.php

Wires or rods are normally equally spaced throughout the length of the parallel components. Many strategies exist for doing this. The components of a VHF or UHF antenna often have enough stiffness on their own, but at lower frequencies, spacers may be necessary. Just so the cords may stay separate. As expected, preventing a short is crucial if they lack insulation. The use of a flat feeder is possible in specific situations.

APPLICATIONS:

The half-wave folded dipole antenna has a number of uses, including those listed below:

Most often seen in antenna designs like Yagis, Parabolics, Turnstiles, Log Periodics, Phased Arrays, and Reflector Arrays among others as a feeder element.

- It is often found in radio receivers.
- Use in TV antennae is quite prevalent.

2.3 HELICAL ANTENNAS:

One kind of wire antenna, the helical antenna, has the form of a helix. This antenna can pick up frequencies from very high to very high frequency.

FREQUENCY RANGE:

A helical antenna's usable frequency spectrum is anywhere between 30 MHz and 3 GHz. There are both very high frequency (VHF) and extremely high frequency (UHF) bands covered by this antenna.

CONSTRUCTION & WORKING OF HELICAL ANTENNA:

The helical antenna, also known as a helix antenna, is an antenna in which a conducting wire is twisted in a helical pattern and fed to a ground plate. It's the most basic antenna design, and it emits waves with a circular polarisation. For communications outside Earth's atmosphere, it relies on satellite relays and similar technologies.

Fig 2.5: Helical antenna system

Ref:https://www.tutorialspoint.com/antenna_theory/antenna_theory_helical.htm

A helical antenna system, such as the one seen above, is often used for satellite communications. There must be more room outside for these antennae. They employ a flat metal plate called a ground plate and a helix of thick copper wire or tubing wrapped in the form of a screw thread as an antenna. The helix's inner conductor is linked to the cable's grounding plate, while the outer conductor is linked to the cable's outer sheath.

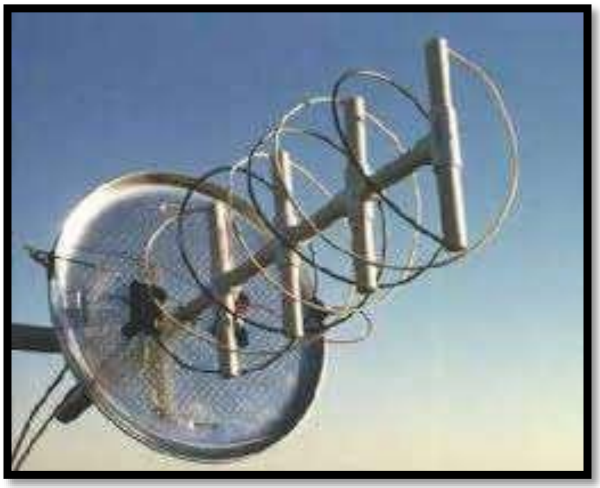

Fig 2.6: Helical antenna in detail

Ref: https://www.tutorialspoint.com/antenna_theory/images/ground_plate.jpg

Above, you can see a picture of a helix antenna that shows the various components of the antenna in more depth. Radiation from a helical antenna is affected by the helix's diameter, the distance between turns, and the antenna's pitch angle. The pitch angle is the inclination of a plane normal to the helix axis with respect to a line tangent to the helix wire.

2.3.1 HELICAL GEOMETRY:

Helical Antenna consists of a conducting wire wound as a screw thread forming a helix. In most cases, the helix is used with a ground plane. The helix is usually connected to the centre conductor of a co-axial transmission line, and the cable's outer conductor is attached to the ground plane. A helical antenna is helpful at very high frequencies and ultra-high frequencies to provide circular polarization.

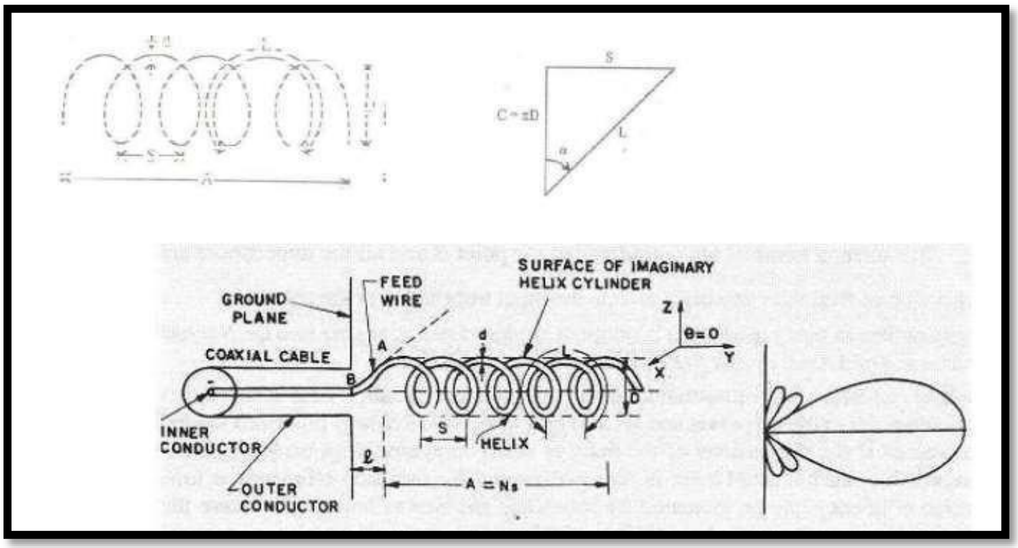

Fig 2.7: Helical antenna and its pattern

Ref: https://mrcet.com/downloads/digital_notes/ECE/III%20Year/ANTENNA%20AND%20WAVE%20PROPAGATIONS.pdf

The ground plane and coaxial wire are joined here with a helical antenna. Conductors that are radial and concentric make up the ground plane. The diameter (D) and spacing (S) of a helical antenna affect its radiation properties.

In the above figure (2.7),

L= length of one turn $=\sqrt{S2 + (\pi D)}$

N = Number of turns

D = Diameter of helix = π D

α = Pitch angle = tan l(S/πD)

l = Distance between helix and ground plane.

By adjusting the size of the geometrical parameters of the antenna relative to the wave length, the radiation characteristics of the antenna can be changed.

2.3.2 HELIX MODES:

A helical antenna's primary modes of operation are,

- Normal or perpendicular mode of radiation.
- Axial or end-fire or beam mode of radiation.

NORMAL MODE:

The radiation field is parallel to the helix axis in the typical radiation mode. The waves being radiated have circular polarisation. If the helix's size is modest about the wavelength, this radiation mode will result. This helical antenna emits radiation in a pattern that combines a short dipole and a loop antenna.

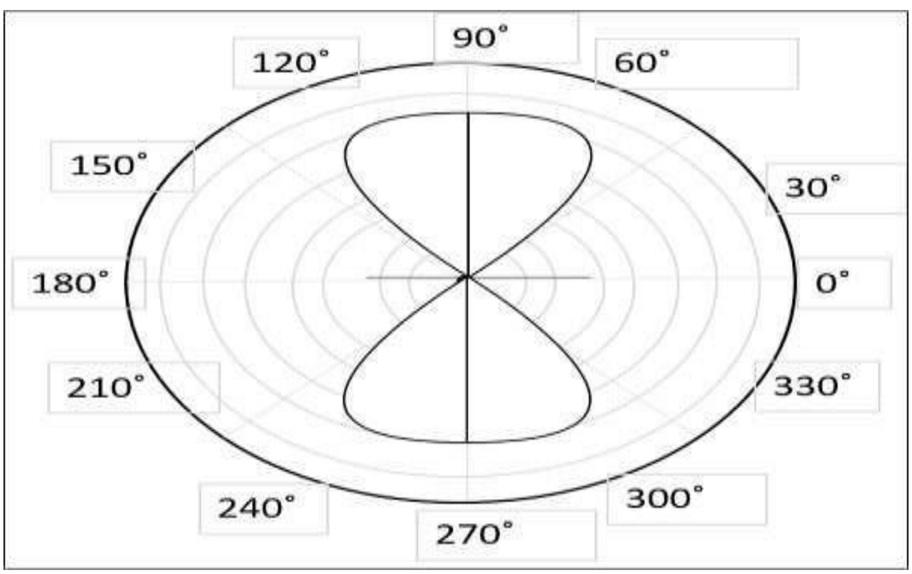

Fig 2.8: Normal mode radiation pattern

Ref:

https://www.tutorialspoint.com/antenna_theory/images/normal_mode.jpg

The radiation pattern for the helical antenna's usual mode of radiation is depicted in the above figure 2.8.It is based on the helix's diameter (D) and turn spacing (S) parameters. The limited bandwidth and low radiation efficiency of this mode of operation are drawbacks. As a result, it is rarely utilised.

AXIAL MODE:

The waves in the axial mode of radiation are circularly or nearly polarised and radiate in the end-fire direction along the helical axis. Raising the radius to the order of one wavelength (λ) and separating roughly λ /4 results in this mode of operation.The axial beam produces minor lobes at oblique angles due to the radiation pattern, which is broad and directed.

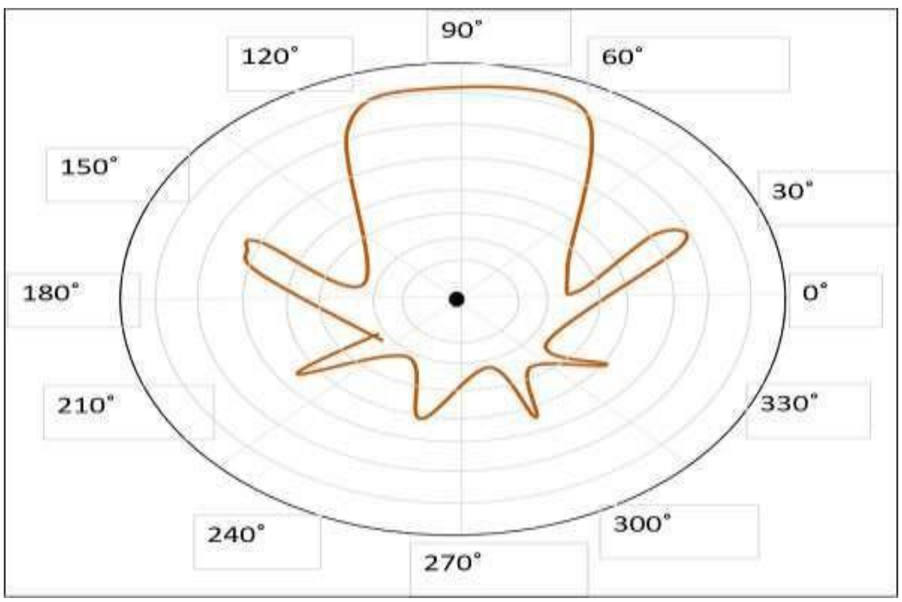

Fig 2.9: Axil mode radiation pattern

Ref: https://www.tutorialspoint.com/antenna_theory/images/axial_mode.jpg

The radiation pattern for the axial mode of radiation in the helical antenna is depicted in the figure (2.9).

This antenna will not receive left-handed circularly polarised waves if it is made for right-handed circularly polarised waves, and the opposite is true. This method of operation can be created quite easily and is utilised more frequently.

2.3.3 APPLICATIONS OF HELICAL ANTENNAS:

Helical antenna applications include:

- Applications for helical antennas are primarily found in space communication.
- Their circular polarisation, large bandwidth, excellent directivity, and simplicity are operating characteristics for in-space communication.
- Helical antennas are typically used in space communication to transmit telemetry data.
- Also, helical antennas can be positioned near the surface in a single or multiple-antenna array to propagate ionosphere waves.
- VHF transmissions can now be sent and received thanks to this.
- Helical antennas are therefore used in satellite and space probe propagation.
- Signals of any polarisation can be quickly received by helical antennas set up in axial mode.
- Because they provide circularly polarised waves across a larger bandwidth, end-fire helical antennas are more commonly employed than broadside helical antennas.

2.4 HORN ANTENNAS AND ITS TYPES:

A waveguide excites a horn antenna, which is a practical and straightforward radiator. One of the most common antennas is the horn antenna, which is utilised as the focal point feed in many of the reflector antennas covered in the following chapter.

A wave guide's natural extension is a horn antenna. There are many types of horn antennas, including the pyramidal horn, sectorial horns for the E- and H-planes, conical horns, corrugated horns, etc. These are shown in part in Fig. 2.10.

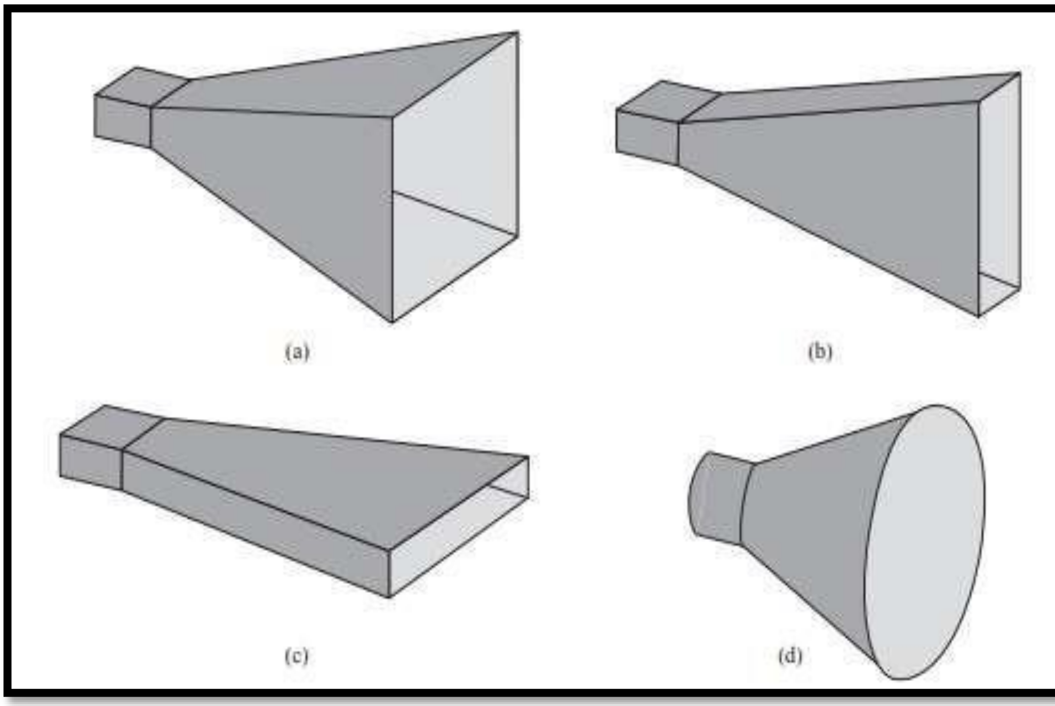

Fig 2.10: Typical horn antennas—(a) pyramidal horn, (b) E-plane horn, (c) H-plane horn, and (d) conical horn

Ref: https://khasimgriet.files.wordpress.com/2016/07/harish-a-r-_-sachidananda-m-antennas-and-wave-propagation-oxford-university-press-2007.pdf

Although coaxial inputs can be provided with an additional wave guide-to-coaxial transition, a waveguide typically activates horn antennas. The input match and the necessary radiation pattern features are the two main requirements that must be met for an antenna to be effective.

The current distribution on the antenna surface or the aperture and the input match, as well as the design of the transition from the input waveguide to the aperture, all affect the radiation characteristics. Transmission line theory is well aware of the fact that if the cross-section of the transmission line is altered gradually, the reflection coefficient caused by the discontinuity can be reduced over a broad frequency range.Another benefit is that by knowing the field distribution in the waveguide at the input, it is possible to approximate the field distribution at any cross-section in the waveguide. For instance, a pyramidal horn is produced by gradually enlarging the rectangular waveguide cross-section to the aperture size [see Fig. 2.10(a)].

The wave impedance asymptotically approaches the free space impedance when the aperture size is significant relative to the wavelength. So long as the transition's length is greater than the wavelength, a pyramidal horn can offer a gradual change from the waveguide impedance to the free space impedance.

The length of the horn is determined by the apex angle of the pyramid, given an aperture size and a waveguide size. The apex angle needs to be narrow for a good input match (considerable length). The pattern properties depend on the aperture size and the field distribution (or the corresponding current distribution over the aperture). One of the most crucial horn antennas is the pyramidal horn.

2.4.1 FERMAT'S PRINCIPLE:

Fermat's principle states that light follows a path between two places, so their optical distances are equal. The fundamental concept connects ray and wave optics. One of the best methods to express Fermat's vision is that the path light beams take between two sites involves either a maximum or minimum time. It implies that the optical path lengths of two golden rays diverging from a far-off object will be the same.

The path taken by light beams between the specified two sites is the absolute path that may be traversed in the shortest amount of time, according to Fermat's principle of Least Time.

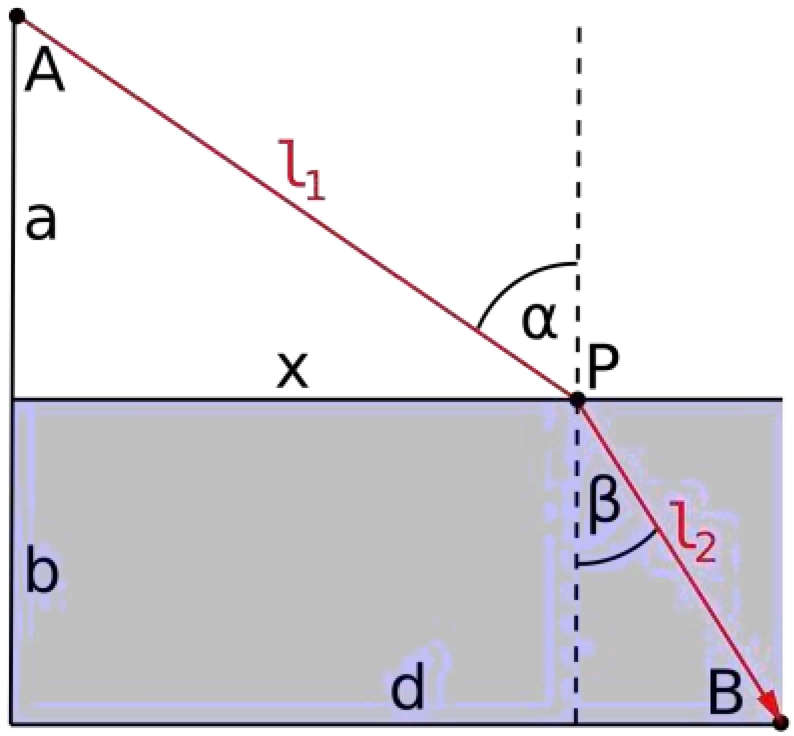

Fig 2.11: Fermat's Principle

Ref:https://upload.wikimedia.org/wikipedia/commons/thumb/d/d9/Fermat_Snellius.svg/1200px-Fermat_Snellius.svg.png

2.4.2 OPTIMUM HORNS:

A flare angle provides a minor reflection and significant gain for a particular frequency and horn length. When the sides start to flare out, the mouth or aperture of the horn and the neck are the two points along the wave path where the impedance drastically changes and cause internal reflections in straight-sided horns.

The horn flare angle affects the quantity of consideration at these two locations (the rise the sides make with the axis). Most reflection occurs at the horn's mouth in narrow horns with small flare angles.

The narrow mouth of the antenna closely resembles an open-ended waveguide, which results in a low gain. The reflection at the mouth rapidly diminishes when the angle is raised, and the antenna's gain also rises. In contrast, most of the thought occurs at the throat in broad horns with flare angles close to 90°.

Again, the horn's gain is minimal due to the throat's resemblance to an open-ended waveguide. The quantity of reflection at this location decreases as the angle is shrunk, and the gain of the horn rises once more.This analysis demonstrates that there is a flare angle between 0° and 90° that provides the most gain and the least amount of reflection. This is referred to as the ideal horn. The majority of helpful horn antennas are constructed as excellent horns. The dimensions of a pyramidal horn that produce the best horn are:

$$a_E = \sqrt{2\lambda L_E} \qquad a_H = \sqrt{3\lambda L_H}$$

For a conical horn, the dimensions that give an optimum horn are:

$$d = \sqrt{3\lambda L}$$

Where,

a_E - The width of the aperture in the E-field direction

a_H - The width of the aperture in the H-field direction

L_E - The slant height of the side in the E-field direction

L_H - The slant height of the side in the H-field direction d - The diameter of the cylindrical horn aperture

L - The slant height of the cone from the apex

λ - The wavelength

2.5 PYRAMIDAL HORNS ANTENNA:

One of the horn antennas that is utilised the most is the pyramidal horn antenna. In antenna measurements, the antenna serves as both a standard gain reference antenna and the primary feed for reflector antennas. The rectangular wave guide's four corners are flared to create the pyramidal horn, which has a rectangular aperture. Figure 2.12 displays the cross-sectional drawings of a typical pyramidal horn antenna.

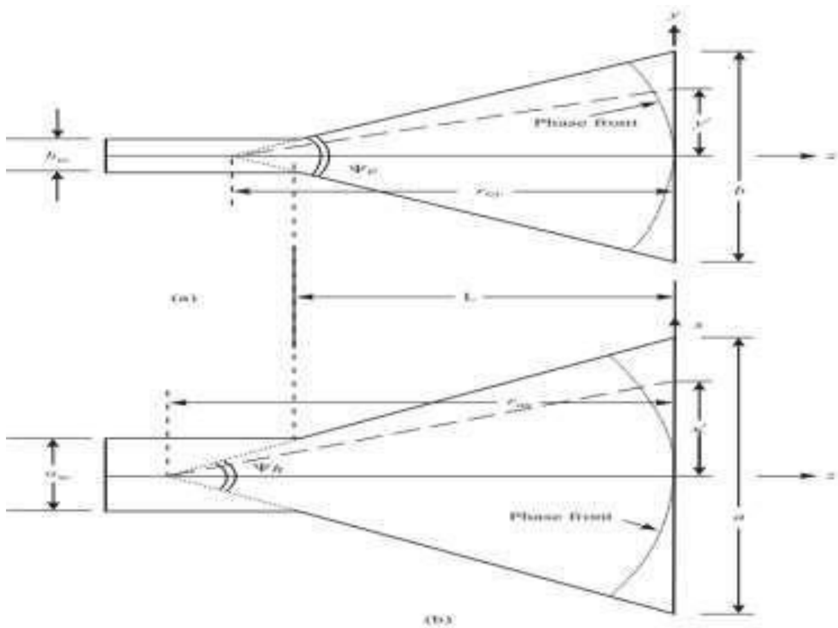

Fig 2.12: Geometry of the pyramidal horn antenna (a) E-plane section (b) H-plane section.

Ref: https://khasimgriet.files.wordpress.com/2016/07/harish-a-r-_-sachidananda-m-antennas-and-wave-propagation-oxford-university-press-2007.pdf

We must first approximate the field distribution over the aperture before using the field equivalence principle and obtaining the far fields. We assume that the aperture fields for small flare angles will resemble the TE10 mode distribution in the exciting wave guidance but with a phase variation over the aperture in both the x and y directions. The wave front is assumed to be cylindrical with its phase centre at the intersection line of the two flared sides, as shown in Fig. 2.12; the propagation constant within the horn section is assumed to be the same as the free space propagation constant, and (c) it is assumed that no higher order modes are generated at the discontinuities at the waveguide to horn junction as shown in Fig. 2.12. These assumptions allow us to determine the phase variation over the aperture.

For minor flare angles, all of these presumptions are roughly true, but for big flare angles, there may be significant discrepancies. The phase centres are not always in the same place in the x-z and y-z planes. We have a directivity expression given by

$$D = 0.8 \times 0.77 \times \frac{8}{\pi^2}\frac{4\pi ab}{\lambda^2} \simeq 0.5 \times \frac{4\pi ab}{\lambda^2}$$

For the horn to be realizable, the horn length, L, must satisfy the following equations,

$$L = \frac{a - a_w}{2\tan\Psi_h}$$
$$L = \frac{b - b_w}{2\tan\Psi_e}$$

Where aw × bw are the waveguide dimensions and a × b are the aperture dimensions. These two equations may not be satisfied simultaneously, but we select the length of the two measurements and modify the flare angle in the other equation to meet both equations. We choose the larger of the two measurements so that the flare angle is optimum in one plane and the phase error in the other plane is less than the optimum. Of course, we can select a horn length much longer than the minimum length, in which case the directivity loss factor is less, for a given horn aperture area, a b, the yield varies from 0.81{4π a b /λ2} to 0.5{4π a b/λ2}; the factor 0.81 is for zero phase error (L → ∞), and the factor 0.5 is for optimum length.

UNIT: III

VHF, UHF AND MICROWAVE ANTENNAS-II

3.1 INTRODUCTION TO MICRO STRIP ANTENNAS AND FEATURES:

Although the first micro strip antennas appeared in 1953, they weren't patented until 1955. In the 1970s, their prevalence increased. A tiny fraction of a wavelength separates the ground plane from the antenna's radiating element, a thin metal patch.Micro strip antennas have a small footprint. Micro strip antennas, often called patch antennas, consisting of a metal patch fixed at ground level with a di-electric substance. These tiny antennas don't put out much of a signal.

Micro strip antennas may be built on many different substrates. Substrates with more significant dielectric constants are ideal for microwave circuits, whereas those with lower dielectric constants are preferable for delivering a wider bandwidth and higher efficiency.

An antenna must be used for radio frequency (RF) front-end electronics to "talk" to electromagnetic waves as they are emitted and travel through air and space. An antenna is extremely useful in microwave and other wireless applications. Engineers in the antenna field have paid close attention to planar-oriented antennas like the micro strip patch and printed dipole due to their high performance and many advantages. Unlike traditional antenna designs, this one can accommodate today's wireless technologies.

Micro strip patch antennas were the subject of much theoretical and practical study by the antenna design community around the end of the 1970s. Due to their simple construction, micro strip antennas are the most often used planer antennas.

As a result of its basic construction, a patch in a micro strip antenna may be designed from scratch using an etching procedure on a dielectric substrate.

A few examples of what these antennas can do are:

- Low profile and Lightweight antennas.
- Most suited for space applications and cellular applications.
- Its integration is easy with electronic components.
- Its arrays can easily integrate.

In a micro strip antenna, a thin metallic strip (patch) (t) in a usually rectangular form is mounted on the antenna's upper surface. A dielectric substrate separates the patch structure from the ground plane, which is located on the opposite phase of the antenna. Fabricated using a photo etching process on a dielectric substrate, the antenna's radiating patch and feed line are located at the top of the device. Radiating patches may take on various geometrical forms, including but not limited to square, circular, elliptical, and rectangular. Nonetheless, square, round, and rectangular shapes are most popular because of their simplicity in analysis and manufacture. The feed line is another conducting strip line made of metal. However, its width is often narrower. Coaxial cables, which have a conductor at their centre, are often employed to stimulate radiating patches.

Because of the microscopically thin construction of a microstrip antenna, the waves created inside the dielectric material (the substrate between the patch and the ground plane) are somewhat attenuated by reflections as they reach the strip's corners. Due to its inefficiency, the antenna is more akin to a hollow than a radiator.

3.2 ADVANTAGES AND LIMITATIONS OF MICROSTRIP ANTENNAS:

- They have several advantages, including:
- The perfect combination of being lightweight and compact.

- They were producing large quantities with a low unit cost of production.
- Polarizations, both linear and circular, are supported.
- Possible to cooperate with integrated microwave circuits (MICs).
- Allows for simultaneous operation at two or more frequencies.
- Due to their simple 2-dimensional physical form, micro-strip antennas are inexpensive to manufacture and design.
- With the help of lithographic techniques, printing several patches on a single substrate is simple.

DRAWBACKS OF MICRO-STRIP PATCH ANTENNAS:

Unfortunately, there are more downsides associated with micro-strip patch antennas than with regular antennas.

This has a number of major downsides, including:

- The bandwidth is narrow.
- Efficiency is low.
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

3.3 RECTANGULAR PATCH ANTENNAS- GEOMETRY AND PARAMETERS:

The convenience of micro strip or patch antennas is growing as a result of their ability to be printed directly onto a circuit board. In the mobile phone industry, micro strip antennas are quickly replacing traditional antenna designs. Patch antennas are cheap, compact, and simple to manufacture.

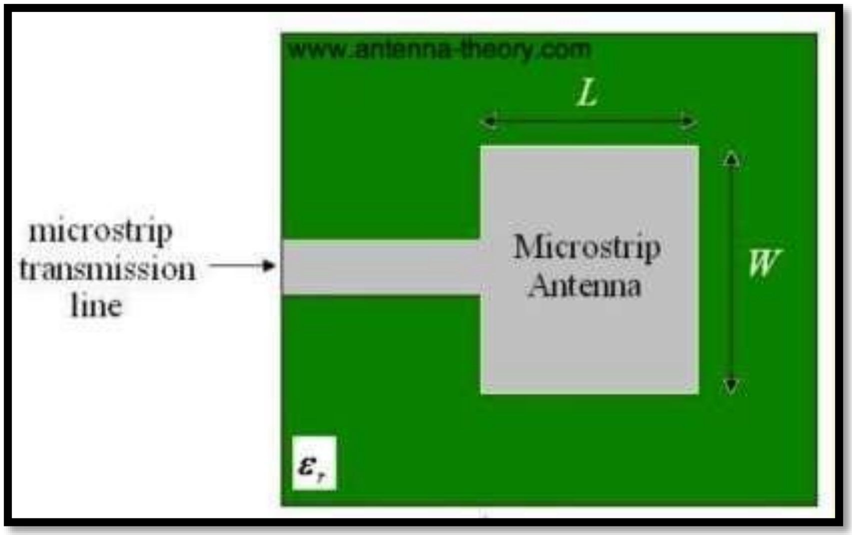

Fig 3.1: (a) Top View of Patch Antenna

Ref: https://www.antenna-theory.com/antennas/patches/antenna.php

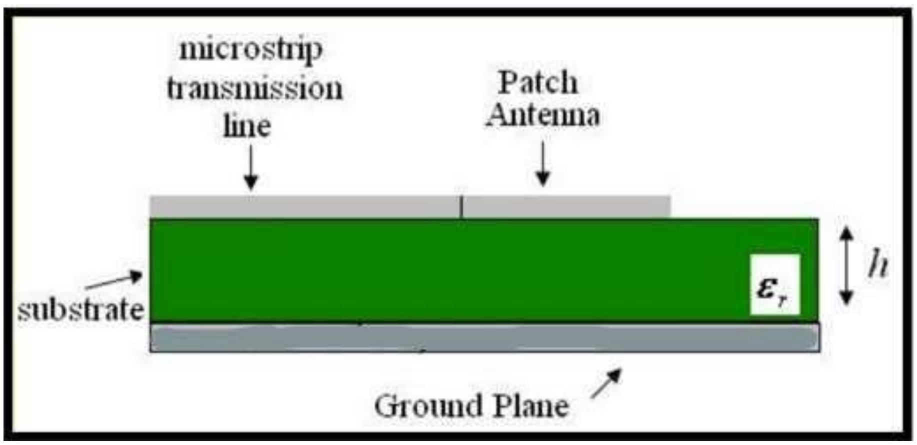

Fig 3.1: (b) Side View of Micro strip Antenna

Ref: https://www.antenna-theory.com/antennas/patches/antenna.php

Think about the micro strip antenna and transmission line setup in Figure 3.1. High conductivity metal is used for the patch antenna, micro strip transmission line, and ground plane (typically copper). The patch has dimensions of L by W and is mounted on a substrate (a dielectric circuit board) of thickness h, the permittivity of which is.

The ground plane or micro strip thickness is not mission essential. The antenna's performance degrades below 0.025 of a wavelength (1/40th of a wavelength), hence height h is often considerably less than the wavelength of operation.

Figure 3.1 shows a patch antenna, the operating frequency of which is set by the length L. Approximate expressions for the fundamental frequency may be found by:

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

According to the aforementioned formula, the micro strip antenna should be half as long as the wavelength inside the dielectric (substrate) medium.The input impedance of a micro strip antenna is determined by its width, W. The bandwidth may be increased by using a wider width. With this configuration, the input impedance of a square patch antenna is about 300 Ohms. To lower the impedance, broaden the base. However, a very broad patch antenna is usually needed to reduce the input impedance to 50 Ohms, which wastes a lot of room. The radiation pattern may also be adjusted by adjusting the width. For a rough approximation of the normalised radiation pattern, we have:

$$E_\theta = \frac{\sin\left(\frac{kW \sin\theta \sin\phi}{2}\right)}{\frac{kW \sin\theta \sin\phi}{2}} \cos\left(\frac{kL}{2} \sin\theta \cos\phi\right) \cos\phi$$

$$E_\varphi = -\frac{\sin\left(\frac{kW \sin\theta \sin\phi}{2}\right)}{\frac{kW \sin\theta \sin\phi}{2}} \cos\left(\frac{kL}{2} \sin\theta \cos\phi\right) \cos\theta \sin\phi$$

A typical patch antenna has a directivity of 5-7 dB. When looking at the micro strip antenna from the side, as in Figure 3.1a, the fields are linearly polarised and horizontal. Later, we'll take a deeper dive into the many facets of Patch (Micro strip) antennas.

Figure 3.1a shows a square patch antenna that is fed at one end. It is assumed that the substrate is air (or Styrofoam with a permittivity of 1) and that L=W=1.5 metres in order for the patch to resonate at 100 MHz. We can say h is 3 centimetres in height. It's important to keep in mind that micro strips are often designed for higher frequencies, making them considerably more compact in actual use. The magnitude of S11 is maximised when used with a 200 Ohm load.

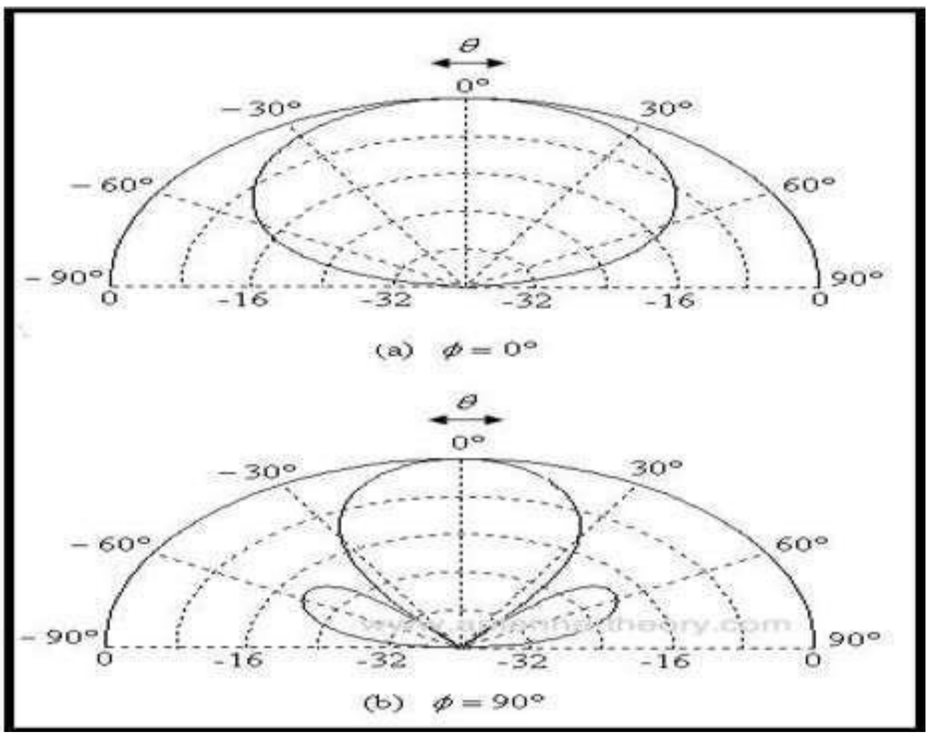

Fig 3.2: Normalized Radiation Pattern for Microstrip (Patch) Antenna.

Ref: https://www.antenna-theory.com/antennas/patches/antenna.php

The radiation originates from the bordering fields. It should be noted that the patch antenna's near-surface fringing fields are in a +y direction. The emission from a micro strip antenna is thus the sum of the E-fields that fringe its edges. If you want to learn about patch antennas, you need to focus on this text. Phase addition also occurs on the patch antenna's current, but the ground plane's current flows in the opposite direction, thus cancelling out the radiation.

The difference in radiation behaviour between the micro strip antenna and transmission line is thus clarified. The micro strip antenna radiates because of the voltage, not the current, because of the fringing fields that result from the favourable voltage distribution. In contrast to wire antennas, which radiate because the currents build up in phase, the patch antenna is a "voltage radiator."

3.4 CHARACTERISTICS OF MICRO STRIP ANTENNAS:

- The form of a patch or micro strip antenna may be almost any regular polygon. The term "patch antenna" is used interchangeably with "printed antenna," "micro strip patch antenna," and "micro strip antenna" (MSA).
- Etching allows the patch antenna to be printed directly onto a circuit board.
- In the early 1970s, the idea of micro strip antennas was given more attention due to the need from aerospace applications including spacecraft and missiles.
- Radiating elements and feed lines are typically photo etched onto the dielectric substrate.
- Many different dielectric substrates with dielectric constants between and may be employed between the patch and ground plane.
- A single patch antenna element or an array of them may be used to achieve either linear or circular polarisation.

- In terms of Q, micro strip antennas are among the best available. To visualise the energy losses caused by the micro strip antenna, consider the quality factor Q.
- In order to function properly, microwave circuitry often employs thin dielectric substrates with high dielectric constants.

3.5 IMPACT OF DIFFERENT PARAMETERS ON CHARACTERISTICS.

EFFECT OF SLOTS ON BANDWIDTH:

Radiation characteristics are sometimes used to establish bandwidth. The frequency range is where the minimum and maximum values for the various radiation parameters, such as gain, HPBW, and side lobe levels, are stated.

$$\text{Bandwidth}=\frac{VSWR-1}{Q\sqrt{VSWR}}$$

The ratio of voltage standing waves, the frequency-dependent input impedance, or the emission pattern. Matching the impedance of the feed line to that of the antenna within certain limitations is known as the VSWR or impedance bandwidth of the micro strip patch antenna. Micro strip patch antenna bandwidth is the frequency range in the antenna's response that is identical to the feed line's response. Micro strip patch antenna bandwidth is proportional to its quality factor Q, which is given by

EFFECT ON SLOTS ON THE GAIN:

The term "gain" refers to the ratio between the actual power output by an antenna and the power output that would be achieved by an ideal antenna that radiates evenly in all directions (isotopic ally) and incurs no losses. The antenna gain may be improved by employing a high permittivity substrate and a non-circular slit.

EFFECT OF SLOT ON RADIATION PATTERN:

$$\vec{E} = \frac{\mu_r}{r\sin\theta}\left[\frac{\partial}{\partial\theta}\ (F_\theta\ \sin\theta) - \frac{\partial F_\theta}{\partial\phi}\right] - \frac{\mu_\theta}{r}\left[\frac{1}{\sin\theta}\ \frac{\partial F_r}{\partial\theta} - \frac{\partial}{\partial r}\ (rF_\theta)\right] + \frac{\mu_\phi}{r}\ \left[\frac{\partial}{\partial r}(rF_\theta) - \frac{\partial F_r}{\partial\theta}\right]$$

When the slots are on the ground plane, they act like a magnetic dipole, and their radiation patterns may be calculated using E fields. The radiation pattern in the E plane shifts dramatically for a ground plane of limited dimension. This occurs because of diffraction effects at the borders of the ground planes, which are inevitable owing to their limited sizes. The slots tend to develop into magnetic dipoles as the ground plane is extended in the E-plane radiation pattern. Unfortunately, the measurable outcomes are not supplied due to a lack of experimental facilities. Diffraction effects from the margins of a limited-size ground plane only impact the E-plane radiation patterns of slots, as shown by the radiation pattern by space.

EFFECT OF SLOT ON AXIAL RATIO:

It is the proportion of the polarisation ellipse's minor to its central axis. When the slot length is decreased, the axial ratio bandwidth is also reduced.

EFFECT OF SLOT ON SIZE OF ANTENNA:

Micro strip patch antenna size may be decreased by using a slot. Modifying the flow of current may achieve this result. By slicing slots into a patch, the electrical current may be altered. The current goes along an additional patch compared to the micro strip patch antenna without a place.

3.6 INTRODUCTION TO REFLECTOR ANTENNAS:

Long-distance radio communications (radio-relay connections and satellite links), high-resolution radars, radio-astronomy, etc., all need high-gain antennas. Among high-gain antennas, reflector systems are among the most common.

Gains of 30 dB or more at microwave and higher frequencies are readily attainable. The ideas used by reflector antennas have been around for a long time and may be found in geometrical optics (GO). Hertz created the first practical radio frequency (RF) reflector system in 1888. (A cylindrical reflector fed by a dipole). However, many radar applications didn't emerge until World War II, when the science of constructing such systems was refined.

Reflector antennas may be broken down into their essential components: a reflecting surface and a considerably smaller feed antenna near the reflector's focus. More intricate designs focus light from the main feed onto a secondary reflector (a sub-reflector) at the point of obsession. Dual-reflector antennas are precisely what they sound like. The parabolic primary reflector is the standard design. Cylindrical, corner, and spherical reflectors are also often used.

3.6.1 FLAT SHEET AND CORNER REFLECTORS:

PLANE OR FLAT SHEET REFLECTOR ANTENNA:

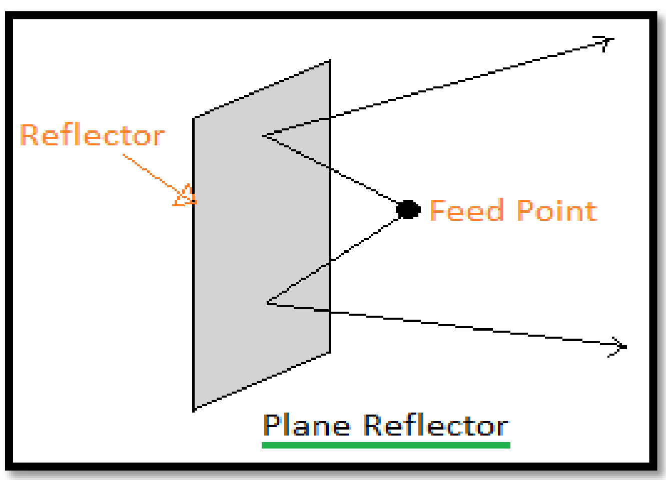

Fig 3.3: Plane reflector

Ref: https://www.rfwireless-world.com/Articles/Antenna-Reflector-basics-and-types.html

The kind of antenna known as a plane reflector is shown in Figure 3.3. There is a primary antenna and a reflecting surface. This configuration helps emit electromagnetic energy in the desired direction, but it cannot be used for forward-facing energy acclimatization.The following variables are affected by the orientation of the primary antenna relative to the plane reflector antenna:

- Radiation Pattern
- Impedance
- Gain
- Directivity

CORNER REFLECTOR ANTENNA:

One sort of antenna, the corner reflector, is shown in Figure 3.4. It's made up of two or three parallel conducting surfaces that connect. The feed element may be a dipole or an array of collinear dipoles in this category. This kind of antenna reflector often has a dihedral shape. Trihedral shapes with parallel surfaces are preferred when utilised as a radar target.

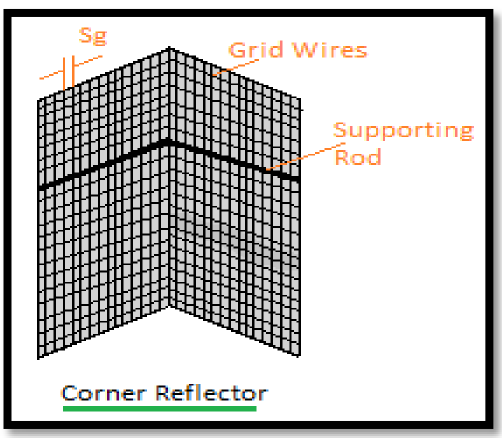

Fig 3.4: Corner reflector

Ref: https://www.rfwireless-world.com/Articles/Antenna-Reflector-basics-and-types.html

Collimation of forward-moving EM radiation is accomplished via a corner reflector antenna. Its primary function is to dampen outgoing waves in the reverse and lateral directions.

3.6.2 PARABOLA REFLECTORS:

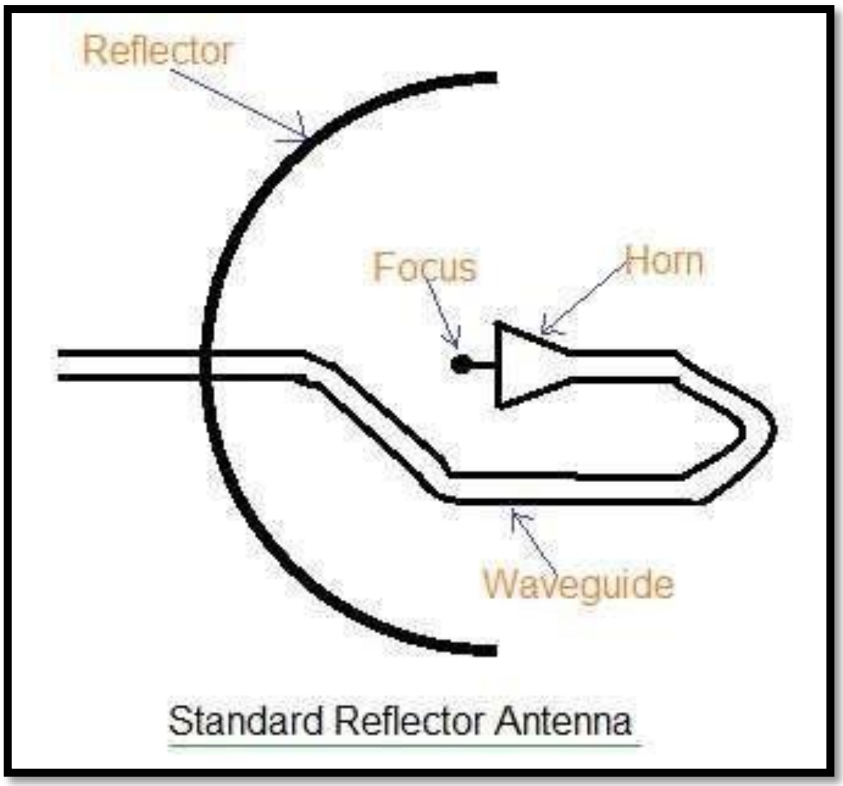

Fig 3.5: Parabolic Reflector Antenna

Ref: https://www.rfwireless-world.com/Articles/Antenna-Reflector-basics-and-types.html

A diagram of a parabolic reflector antenna is shown in Figure 3.5. Because of its parabolic form, this antenna type has many characteristics with parabolas. At the centre, where all the antennas converge, the different feeds are put to use. This figure depicts the feed point of a horn antenna.

Learn how the parabolic reflector antenna works. Horn antenna waves are seen to be incident on the reflector. If you send waves toward a reflector and then reflect them back, you'll get a nice, flat wave front. The direction of maximum radiation intensity is along the parabola axis. Path and phase mismatches cause the waves to cancel out in the opposite direction. A parabolic reflector antenna uses this principle to flatten out a sphere's worth of radio waves.

There are many subtypes of parabolic reflector, distinguished by the shape of the reflector plate.

- Parabolic cylinder reflector
- Cut or truncated parabolic reflector
- Pill box or cheese antenna reflector
- Torus antenna reflector
- Offset parabolic reflector antenna.

3.6.3 PATTERN CHARACTERISTICS:

Given below are a few of the parabolic reflector's most notable characteristics. Aperture amplitude, polarisation characteristics, phase angles, etc., are some examples of the features under consideration here. The magnitude of the signal varies with feed-to-reflector distance. Different buildings have different proportions. The ratio is inversely proportional to for a cylinder, and inversely proportional to the square of the radius of a parabola.The reflector's focus point has a unique effect on various geometric arrangements.

A line source characterises the cylindrical structure, whereas a point source characterises the parabolic shape.Any potential for cross-polarizations is eliminated if the feed is linearly polarised and runs in a direction perpendicular to the cylinder's axis. It is not true of parabolas or other similar shapes.

3.7 FEED METHODS:

Several distinct feed mechanisms for parabolic reflectors are available. Depending on the specifics of the use case, one of these options may be modified to suit your needs better.

- Focal feed - often also known as axial or front feed system
- Cassegrain feed system
- Gregorian feed system
- Axis or offset feed

3.7.1 FOCAL FEED SYSTEM:

The dish or parabolic reflector antenna uses a radiating element, which may be anything from a basic dipole to a waveguide horn antenna. Put this just at the point where the parabolic mirror focuses light.

The radiating component's energy is directed to light up the reflecting surface. After being reflected, the power exits the antenna system in a concentrated beam. Gains of a substantial magnitude are, therefore, possible.

As this depends on the radiator used, it is not always straightforward. It is common practice to utilise a dipole element at lower frequencies and a circular waveguide at higher frequencies. A circular waveguide is one of the best light sources available.

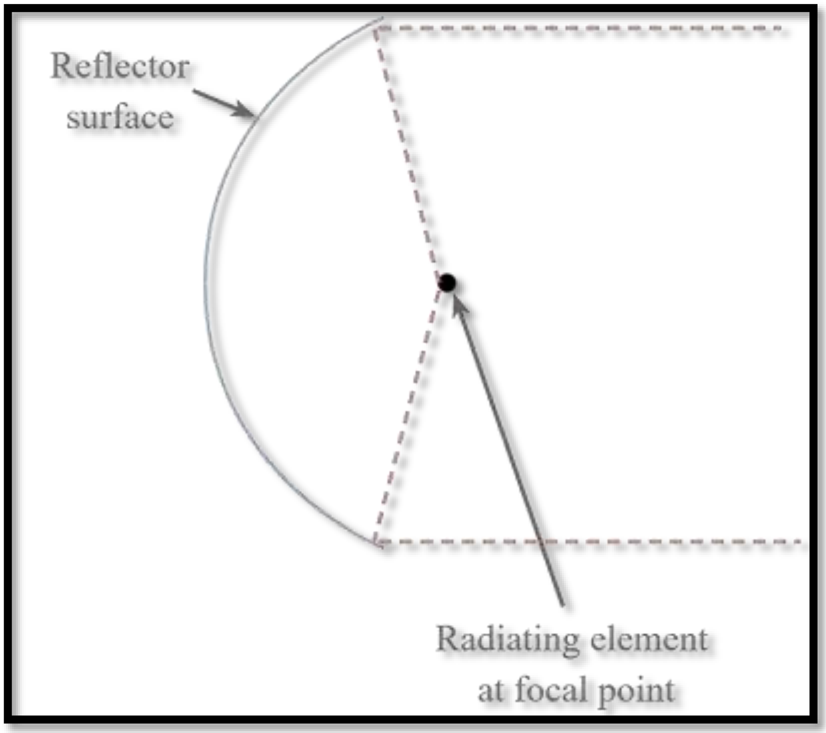

Fig 3.6: Focal feed system

Ref: https://www.electronics-notes.com/images/antenna-parabolic-reflector-focal-feed-01.svg

For more giant parabolic reflector antennas, a focal feed method is a popular option because of its simplicity. The feed and supports obstruct a portion of the beam, reducing the aperture's effectiveness to about 55-60%.

3.7.2 CASSEGRAIN FEED SYSTEM:

The Cassegrain feed method offers the benefit of a shorter total dish antenna length due to the use of a shorter distance between the radiating element and the parabolic reflector while necessitating a second reflecting surface. The physical measurement is reduced due to reflection during signal concentrating. It's possible that in specific setups, this will be beneficial.

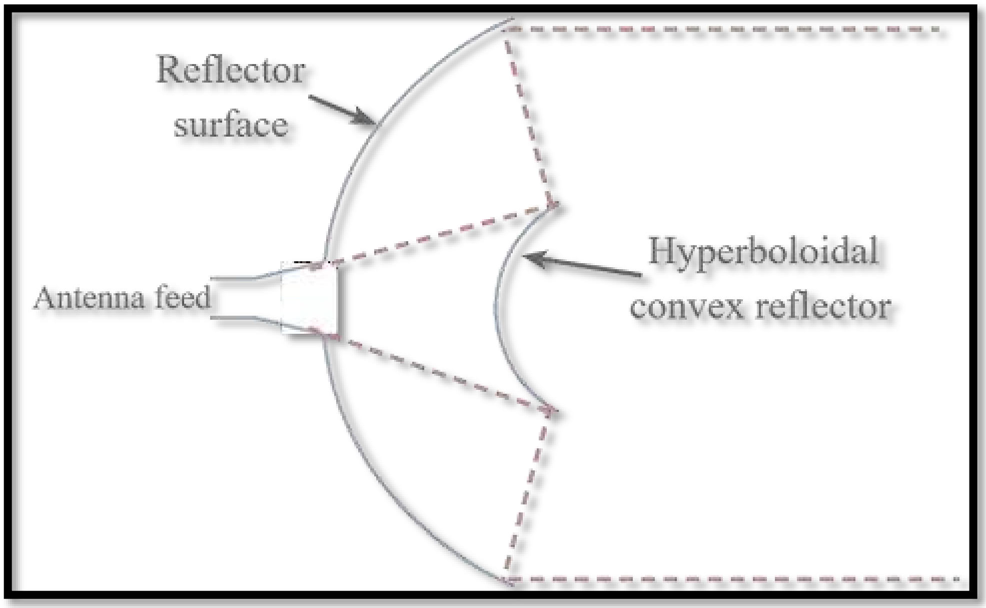

Fig 3.7: Cassegrain feed system.

Ref: https://www.electronics-notes.com/images/antenna-parabolic-reflector-cassegrain-feed-01.svg

This parabolic reflector feed system often achieves efficiencies between 65% and 70%. The original idea for the Cassegrain parabolic reflector antenna came from the Cassegrain telescope, thus the name. According to French priest Laurent Cassegrain, the invention of this reflecting telescope took place around 1672.

3.7.3 GREGORIAN PARABOLIC REFLECTOR FEED:

The feeding method used by Gregorian parabolic reflectors is very similar to that used by Cassegrain telescopes. The secondary reflector is concave or, more accurately, ellipsoidal, which is the main difference.

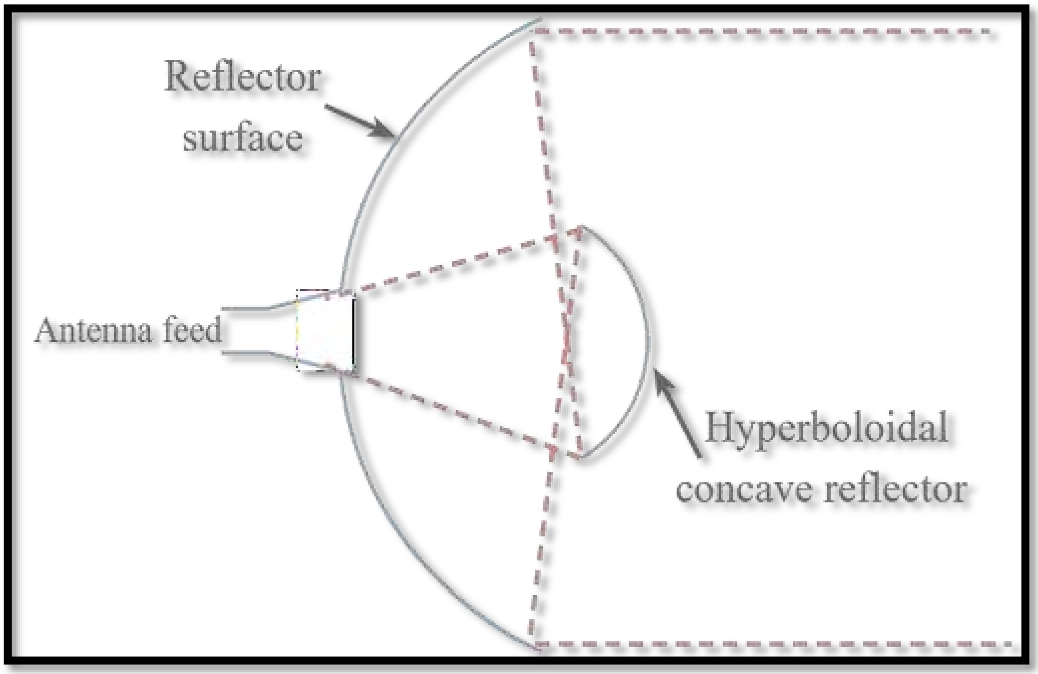

Fig 3.8: Diagram of a Gregorian feed parabolic reflector

Ref: https://www.electronics-notes.com/images/antenna-parabolic-reflector-gregorian-feed-01.svg

Because the technology improves lighting across the board, typical aperture efficiency values of over 70% are possible.

3.7.4 AXIS OR OFFSET PARABOLIC REFLECTOR ANTENNA FEED:

This kind of parabolic reflector antenna feed is not centred on the antenna dish itself, as the name suggests. An irregular section of the more commonly used parabolic reflector is substituted for this particular feed system. The focus and the feed antenna are off to one side of the reflector's surface in this configuration. This method improves upon the conventional parabolic reflector feed system by relocating the feed structure outside the beam path. In this configuration, it will not interfere with the light source.

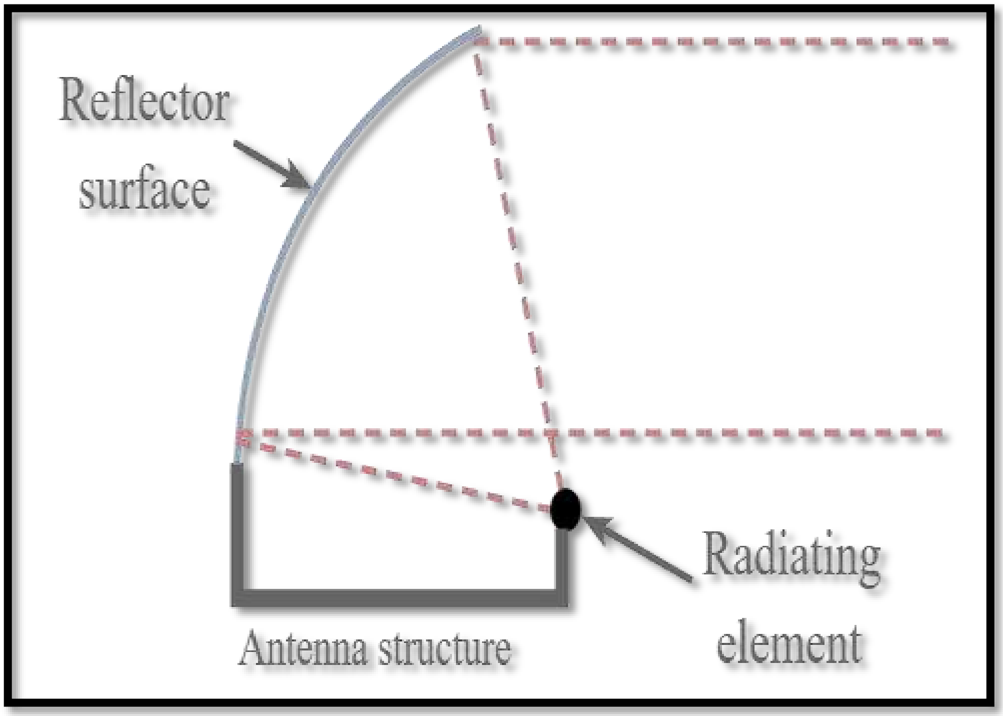

Fig 3.9: Diagram of an Offset feed parabolic reflector

Ref: https://www.electronics-notes.com/images/antenna-parabolic-reflector-offset-feed-01.svg

This method is often employed in residential satellite TV antennas, typically on the smaller side. It would suffer from decreased efficiency and signal strength if any part of the feed structure, such as the low noise box (amplifier, etc.), blocked a significant portion of the beam.

The offset feed is employed in multiple reflector designs like the Cassegrain and the Gregorian to avoid the same problems with the tiny reflector.The flexibility to tailor the antenna's feed system to a given application—be it satellite TV reception, microwave links, satellite communications, or general radio communications—is a crucial benefit of the parabolic reflector antenna.

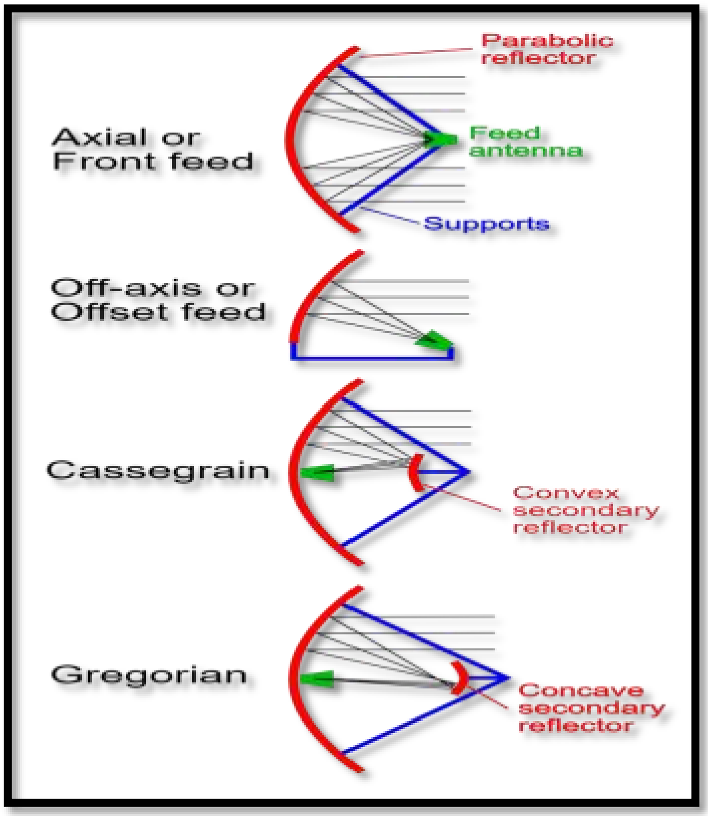

Fig 3.10: Types of Parabolic reflector feeds

Ref: https://lambdageeks.com/wp-content/uploads/2021/01/Parabolic_antenna_types2.svg

3.8 Reflector Types:

As depicted in the drawing, there are three main categories of reflecting surfaces: flat, spherical, and parabolic. Neither are flat plate reflectors always highly reflective, nor are they ever totally flat. Only a tiny part of the light is projected forward in a direction helpful to a mariner by a flat plate reflector, which reflects light in several directions.

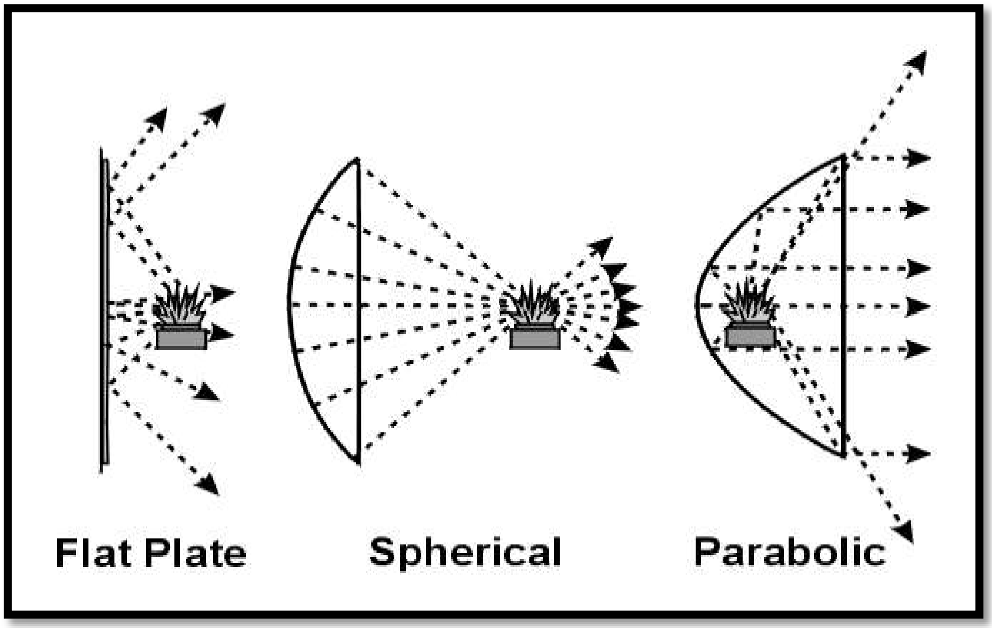

Fig 3.11: Types of reflector

Ref: https://uslhs.org/reflectors

Spherical reflectors direct the light beams toward the lamp's placement at the reflector's focal point. Although a spherical reflector makes the flame appear brighter, it does not focus the light into a helpful beam for mariners. In a concentrated beam that is directed in the direction the reflector is facing, parabolic reflectors collect light from the reflector's focus.

This focused beam of light can be manoeuvred and aimed toward the horizon to create a beneficial light for the mariner. However, a third of the entire amount of light that is available escapes from the reflector's edge and does not focus on the beam.Reflector manufacturing issues prevented them from achieving their theoretical potential. It was challenging to create the parabolic shape manually.

There were two main construction techniques used. In the early approach, a flat sheet of metal, typically copper, was hammered into a primitive parabolic shape using just the craftsman's expertise as a guide.Later, wooden moulds were hand-carved and compared to brass or paper templates. Later, iron moulds were employed to make more intricate parabolic reflectors after the metal sheets were first bent into figurative forms by hammering them into the mould. After that, the copper reflectors were polished to create a shiny surface for light reflection.

However, plain copper was quickly abandoned since it was not a mainly reflecting surface. To increase the copper's reflecting properties, a second building technique used hefty silver cladding that adhered to the metal. Sadly, silver oxidises (tarnishes) quickly, necessitating ongoing polishing.When chimney-less lamps were used, the reflectors had to be polished extremely frequently to remove the tarnish and the soot that was deposited on them by the lamp flame. In several instances, the silver cladding was polished so extensively that it was removed entirely off the copper surface, leaving the reflector ineffective at reflecting light.

Any metallic surface will have some of the light absorbed by microscopic blemishes, scratches, soot, and the metal itself. Experiments revealed that the most significant metal reflectors reflected just 55% of the available light, despite their best silvering and polished surfaces. Additionally, it was found that the reflector gathered only 70% of the total light from the lamp since some light is lost around the perimeter of the glass.

Thus, a virtually ideal reflector would produce around 39 per cent of the total light it received and directed in a beneficial direction, compared to as low as 20 per cent from an average-quality reflector. At any one time, an Argand lamp produced between 6 and 7 candlepower.

The combination of an Argand lamp with a high-quality 21-inch diameter, silvered parabolic reflector produced 2450 candlepower by collecting and reflecting 39% of the lamp's total output into a focused beam of light that improved the lamp's power by nearly 350 times.

The central axis of a parabolic reflector's beam is where the most intense light is concentrated. The effective candlepower is just 10% of that in the centre at places as close as 8 degrees on either side, or the light decreases rapidly after that point. To view the light beam from a distance, the mariner had to be virtually immediately in front of the reflector due to the light beam's tiny divergence. The useful beam of a typical reflector covers around 14 degrees of the horizon, and bright illumination covers about 5 degrees. The divergence depends on the size of the lamp flame and the reflector's focal distance.

3.9 LENS ANTENNAS:

The planar surface was employed by the antennas that we have discussed so far. The lens antennas use a curved surface for both transmission and reception. Glass is used to construct lens antennas, which adhere to lenses' converging and diverging characteristics. For applications requiring higher frequencies, lens antennas are employed.

RANGE OF FREQUENCY:

The lens antenna's frequency range begins at 1000 MHz, but its use increases from 3000 MHz and above. A lens's workings must be understood to comprehend the lens antenna. The refraction concept underlies how a typical glass lens functions.

LENS ANTENNA DESIGN & OPERATION:

The rays pass through the lens as collimated or parallel beams on the plane wave front if a light source is believed to be present at the focal point of the lens, which is at the focal distance from the lens.Rays that travel through the lens's centre are less distorted than those that travel via its corners. All of the rays are directed parallel to the wave front of the plane. Divergence is the name given to this lens phenomenon.

The process is reversed if a light beam is directed from the right side to the left of the same lens. The beam is then refracted and converges at a location known as the focal point, at a lens's focal length away. The term convergence refers to this occurrence.

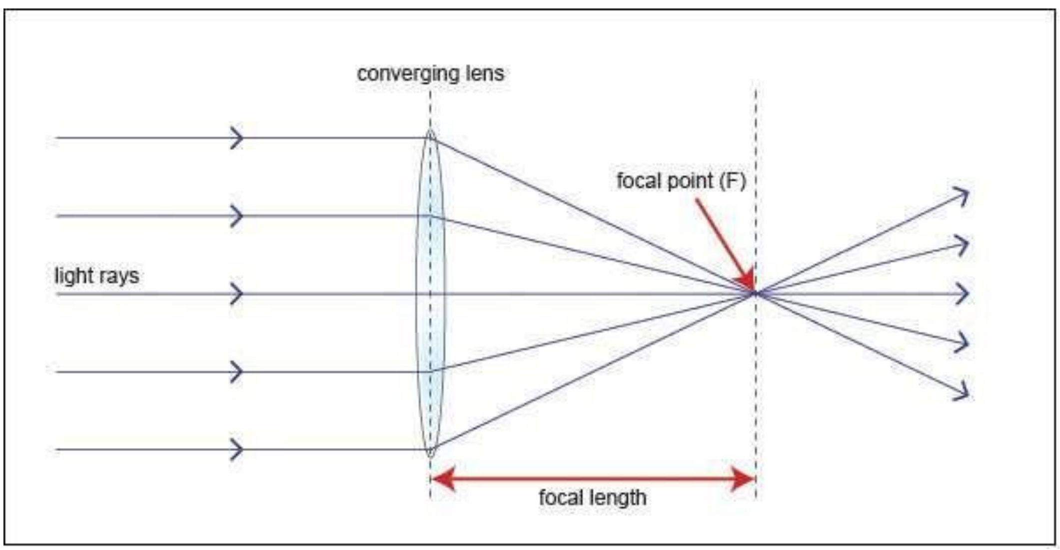

Fig 3.12: Ray diagram for lenses.

Ref:https://www.tutorialspoint.com/antenna_theory/antenna_theory_lens.htm

The focal point and focal length from the source to the lens are shown in the ray diagram. Collimated rays are another name for the parallel rays that are produced. In the illustration above, the source at the focal point becomes collimated in the plane wave front at a distance from the lens called the focus distance. This effect may also occur in reverse, which means that if a light is delivered from the left side of the lens, it will converge on the right side. The lens may be used as an antenna because of its reciprocity, which enables the use of the same antenna for both transmission and reception.

The representation of a lens antenna model is displayed.

Fig 3.13: Lens antenna

Ref:https://www.tutorialspoint.com/antenna_theory/images/working_lens_antenna.jpg

The refractive index should be smaller than unity to provide the focusing effects at higher frequencies. Whatever the refractive index, a lens's job is to make the waveform straight. This leads to the development of the E-plane and H-plane lenses, which also delay or accelerate the wave front.

VARIOUS LENS ANTENNA TYPES:

There are several different kinds of lens antennas available:

- Di-electric lens or H-plane metal plate lens or Delay lens (Travelling waves are delayed by lens media)
- E-plane metal plate lens
- Non-metallic di-electric type lens
- Metallic or artificial dielectric type of lens

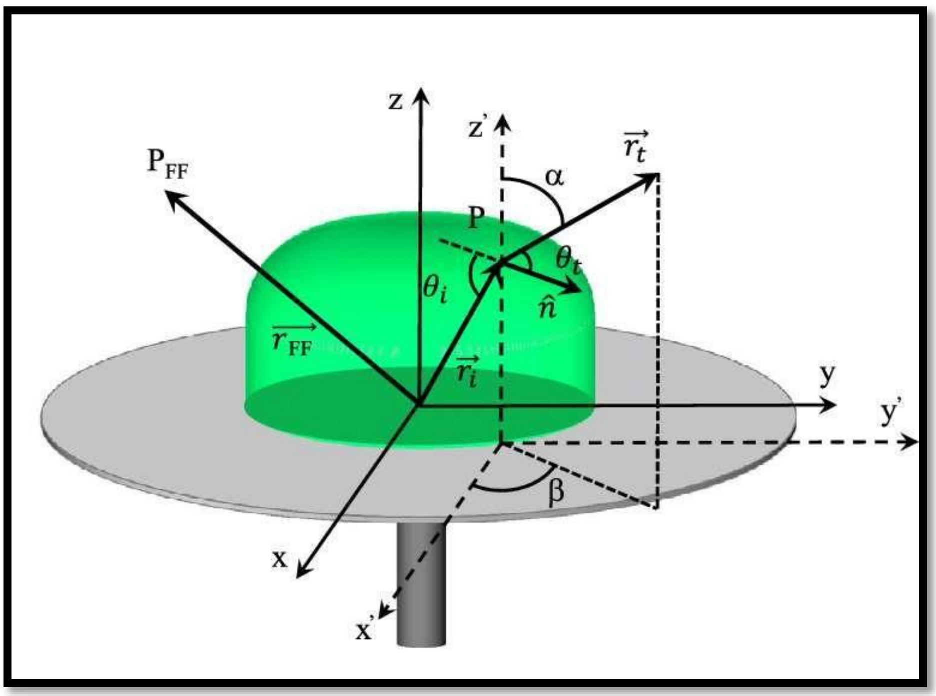

Fig 3.14: Geometry of dielectric

Ref: https://www.researchgate.net/figure/Geometry-of-a-dielectric-lens-antenna_fig1_258226874

3.9.1 ZONING:

A lens antenna's weight and dimensions are reduced by zoning the surfaces. The electromagnetic waves refracted by adjacent zones leave the lens with a 360° phase shift thanks to the form and height of the individual zones' profile. The aperture's field is still coastal.For frequencies over 3000 MHz, lenses and antennas are suitable. Lens antennas are thicker when the frequency is below 3000 MHz. Zoning can be used to reduce the thickness of lens antennas. Thickening (t) is determined by,

$$t = \frac{\lambda}{\mu - 1}$$

Where,

t = Thickness

λ= Free space wavelength

μ = Refractive index =(c/v)

Zoning is classified into two types.

(i) Curved surface zoning

(ii) Plane surface zoning.

3.9.2 TOLERANCES:

Feed and feed support shouldn't block the aperture in lens antennas. It has more design latitude. A parabolic reflector cannot handle waves of this size. The beam can be rotated with respect to the axis.

3.9.3 APPLICATIONS.

The applications of the Lens antenna are as follows:

- Used as wide band antenna
- Especially used for Microwave frequency applications
- Unstopped dielectric lenses are utilised as wideband antennas because they may operate over a broad frequency range, and their shape is independent of wavelength.
- Above 1000 MHz, lens antennas are frequently employed.
- It is designed to be utilised typically above 3000 MHz and not below because it is a microwave device.

In order to create higher level antennas known as parabolic reflector antennas, which are extensively used in satellite communications, one can use the convergent characteristics of lens antennas.

UNIT: IV

ANTENNA ARRAYS

4.1 INTRODUCTION:

The current distribution influences an antenna's radiation properties. By changing the structure's geometry, the current distribution can be somewhat controlled. For instance, by lengthening the dipole, the radiation pattern of a dipole antenna supporting a sinusoidal current allotment can be made more direct. The radiation pattern can only be modified to a finite extent by changing the current distribution. The limitations resulting from the fact that the current distribution of a structure must meet specific requirements to existing.

For instance, when a voltage is supplied to a dipole's terminals, the forward and reflected waves set up the dipole's current distribution, ensuring that the continuity condition and Maxwell's equations are satisfied everywhere. This results in zero current at the ends of the dipole and a sinusoidal distribution with a propagation constant of k.

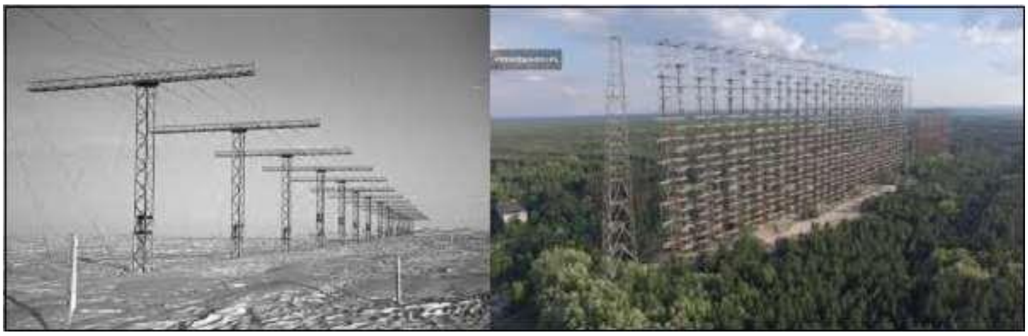

Fig 4.1: Antenna array

Ref:https://www.tutorialspoint.com/antenna_theory/antenna_theory_arrays.htm

The examination of the greater than dipoles makes it clear that the current distribution is sinusoidal and undergoes phase shifts every /2 distance. Therefore, maintaining an in-phase current distribution over a substantial portion of the wire is necessary to generate a larger field along the broadside direction. This cannot be done by merely lengthening the dipole.

It is possible to change the distribution's nature by altering the structure. Nevertheless, inserting arbitrary step changes into the present distribution is not simple. A step change can be introduced by including a charge storage device (a capacitor) while maintaining the current continuity condition. Let's think about a technique for sustaining the current source's phase across a length that is many wavelengths long.

Let multiple /2 dipoles placed end to end and triggered by in-phase currents create this long-line current distribution. Due to their independence, we can activate each dipole with a different amplitude and phase. A linear array is a name given to this configuration of antennas. A component of the collection is referred to as each antenna. The antenna components can also be organised into arrays in a 2D or 3D space. Another option is to build an array antenna from several component kinds. The fields of the various members are superimposed to form the array's pattern.

But adding some structure makes the analysis simpler. Array antennas are often comprised of identical components and set up in a regular grid, either in a 2D plane or along a line. Each element's orientation is also maintained to simplify the array pattern statement further.

DEFINITION:

An antenna array is a collection of antennas that are linked together and placed in a certain configuration to form a single antenna that may emit radiation in ways that individual antennas cannot.Antenna arrays are collections of isotropic electromagnetic frequency and energy radiators.

They offer a remedy for the issues brought on by single antennas. For example, the dipole antenna offers for better direction control than an isotropic antenna, but as the dipole's length increases, direction control may diminish. With a dual radiator setup, more control and flexibility can be quickly restored for beam direction.

4.2 Patterns:

An antenna array is a radiating system made up of radiators and other components. These radiators each have their unique induction field. The elements are arranged so closely together that their induction fields overlap. Thus, the radiation pattern they would emit would equal the vector sum of each one.Each antenna radiates independently, but when arranged in an array, all elements combine their radiation to create a single, high-gain, high-directivity beam that performs better while generating the fewest losses. Suppose the relative phases and amplitudes of the currents present at each antenna in the array determine the shape and direction of the radiation pattern. In that case, the antenna array is said to be phased.

Let's say we're thinking about an array made up of 'n' individual components of isotropic radiation. The following diagram (4.2) should clarify the situation. In this case, let's say that'd' units will serve as the separation between each next element.

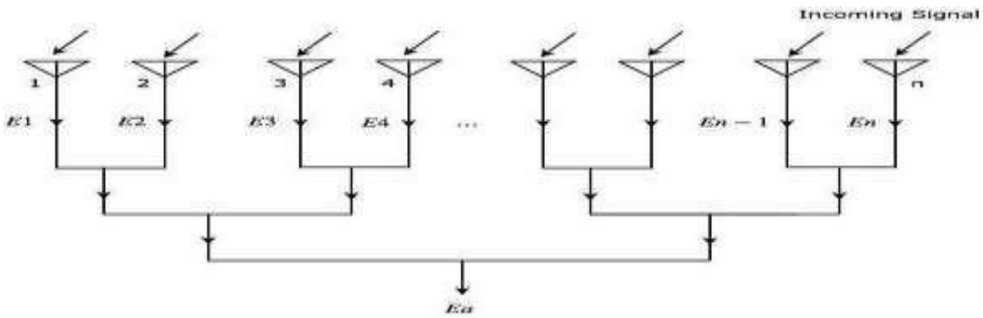

Fig 4.2: pattern radiation

Ref:
https://www.tutorialspoint.com/radar_systems/radar_systems_phased_array_antennas.htm

All the radiation elements are simultaneously exposed to the same incoming signal, as seen in the diagram. Therefore, the voltage produced by each component is also sin(ωt). Nonetheless, the phase difference Ψ between neighbouring components will remain constant.

It may be expressed mathematically as

$$\Psi = \frac{2\pi d \sin\theta}{\lambda}$$

Where,

Each radiation element has an incidence angle of θ.

For 'n' separate radiation elements, we can write the mathematical formulas for their output voltages as

$$E_1 = \sin[\omega t]$$

$$E_2 = \sin[\omega t + \Psi]$$

$$E_3 = \sin[\omega t + 2\Psi]$$

$$E_n = \sin[\omega t + (N-1)\,\Psi]$$

Where,

The voltages at which the first, second, third,..., nth radiation elements are able to emit energy are denoted by E1, E2, E3,..., En.

The signal's angular frequency is denoted by ω.

All the radiation elements are linked in a linear array, thus we can calculate the total output voltage Ea by summing the voltages of each element in the array.

It has a mathematical representation of,

$$E_a = E_1 + E_2 + E_3 + \ldots + E_n$$

$$E_a = \sin[\omega t] + \sin[\omega t + \Psi] + \sin[\omega t + 2\Psi] + \sin[\omega t + (n-1)\,\Psi]$$

$$\Rightarrow E_a = \sin\left[\omega t + \frac{(n-1)\Psi)}{2}\right] \frac{\sin\left[\frac{n\Psi}{2}\right]}{\sin\left[\frac{\Psi}{2}\right]}$$

The field intensity pattern. The field intensity pattern will have the values of zeros when the numerator of Equation 5 is zero

$$\sin\left[\frac{n\pi d \sin\theta}{\lambda}\right] = 0$$

$$\Rightarrow \frac{n\pi d \sin\theta}{\lambda} = \pm m\pi$$

$$\Rightarrow nd \sin\theta = \pm m\lambda$$

$$\Rightarrow \sin\theta = \pm\frac{m\lambda}{nd}$$

Where,

An integer, (m) may take on the values 1, 2, 3, and so on.

When both the numerator and denominator of Equation are zero, we may use the L-Hospital rule to determine the maximum values of the field intensity pattern. When the denominator in Eq. is zero, the numerator in Eq. is likewise zero.Now, let us get the condition for which the denominator of Equation becomes,

$$\sin\left[\frac{\pi d \sin\theta}{\lambda}\right] = 0$$

$$\Rightarrow \frac{\pi d \sin\theta}{\lambda} = \pm p\pi$$

$$\Rightarrow d\sin\theta = \pm p\lambda$$

$$\Rightarrow \sin\theta = \pm\frac{p\lambda}{d}$$

Where,

(p) is a complete integer that may take on the values 0, 1, 2, 3, and so on.

By setting p equal to zero, we have sin equal to zero. In this scenario, the major lobe's maximum field intensity value will be obtained. Maximum values of the field intensity pattern due to side lobes will be obtained for different values of p.Changing the relative phases of the current at each Antenna may control the radiation pattern's direction in a phased array. To this end, electronic scanning phased arrays have proven useful.

4.3 ARRAYS OF 2 ISOTROPIC SOURCES DIFFERENT CASES:

The Cramer-Rao bound (CRB) for the degree of overlap (DOA) of a single source is the same for all angles in an isotropic array.We determine what requirements must be met about the placement of array elements in both planar and volume arrays for the array to be isotropic.

The following arrays of two isotropic point sources:

- Equal amplitude and equal phase
- Equal amplitude and opposite phase
- Unequal amplitude and any phase

4.4 Principle of Pattern Multiplication:

Imagine a location in free space (0, 0, Z1) where an infinitesimal dipole of length dl is maintained (Fig. 4.3). Take I1 to be the dipole's current flowing in the direction of z. The vector potential method is used to determine the dipole fields.Different radial lengths l0, l1, l2, l3,... are shown in Figure 4.3, representing a more general scenario of identical antenna components distributed in three-dimensional space and the coefficients for the antenna feed are a0, a1, a2, and a3...

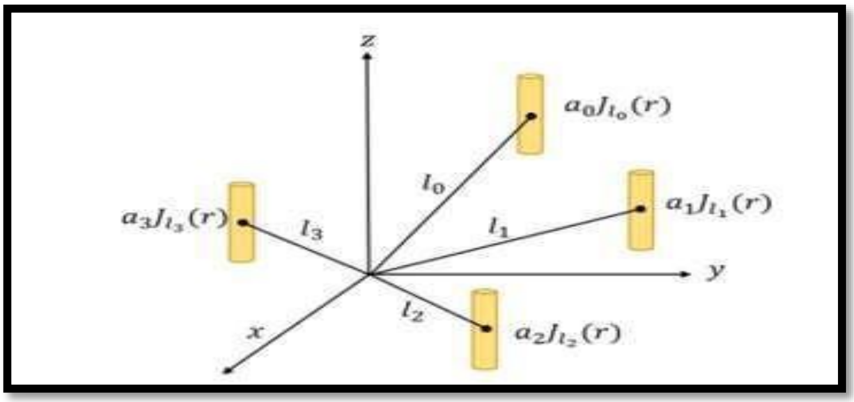

Fig 4.3: Current densities of antenna elements shifted in space

Ref: Current densities of antenna elements shifted in space – contributors to array factor of phased array antenna

Individual antenna element current densities are,

$$J_{l_0}(r) = a_0 J(r - l_0)$$
$$J_{l_1}(r) = a_1 J(r - l_1)$$
$$J_{l_2}(r) = a_2 J(r - l_2)$$

The total current density of the antenna array structure is

$$J_{total} = a_0 J(r - l_0) + a_1 J(r - l_1) + a_2 J(r - l_2) + \cdots$$

If we plug the preceding equation into the translational phase-shift property, we get the following expression for the total radiation vector of an N-element antenna array:

$$\begin{aligned}\mathbf{F}_{total}(\mathbf{k}) &= \mathbf{F}_{l_0}(\mathbf{k}) + \mathbf{F}_{l_1}(\mathbf{k}) + \mathbf{F}_{l_2}(\mathbf{k}) + \cdots \\ &= a_0 e^{j\mathbf{k}l_0}\mathbf{F}(\mathbf{k}) + a_1 e^{j\mathbf{k}l_1}\mathbf{F}(\mathbf{k}) + a_2 e^{j\mathbf{k}l_2}\mathbf{F}(\mathbf{k}) + \cdots \\ &= \mathbf{F}(\mathbf{k}) \sum_{i=0}^{N} a_i e^{j\mathbf{k}l_i} \\ &= \mathbf{F}(\mathbf{k})\,\mathbf{A}(\mathbf{k})\end{aligned}$$

$$\boxed{\mathbf{F}_{total}(\mathbf{k}) = \mathbf{F}(\mathbf{k})\,\mathbf{A}(\mathbf{k}) \qquad \text{(array pattern multiplication)}}$$

Array factor, denoted as A (k), combines the relative translational phase shifts and feed coefficients of the array members.

$$\boxed{\mathbf{A}(\mathbf{k}) = \sum_{i=0}^{N} a_i e^{j\mathbf{k}l_i} \qquad \text{(array factor)}} \qquad , \mathbf{k} = k\hat{r}$$

or equivalently,

$$\boxed{\mathbf{AF}(\theta, \phi) = \sum_{i=0}^{N} a_i e^{jk\left(\hat{\theta} \times \hat{\phi}\right) l_i} \qquad \text{(array factor)}}$$

The entire radiation pattern of an antenna array built with N identical antennas is equal to the product of the radiation vector of a single antenna element (also called the element factor) and the array factor, according to the array pattern multiplication property.

4.5 UNIFORM LINEAR ARRAYS – BROADSIDE ARRAYS:

Broadside antenna arrays have identical components arranged in a row perpendicular to the antenna's axis. This is the most common antenna setup, and it consists of a variety of identically spaced, horizontally arranged components, each of which receives a uniform phase and amplitude current. When the elements are excited, radiation is emitted most strongly in the average direction of the antenna axis and less firmly in the other rules. As a result, the radiation is sent in two directions simultaneously.

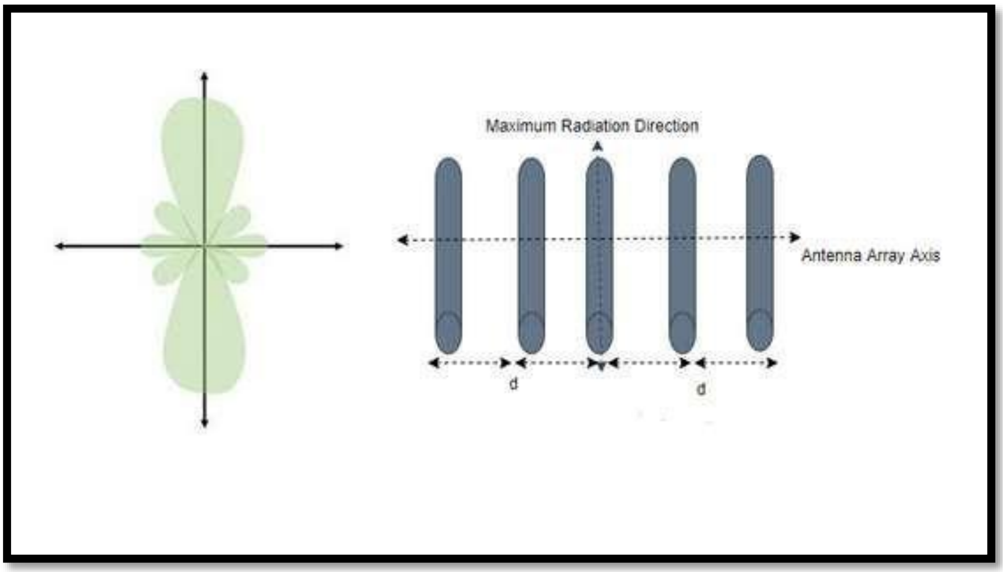

Fig 4.4: Broadside Type

Ref: **https://www.watelectronics.com/wp-content/uploads/Broadside-Antenna.png**

BROADSIDE ARRAYS OF ANTENNAS HAVE SEVERAL DISTINGUISHING FEATURES:

- The beam width might be anything from 2λ to 10λ.
- They are chiefly used for international broadcasting at low, high, and high frequencies.
- The number of array elements is determined by element spacing, cost, and required beam width.
- It is possible to improve the broadside array's directivity and gain by using a reflector in conjunction with it.

4.6 END FIRE ARRAYS:

The end-fire type's element layout is identical to that of the broadside array; the excitation pattern is what sets it apart. In this case, the components receive a signal that is 180 degrees out of phase with one another. These arrays are designed to maximise radiation along all axes.

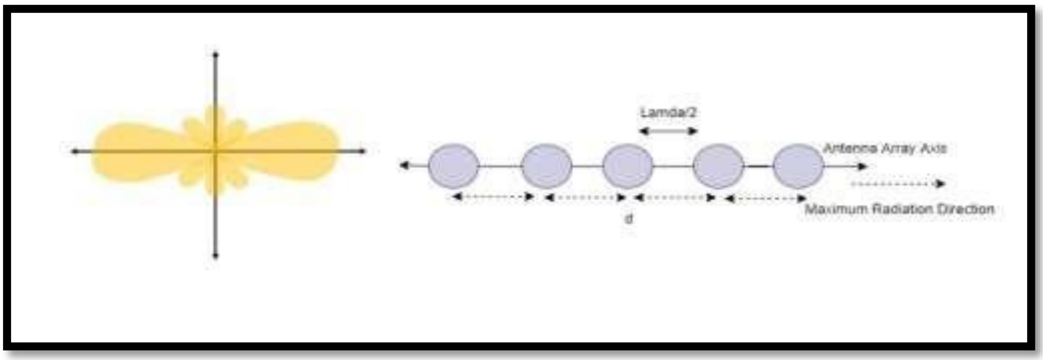

Fig4.5: End-Fire Type

Ref: https://www.watelectronics.com/antenna-array/

The end-fire antenna generates a unidirectional radiation pattern when triggered by a current with a constant amplitude but varying phase along the transmission line. It's been suggested that the phase difference between two objects should shift as their distance apart grows.

THE END-FIRE ANTENNA ARRAY HAS SEVERAL DISTINGUISHING FEATURES:

- The number of array elements is determined by element spacing, cost, and required beam width.
- Gain and directivity may be improved when a broadside antenna array is used with a reflector.
- They are mainly used for point-to-point communication and transmission to other countries.
- Either $\lambda/4$ or $(3\lambda)/4$. Separates the components.
- Use the sum of dipoles or elements of the same size.

THE BENEFICIAL AND NEGATIVE POINTS OF THE ANTENNA ARRAY ARE LISTED BELOW:

ADVANTAGES:

- Maximum gain and directivity may be attained using an antenna array.
- Maximal SNR ratio and high performance are attainable.
- Lowest possible energy waste
- Smaller lobes are diminished drastically.
- The power of the transmission has been amplified.

DISADVANTAGES:

- Antenna array maintenance is difficult.
- Additional room in the universe is required for the implementation of this system.
- A lot of energy is being lost due to resistance in the system.

USES FOR ANTENNA ARRAYS:

- Some scenarios in which the antenna array might be useful include:

- The communication field is a key application area for antenna array technology.
- Used in the military's radar equipment.
- Typically used for communicating across great distances.
- Wireless and satellite data transfer.
- In astronomy, they are an essential tool.

4.7 ANTENNA MEASUREMENTS INTRODUCTION:

Following the reciprocity theorem, it is known that any given antenna will exhibit identical transmit and receive patterns. Measuring the receive pattern instead of the sending pattern is standard practice due to the former's greater accessibility.

The antenna's receive pattern is the plot of the received power against the direction of arrival of the incident plane wave at a constant power density. That's why, before reading the received power, you need to be sure the antenna is indeed receiving a plane wave and that there's just a single plane wave incident on the antenna.

One transmitting and one receiving antenna are needed for pattern measurement. Unless otherwise specified, the remainder of this article will presume that the antenna being tested is the receiving antenna and that the transmitting antenna is being used to generate a plane wave at the site of the receiving antenna or the test antenna. To the human eye, the spherical wave emitted by an antenna at far distances seems to be a flat wave. Keeping the broadcast antenna at a great distance allows us to employ this technique to create a plane wave at the site of the receive antenna.

Maximizing R, the separation between the antennas, has a dual purpose:

- It makes sure that the wave that hits the receiving antenna is a flat plane and

- Very little energy is transferred between the two antennas, therefore the receive antenna's performance is unaffected by the transmitter's presence.

The far-field approximation works for transmission distances R > 2D2/λ from the antenna. The width, or D, of the transmitter antenna, is the greatest of any of its transverse dimensions. According to Fig. 4.6, R is the most significant path difference across a transverse dimension D for a spherical wave emitted from a point source retained at a distance δR.

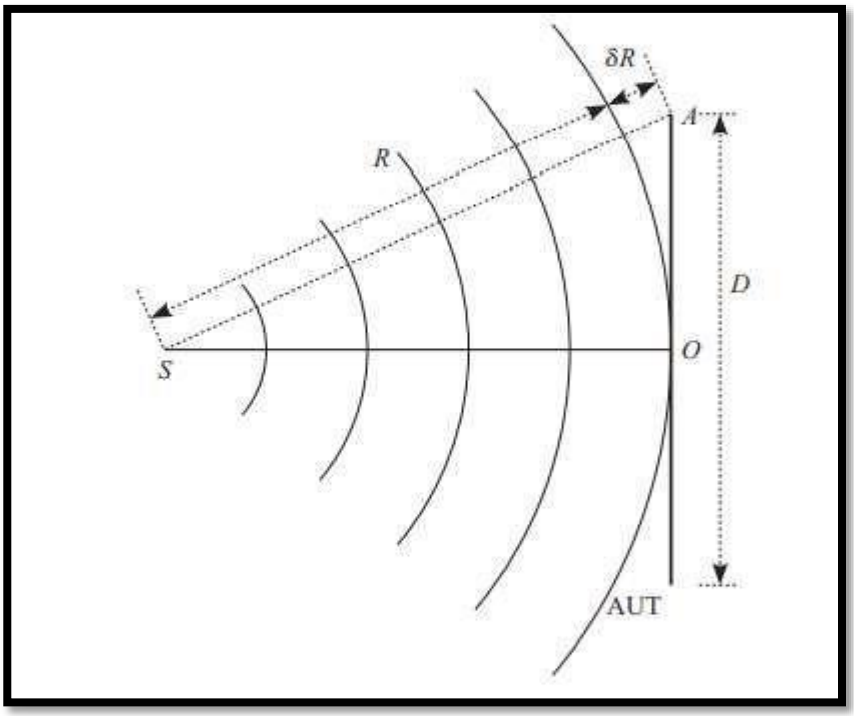

Fig 4.6: Phase difference between the plane wave-front and spherical wave-front

Ref: https://khasimgriet.files.wordpress.com/2016/07/harish-a-r-_-sachidananda-m-antennas-and-wave-propagation-oxford-university-press-2007.pdf

The path difference concerning the average distance SO = R is shown in the figure, with the point source located at S and the transverse dimension D used for the measurement. If R = 2D2/λ, the highest phase error is near the edge, where kδR equals π /8. Since two antennas are used in this measurement setup, we must choose the greater two transverse dimensions as D to place them in mutually inaccessible far fields.

Since the transmit antenna is often a compact horn, its transverse dimension D is used to determine the size of the receive antenna or test antenna, and R is set to be larger than 2D2/λ. Below this threshold, the nulls and amplitudes of the measured pattern might deviate from the antenna's far-field pattern.

Equally crucial is ensuring that there is precisely one plane wave at the antenna being tested (AUT). Since the transmit antenna emits radiation in all directions, the AUT may also be subject to interference from a reflected wave if there are any objects between the antennas. In most cases, this is not what you want to happen.

Therefore, it is essential to build the antenna array so that the reflected waves are either entirely removed or employed constructively to generate a lock with a uniform wavefront. It is possible to set up an antenna range outside. An outdoor range is a range that is open to the elements. The ground isn't the only thing that may reflect light in an outdoor range; buildings, trees, passing cars, and other items could do the same. When taking readings in the great outdoors, you could encounter electromagnetic interference from other systems like nearby radio/TV broadcasts, radar, mobile phones, etc.

An interior range, or indoor antenna range, may also be built. The absorber is a unique substance used to cover a structure's walls, floor, and ceiling to decrease reflections from these surfaces. Here we'll take a closer look at three outdoor range configurations: the raised, review, and slant. Measurements of the far-field pattern at the indoor and the compact ranges are also reviewed at length.

4.8 NEAR AND FAR FIELDS:

Antenna characteristics are just half the story; the near field and distant field must also be considered.When compared to readings taken at greater distances from the antenna, the radiation intensity changes when measured closer to the antenna, the distance from the antenna doesn't matter since the radiation intensity is still high enough to be effective.

NEAR FIELD:

Near-field refers to the region of electromagnetic space closest to the antenna. Although it contains radiation elements, its inductive effect gives it an additional name: inductive field.

FAR-FIELD:

The term "far-field" describes the field's location away from the antenna. As the radiation impact is decisive in this region, it is sometimes referred to by that name. This is the only area where the antenna's directivity, radiation pattern, and other vital factors are considered.

FIELD PATTERN:

Field pattern refers to the quantitative description of the field distribution in terms of the field intensity. Therefore, the electric field, E (v/m), is a convenient metric to use when plotting the radiated power from the antenna. This is why this phenomenon is referred to as a field pattern. When measured in watts (W), the phenomenon is called a power pattern.

Radiated field or power will be shown graphically as a function of

- Spatial angles (θ, Ø) for far-field.
- Spatial angles (θ, Ø) and radial distance(r) for near-field.

A diagram's visual aids make it easy to grasp the near and distant field distribution.

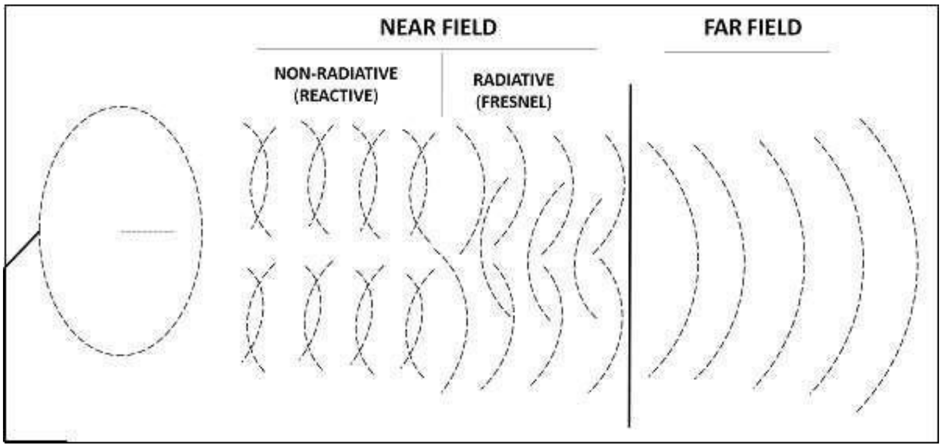

Fig 4.7: Distribution of near and far field regions

Ref:https://www.tutorialspoint.com/antenna_theory/images/field_pattern.jpg

DIFFERENT TYPES OF FIELD PATTERNS MAY BE IDENTIFIED BY:

- Two types of "near-field" regions exist the reactive near-field area and the radioactive near-field part.
- The area far away from the radiation source is termed the far field.

It is a near-reactive or non-radioactive field since radiation does not dominate in this region close to the antenna. Fresnel's field describes the area immediately next to an antenna where radiation predominates and where the distribution of the angular field is a function of the physical distance from the antenna. The neighbouring area is a far-field radiation source. The field distribution does not change as the distance from the antenna increases in this area. This area has a characteristic radiation pattern.

4.9 PATTERN MEASUREMENT:

Pattern measurements are performed only with the AUT in the receiving mode. Power received by an antenna at a matched load as a function of the incoming plane wave's direction and intensity is known as the antennas receive pattern.

Therefore, a second antenna must be maintained at a distance R > 2D2 /λ and send electromagnetic energy to form a plane wave at the site of the receive antenna; this allows us to measure the antenna's pattern.Now, with the test antenna at the sphere's epicentre, we may plot the received power vs. the plane wave's angle of incidence by moving the transmit antenna across the sphere's surface. There must be a constant direction of propagation between the transmit antenna and the sphere's centre.This guarantees that the plane wave's power density remains constant regardless of its incidence angle. The receive antenna rotates around the sphere's centre while the sending antenna remains in its original location. This configuration involves turning the reception antenna to modify the plane wave's orientation concerning the antenna while maintaining the plane wave's actual direction of arrival.

So long as the surrounding environment of the receiving antenna does not change, this is an identical simulation of physically shifting the broadcast antenna. The surroundings of the receive antenna are insensitive to rotation around its axis if an outdoor or indoor antenna measuring range is suitably configured to have zero or minor reflections in all directions replicating the free space conditions. Therefore, the transmit antenna must be permanently mounted on the antenna measurement range, whereas the receive antenna must have a movable mount (the test antenna).

Some measurements of antenna patterns, including those of polarization-dependent characteristics, require rotating the transmit antenna. However, 0◦ or 90◦ are usually all needed as the rotation limits. As a result, the transmit antenna mount often has a selection of fixed angles rather than a continuous rotational range. Only the receive antenna mount, also known as the antenna positioner, allows for rotation. An antenna's pattern may be gauged using this setup and the right transmit and receive gear. Instead of measuring the received power, the field pattern, phase pattern, polarisation pattern, etc., are calculated using the same setup but with other sensors to measure the appropriate characteristics.

4.10 DIRECTIVITY MEASUREMENT:

One of the most basic characteristics of an antenna is its degree of directivity. It quantifies an antenna's ability to direct the energy it emits in a certain direction. The directivity, or lack thereof, of an antenna would be 1 if its radiation pattern was uniform in all directions or (0 dB).The normalised radiation pattern of an antenna is expressed as a function in three-dimensional space:

$$F(\theta, \phi)$$

In essence, a normalised radiation pattern is essentially a radiation pattern with the magnitude scaled such that the highest value of the magnitude of the radiation pattern equals to 1.The mathematical expression for directivity (D) is as follows.

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}|F(\theta, \phi)|^2 \sin\theta d\theta d\phi}$$

Although this directivity equation seems to have a lot of moving parts, all it really measures is the "average power radiated throughout all directions" in the denominator and the highest value of F in the numerator.The directivity of an antenna may be calculated using this simple equation: peak radiated power divided by average radiated power.

4.11 GAIN MEASUREMENTS (BY COMPARISON, ABSOLUTE AND 3-ANTENNA METHODS):

ABSOLUTE GAIN MEASUREMENT:

Absolute gain is calculated using Friis's transmission formula. In decibels, the Friis transmission formula looks like this:

$$P_{r\text{dBm}} = P_{t\text{dBm}} + G_{t\text{dB}} + G_{r\text{dB}} + 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

To illustrate, imagine two identical antennas orientated and aligned in such a way that they are facing each other from a high vantage point or within a rectangular anechoic chamber.

(i) They are polarization matched and

(ii) Main beams of the two antennas are aligned with each other.

In this set-up, we are able to quantify the progress toward the maximum. From the radiation pattern, we may calculate the gain in any other direction. In order for the antennas to function in the far-field zone, R must be the distance between them. Allow us to denote the operating frequency by the wavelength,

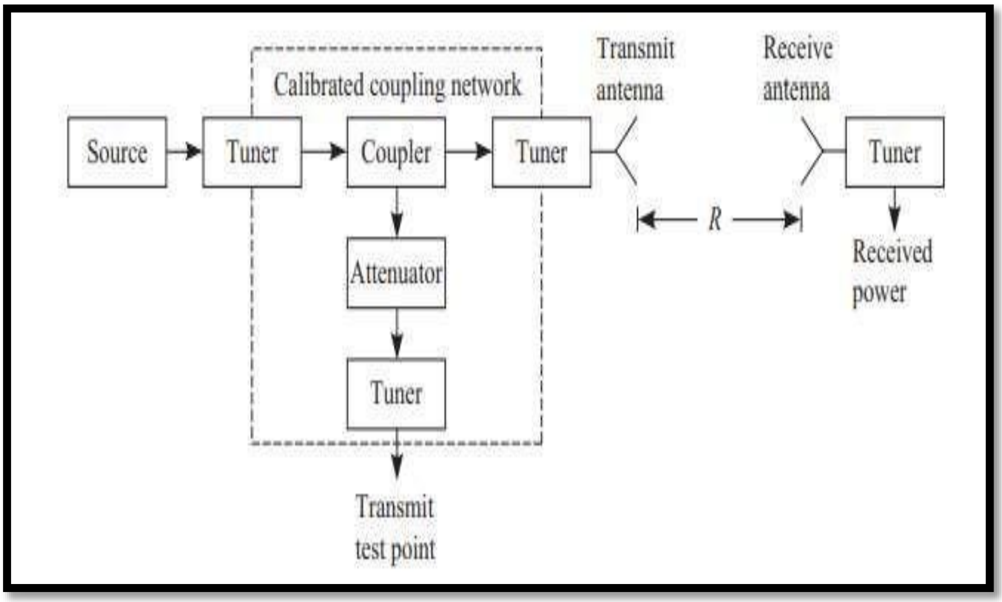

Fig 4.8: Measurement of transmit and receive powers

Ref: https://khasimgriet.files.wordpress.com/2016/07/harish-a-r-_-sachidananda-m-antennas-and-wave-propagation-oxford-university-press-2007.pdf

As can be seen in (Fig. 4.8) the transitions and receive powers PtdBm and PrdBm are measured using a calibrated coupling network and a matching receiver unit. Tuners are used for impedance matching of all components.

If the two antennas are identical, their gains are identical and Eqn. can be written as

$$G_{t\mathrm{dB}} = G_{r\mathrm{dB}} = \frac{1}{2}\left[P_{r\mathrm{dBm}} - P_{t\mathrm{dBm}} - 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)\right]$$

Hence it is possible to determine the antennas' gain. This technique is referred to as the two-antenna approach for gain measuring since it employs the usage of two antennas. If you don't have access to a set of mirror-image antennas, a third antenna will be needed to calculate the gain.

$$G_{A\mathrm{dB}} + G_{B\mathrm{dB}} = P^{AB}_{r\mathrm{dBm}} - P^{AB}_{t\mathrm{dBm}} - 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

$$G_{B\mathrm{dB}} + G_{C\mathrm{dB}} = P^{BC}_{r\mathrm{dBm}} - P^{BC}_{t\mathrm{dBm}} - 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

$$G_{C\mathrm{dB}} + G_{A\mathrm{dB}} = P^{CA}_{r\mathrm{dBm}} - P^{CA}_{t\mathrm{dBm}} - 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

Which may be solved in parallel to determine individual antenna gains.

4.12 GAIN TRANSFER METHOD:

To determine the gain of the test antenna, it is compared to a reference antenna whose gain has already been determined. A plane wave with the same polarisation as the test antenna is used to light the antenna. The matching load receive power (PT rdBm) is then calculated. The gain of the test antenna will be GT dB. Friis' formula,

$$G_{t\mathrm{dB}} + G^{T}_{\mathrm{dB}} = P^{T}_{r\mathrm{dBm}} - P_{t\mathrm{dBm}} - 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

This time, a standard gain antenna with a gain of GS dB is used in lieu of the test antenna, and the resulting P S rdBm is evaluated.Once again, the formula for transmitting information comes from Friis.

$$G_{t\mathrm{dB}} + G^{S}_{\mathrm{dB}} = P^{S}_{r\mathrm{dBm}} - P_{t\mathrm{dBm}} - 20\log_{10}\left(\frac{\lambda}{4\pi R}\right)$$

$$G^{T}_{\mathrm{dB}} = G^{S}_{\mathrm{dB}} + P^{T}_{r\mathrm{dBm}} - P^{S}_{r\mathrm{dBm}}$$

This allows us to calculate the antenna gain used in the experiment. The test antenna, the standard gain antenna, and the transmitter must all have the same polarisation for the transmission to succeeding. Matching the receiver's impedance to that of both antennas improves performance. This method may be used to figure out the gain of a linearly polarised antenna. One way to evaluate a circularly polarised antenna's gain is to compare it to the standard gain antenna for linear polarisation. The gain of a circularly polarised wave may be measured by isolating its two linear components using a linearly polarised antenna, then adding those two gains together.

To do this, we turn a linearly polarised transmit antenna vertically to emit vertically polarised radio waves. The next thing to do is to compare the power read by the test antenna to the power read by a standard-gain antenna set up to receive vertical polarisation. Calculating the test antenna's gain for a wave with a vertical polarisation requires. This enhancement will be referred to from now on as GT V dB.

To broadcast waves with a horizontal polarisation, rotate the antenna used for transmission by 90 degrees. This time, the reference antenna will be turned by 90 degrees to allow it to pick up horizontally polarised waves. We'll obtain measurements from both the test and the reference antenna, as usual.

How much of a boost did the test antenna for horizontally polarised waves experienced.

The total gain of the antenna used in the experiment is

$$G_{\mathrm{dB}}^{T} = 10\log_{10}(G^{TV} + G^{TH}) \quad \mathrm{dB}$$

The gains used in the aforementioned equation are ratios, not absolute values, and are denoted by GT V and GT H, respectively.

UNIT: V

WAVE PROPAGATION

5.1 INTRODUCTION:

The antenna fields computed from a given current distribution on the antenna have been the primary focus of the previous chapters' presentation of antenna theory. Radio waves' propagation was supposed to occur in an endless vacuum, and the effects of medium and discontinuities were disregarded. Unfortunately, this utopian scenario seldom happens in real life. Radio waves encounter various obstacles in the real world that might alter their path.

The most important of these are:

ASSUMING A SPHERICAL EARTH:

Because radio waves propagate in a straight line across space, the maximum distance that may separate any two sites on Earth's surface when using radio waves for communication is the horizon. Because of this, radio waves need a change in propagation direction to establish a communication connection beyond the horizon. This shift may be accomplished via several different means.

THE ATMOSPHERE:

The Earth's atmosphere begins to thin out all the way up to roughly 600 kilometres. The troposphere, stratosphere, mesosphere, and ionosphere are the several layers of the atmosphere. The troposphere, which stretches from the surface of the Earth to a height of 8-15 km, significantly impacts the propagation of radio waves near the character. The ionosphere, located at a higher altitude, is responsible for influencing radio signals.

ENGAGING WITH THE WORLD OF GROUNDED OBJECTS:

Many things, including buildings, trees, hills, valleys, bodies of water, and more, may block radio waves when they move near Earth's surface. Reflection, refraction, diffraction, and scattering are the most prominent effects of such objects' or discontinuities' interactions with radio waves.

Elements are involved in transmitting radio waves when mediums and barriers are present. The issue here might be seen as one of the electromagnetic fields. The issue, as mentioned earlier, with electromagnetic fields may be stated more formally by requiring that the field distribution be designed to satisfy Maxwell's equations everywhere and at all times. A mathematical formulation of this assertion and solving the related equations are challenging except for exceedingly simplified cases.

The interaction of electromagnetic fields with their surroundings is often broken down into a handful of well-understood, idealised wave phenomena like reflection, refraction, diffraction, scattering, etc., to simplify the field calculation. All of these may exist together in a complicated system. If we can distinguish between the various events, we can then handle them independently, and the superposition of the fields may be used to calculate the effective field behaviour. This kind of study requires a great degree of idealisation, simplification, and modelling. When the environment is modelled thoroughly, accurate predictions of the fields needed to set up communication linkages may be made.

Reflection, refraction, diffraction, and scattering are the four basic phenomena used to analyse radio wave propagation when considering the interaction of the fields with the medium and the discontinuities. A plane wave is reflected and refracted at a flat interface between two media with distinct electrical properties, as is well known. The fields' behaviour at the interface is described using Snell's equations of reflection and refraction.

However, this is an idealisation. If both the local radius of curvature of the interface and the wave front are significant relative to the wavelength of operation, then this approach may be used in practice. Geometric ray approaches may be used to forecast the ray pathways and field strengths since the scenario are similar to a plane wave interacting with a plane interface.

When electromagnetic fields hit a corner of an otherwise flat surface, induced currents may travel around the corner to the other side of the character, where they can generate domains in the shadow area. Diffraction is the term for this occurrence. Different and more advanced mathematics than Snell's rules are needed to compute the fields in the diffraction zone.

5.2 DEFINITIONS:

Propagation of these waves occurs along the line-of-sight distance, which is the same as the range of communication and is measured from the sending antenna to the receiving antenna.

It describes the connection between the speed of a wave (V), its frequency (F), and its wavelength (λ). The principle of wave motion. The speed of a wave in a vacuum is defined as the product of its wavelength (λ) and the frequency (F) of the waves it generates.

5.3 CHARACTERIZATIONS AND GENERAL CLASSIFICATIONS:

The electrical qualities of a medium affect the propagation constant. Since the only difference between free space and an isotropic media is the propagation constant, the calculations for propagation in an isotropic medium are similar to those in free space. The amplitude of a wave is reduced if the propagation constant is complicated. However, the pathways of propagation are not linear in an inhomogeneous medium. Refraction is a phenomenon in which the course of a ray is bent.

In other cases, the irregularities or interacting discontinuities have dimensions much smaller than the operating wavelength. When a ten cm-long electromagnetic plane wave lights a one mm-diameter raindrop, the induced currents on the drop generate secondary fields in all directions. We refer to these fields as "scattered fields." Scattering refers to the process through which fields interact with in homogeneities and discontinuities that are on the order of the wavelength or less. Due to atmospheric in homogeneities, turbulence, rain droplets, etc., scattering may occur.

Fields caused by a single, perfectly spherical, scattering particle lighted by a plane wave may be formally described and solved; however, statistical approaches are used to analyse more complicated circumstances, including a dispersion of particles or random irregularities and turbulence. The propagation characteristics of the area between transmit and receive antennas must be investigated before establishing a connection between the two sites. The presence of the earth and atmosphere significantly alters the field distribution close to the antenna and, by extension, the characteristics of the communication connection.

The troposphere, ground reflections, diffraction and scattering by barriers like buildings, trees, in homogeneities, etc., and the ionosphere are the key elements that impact the propagation when creating a practical communication connection between two sites on the planet. Ground wave propagation refers to studying electromagnetic wave propagation, particularly the interaction between the ground and the troposphere. Ionosphere propagation is seen as a distinct phenomenon from expected propagation.

THE TRANSMISSION AND RECEPTION OF RADIO WAVES:

Electromagnetic waves propagated without wires are used as the transmission medium in radio communication systems. For these tasks, a wide variety of antenna parameters is available.

The bandwidth and frequency of the signal being broadcast determine the size of these antennas. The propagation of electromagnetic waves may be broken down into two categories.

Specifically, these three types

- Line of sight (LOS) propagation
- Ground wave propagation
- Sky wave propagation

The Earth and the ionosphere are a waveguide for electromagnetic wave transmission in the ELF and VLF frequency regions.It is in these frequency bands that global coverage of communication signals is possible. Narrow bandwidths characterise the channels. This means the data can only be sent in a digital format and at a modest rate through these channels.

5.4 DIFFERENT MODES OF WAVE PROPAGATION:

Electromagnetic waves may travel through the air, through space, and through the ground. Radio waves are electromagnetic waves that have a frequency between a few hertz (Hz) and around 10^{11} Hz. In the absence of a physical connection, these waves may be used to convey data.

PROPAGATION OF GROUND WAVES:

Ground waves or surface wave propagation refers to the transmission and reception of radio waves along the earth's surface from a sending antenna to a receiving antenna. To put it simply, radio waves that move or spread along the ground are called ground waves. When these radio waves travel through the earth, they cause a current to flow. While travelling through a medium, waves will experience both loss and absorption. Inevitably, there will be some kind of power or signal degradation. For every given wave's frequency, the losses will be proportional to the square of the wave's frequency. For this reason, it works well with low-frequency waves alone. This method is often used in the realm of broadcasting.

SPACE WAVE PROPAGATION:

Space wave propagation is the process by which radio waves from a broadcasting antenna travel into space, around the earth, and into a receiving antenna. There is another name for this phenomenon: line-of-sight propagation. Space waves are another name for the radio waves that pass unimpeded from the sending antenna to the receiving antenna. Space wave transmission typically employs megahertz (MHz) frequency waves. Since our planet is spherical, the antenna's height must be maximised in order to get maximum range.

SKYWAVE PROPAGATION:

When radio waves travel from a transmitter to a receiver, either directly or by ground reflection, the process is known as sky wave propagation. Propagation of electromagnetic waves via the ionosphere.The ionosphere has a lower refractive index than empty space, and this index decreases with altitude. Accordingly, radio waves undergo TIR. The ionosphere has been shown to contain radio waves with a frequency lower than 3 MHz, while radio waves with a frequency higher than 30 MHz may travel through it with just a little shift.

5.5 RAY AND MODE CONCEPTS:

RAY THEORY:

The term "ray" is often used to describe a concentrated light beam. Classical optics or geometry-based theory of light describes this. Light's restricted qualities, such as refraction and reflection, are poorly represented by the ray theory. One definition of a light ray is a line or curve that is perpendicular to the direction of the light's wave fronts. In this sense, the light ray is the same as the wave vector. Light refraction may be modelled using rays. Light rays will necessarily be deflected at the boundary when travelling between two different mediums.

The bending angle is based on the refractive indices of the medium involved. Ray's theory of light is used to do even the most basic calculations involving optical devices like telescopes, microscopes, or simple lens systems.

MODE THEORY:

Fibre optics relies heavily on the principles of the mode theory of light propagation. One must first comprehend the meaning of the word "mode" before studying the mode theory of light. The study of standing waves uses the concept of "mode" to describe the wave's characteristics. When two waves of the same frequency and amplitude but in different directions interact, a standing wave is created. There is no overall movement of energy in a stationary wave. The total number of loops determines the mode of the standing wave. Fibre optics rely on modes produced when waves reflect off the fibre's cylindrical walls. There will be signal attenuation if a standing wave is generated. Therefore, the number of frequencies sent over optical fibre is limited by the number of modes within the thread.

The term "channel bandwidth" describes how wide the channel is. To define itself, mode theory relies on the wave theory of light to explain things like diffraction and interference.

DISTINCTIONS BETWEEN THE MODE THEORY AND THE RAY THEORY OF LIGHT:

The concept of rays has close ties to geometric optics. Neither the wave nor particle nature of light is assumed. Assuming light to be a wave is essential to the mode theory of light. Calculating values like bandwidth requires knowledge of the light's mode theory, whereas features like magnification or distance to the object or picture need an understanding of the light's ray theory.

GROUND WAVE PROPAGATION:

5.6 INTRODUCTION TO GROUND WAVE PROPAGATION:

Ground wave propagation refers to transmitting electromagnetic waves near the Earth's surface, especially in the troposphere. Multiple pathways exist for a sent wave from a transmit antenna to a receiving antenna on Earth. A direct route will exist if the antennas are within visual range of one another.

That kind of wave is called a natural wave since it travels straight. Electromagnetic radiation may also get to the receiving antenna through a ground-reflection route. Aside from direct propagation, the wave may also reach the receiver by scattering and diffraction. A space wave is any electromagnetic radiation that travels across space, including those transmitted directly, reflected, diffracted, or scattered. For instance, electromagnetic waves in a cellular communication system must traverse a highly complex environment, including many buildings, trees, roadways, etc. Electromagnetic waves emitted by a transmitter may travel to a receiver in a variety of indirect ways, including reflection (off the ground or building walls), scattering (from tree leaves or rain), and diffraction (from the edges of structures). Besides conduction, surface waves may also transmit energy. In addition to being reflected and shipped, a portion of an electromagnetic wave's energy may also travel in a straight line over an interface between two different media; this is what we call a surface wave. This is the most common path for vertically polarised radiation to transmit energy at low and medium frequencies (LF and MF). In this part, we discuss ground wave propagation's many methods and properties. Incorporating this data into terrestrial communication setups is a good idea.

The shape of the Earth itself determines the path of a ground wave. One term for this kind of wave is "square wave." The Earth's magnetic field deflects the wave and reflects the receiver. A wave like this is called a reflected wave.

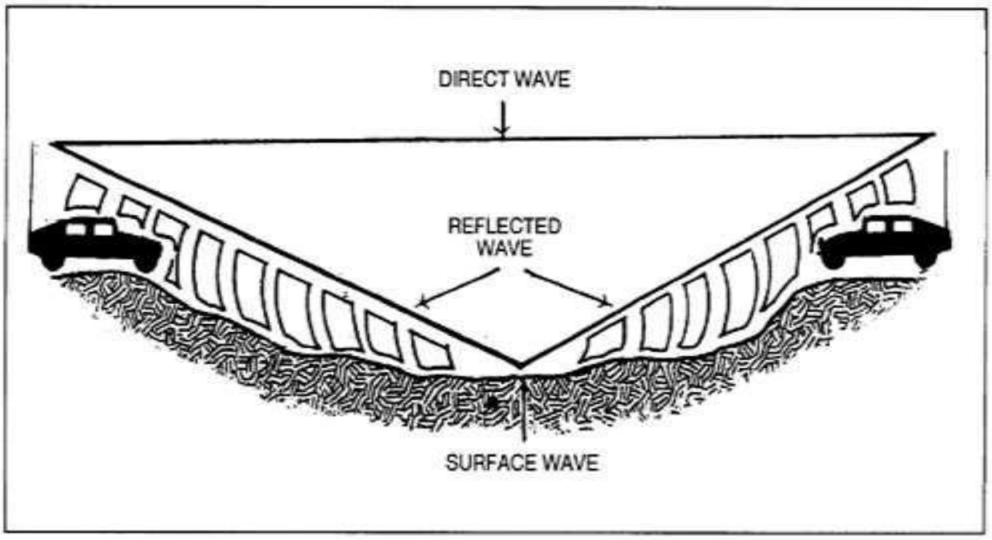

Fig 5.1: Parts of Ground wave propagation

Ref:https://www.tutorialspoint.com/antenna_theory/images/ground_wave_propagation.jpg

The propagation of ground waves is shown in the above figure (5.1). A ground wave is a kind of wave that travels through the Earth's atmosphere. At the receiving station, the signal combines the direct and reflected waves. When the wave reaches the receiver, the delays are eliminated. The movement is boosted for clear transmission and filtered to remove noise.

5.6.1 PLANE EARTH REFLECTIONS:

- The phenomenon of reflection occurs when a wave strikes a big object concerning its wavelength. The Earth's surface and tall structures are two such instances.
- Diffraction happens when an item with sharp edges or imperfections on its surface blocks the radio signal between the transmitter and the receiver. The wave's movement around the barrier is affected by the edges.
- When a wave travels through a medium, the direction of the wave changes (via refraction) when it encounters an interface.

- For this reason, we will focus on how atmospheric refraction and bending of radio waves facilitate long-distance communication.
- Scattering happens when radio waves bounce off of particles considerably smaller than the wavelength, and the density of these particles might be relatively high. For instance, radio signals may be significantly attenuated depending on their frequency if they reflect off of raindrops.

The Earth's surface is the most important for terrestrial linkages among environmental reflection sources.

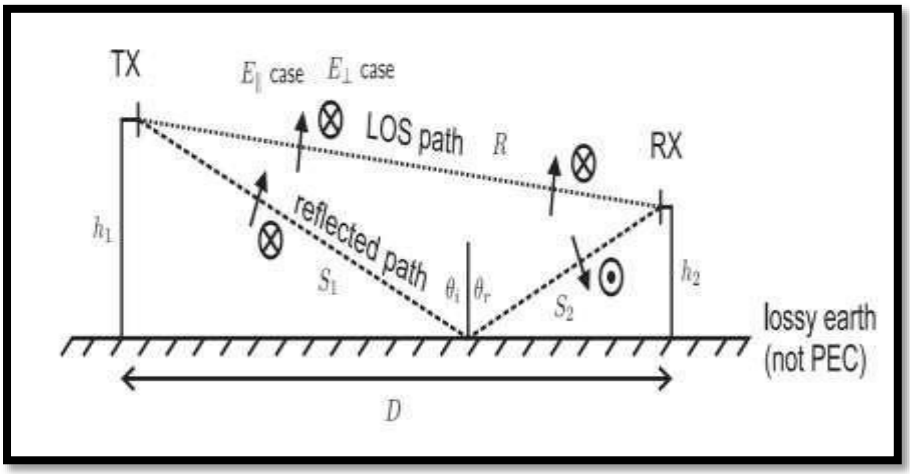

Fig 5.2: Plane Earth-Reflection

Ref: https://www.waves.utoronto.ca/prof/svhum/ece422/notes/18a-planeearth.pdf

For both the parallel and perpendicular polarisation instances, E-field vectors are provided. You should know that there are two ways for a signal to get from the TX to the RX: directly via the air (line-of-sight, or LOS) or indirectly (reflected, or IR). We have previously drawn and deduced the polarizations of the components proved to be true for the situation of a TE/TM polarised wave impacted upon a media interface, and they match up well. The LOS route maintains the same polarisation in the TE and TM polarisation cases. At the same time, the reflected path displays reflected components whose polarization is 180 degrees out of phase with the LOS path.

This happens when contact with a lossy dielectric material has an incidence angle of fewer than ninety degrees θi → 90◦ (grazing incidence).

Since the antenna heights h1 and h2 are often much less than the TX-RX spacing, the grazing angle assumption holds. For this progression, we also regard the Earth as a flat surface, albeit a spherical Earth will be considered in subsequent challenges. The amount of power received at the receiver under these circumstances is of interest to us. To examine the scene shown, it is tempting to use picture theory. Remember that the electric fields generated by the "picture" in this scenario are 180 degrees out of phase with the transmitted field since the signs of $\Gamma_{\parallel}$ and Γ⊥ for grazing incidence are opposite.

We do this by invoking a "modified" image theory, in which the vertical components of the field created by the picture are inverted concerning classical image theory with a PEC ground plane. Alternatively, we can think of the image plane as satisfying the boundary conditions; in the PEC-based image theory case, the tangential E-fields must sum to zero at the interface, whereas in the "modified" image theory case, the image plane represents the interface between two dielectrics where the tangential E-fields are equal but do not cancel.

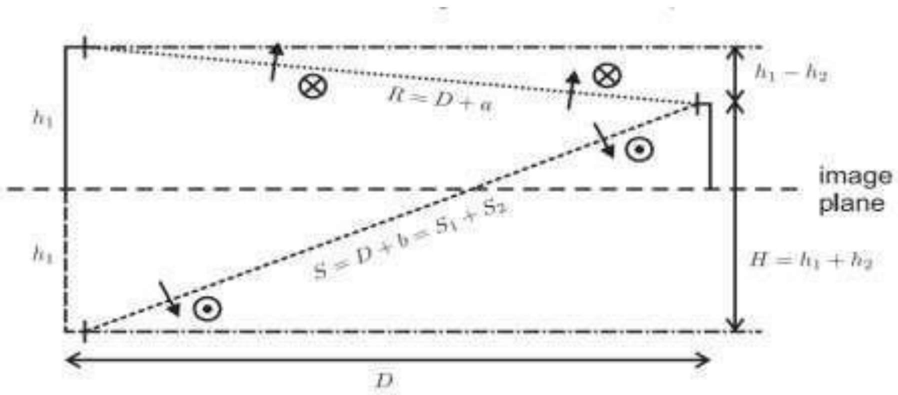

Fig 5.3: Image plane of PER

Ref: https://www.waves.utoronto.ca/prof/svhum/ece422/notes/18a-planeearth.pdf

$$H^2 + D^2 = S^2 = (D+b)^2 = D^2 + 2Db + b^2.$$

$D \ll b,$

$$H^2 \approx 2Db \Rightarrow b = \frac{H^2}{2D} = \frac{(h_1+h_2)^2}{2D}.$$

$$a = \frac{(h_1-h_2)^2}{2D}.$$

Comparable reasoning was used to analyse the 2-dipole array that was regarded back in the past tense. In this situation, there are two pathways leading to the receiver: the line-of-sight (LOS) path (length R = D + a) and the reflected way (length S = D + b). Thus, the horizontal separation distance D is more than the total length of each route plus an or b.. Comparing the diagram's more giant triangle to the smaller one,

As a result of the superposition principle, the intensity of the electric field measured by the receiving antenna is directly related to

$$\frac{e^{-j\beta R}}{R} - \frac{e^{-j\beta S}}{S} = \frac{e^{-j\beta R}}{R}\left[1 - \frac{e^{-j\beta(S-R)}}{S/R}\right]$$

Given that the image generates a field with the opposite sign as the line-of-sight route due to the 180° phase shift created at the reflection interface, the term in parentheses is understood to be a correction term for the reflection, a kind of array factor for an antenna and its image. The bracketed phrase is a commonplace line-of-sight propagation term, similar to what we view from an antenna.The following is a close approximation of this adjustment phrase. In the first place, we may assess the exponential term by

$$\begin{aligned} S - R &= (D+b) - (D-a) = b - a \\ &= \frac{(h_1+h_2)^2}{2D} - \frac{(h_1-h_2)^2}{2D} \\ &= \frac{2h_1h_2}{D}. \end{aligned}$$

$$\frac{S}{R} = \frac{D+b}{D+a} = 1 + \frac{b-a}{D} = 1 + \frac{2h_1h_2}{D^2} \approx 1$$

By the above equations, the field term becomes,

$$\begin{aligned} 1-\frac{e^{-j\beta(S-R)}}{S/R} &= 1-e^{-j\frac{4\pi}{\lambda}\frac{h_1h_2}{D}} \\ &= e^{-j\frac{2\pi}{\lambda}\frac{h_1h_2}{D}}\left(e^{j\frac{2\pi}{\lambda}\frac{h_1h_2}{D}}-e^{-j\frac{2\pi}{\lambda}\frac{h_1h_2}{D}}\right) \\ &= j2e^{-j\frac{2\pi}{\lambda}\frac{h_1h_2}{D}}\sin\left(\frac{2\pi h_1h_2}{\lambda D}\right) \end{aligned}$$

The received power may be calculated by using the square root of the size of this adjustment factor to Friis' calculation.

$$\begin{aligned} \frac{W_r}{W_t} &= \frac{G_rG_t\lambda^2}{(4\pi R)^2}\cdot 4\sin^2\left(\frac{2\pi h_1h_2}{\lambda D}\right) \\ &= \frac{G_rG_t\lambda^2}{(4\pi R)^2}\cdot g_{PE} \end{aligned}$$

Where the plane earth reflection is accounted for by the gain term g_{PE} (equivalent to 1/l P E, the reciprocal of the plane earth reflection loss), an interference process at the receiver is reflected in the sinusoidal shifts we see when we change h1, h2, λ, and D. If the line-of-sight and reflect pathways are 180◦ degrees out of phase, destructive interference will occur, causing the signal to be nulled entirely (faded) at the receiver. This is a very undesirable consequence of any kind of communication system. More so, if we think about what occurs at extremely distant sites when the parameter to the sin is relatively little then,

$$\sin^2\left(\frac{2\pi h_1h_2}{\lambda D}\right)\approx\left(\frac{2\pi h_1h_2}{\lambda D}\right)^2$$

$$D\approx R,$$

$$\frac{W_r}{W_t}=\frac{G_rG_t\lambda^2}{(4\pi R)^2}\cdot 4\left(\frac{2\pi h_1h_2}{\lambda D}\right)^2=\frac{G_rG_th_1^2h_2^2}{R^4}.$$

As a

result, the received power becomes independent of frequency and, more importantly, decays at an astounding rate of 1/R4. So instead of losing just 20 dB of signal strength as would happen in open space, we lose 40 dB when the distance increases by a factor of 10.

5.6.2 SPACE AND SURFACE WAVES:

(a) Free Space Propagation:

Free space is the absence of any material or things that may potentially interfere with electromagnetic radiation. At great distances from an antenna emitting electromagnetic waves, the radiated fields take the shape of spherical waves, with the angular power distribution determined by the antenna design. For a given distance R, the Friis formula may be used to calculate the power received, Pr.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$$

Pt is the transmit power, and Gt and Gr are the gains at the send and receive antennas. Because electromagnetic radiation travels straight from the transmit antenna to the receive antenna, this communication connection is known as a line-of-sight (LOS) link. The free space path loss is the multiplier [λ/(4R)]2 that occurs because of the propagation. It is a representation of the signal's weakening as a result of power dispersion with increasing distance, denoted by the parameter R. Using a decibel scale, we can write the route loss as

$$P_L = 10 \log_{10} \left(\frac{4\pi R}{\lambda} \right)^2 \text{ dB}$$

(b) Surface Waves:

The electric field is created by a vertically positioned dipole in the air. R2 = R1 = d and ψ = 0 if the dipole and field points are both on Earth's surface but separated by a distance of d. There is no net electric field because the electric fields from the dipole and its image cancel with each other if the ground has finite conductivity (typically from 10^−3 S/m to 30 × 10−3 S/m), Γ = −1. There is no net electric field on Earth's surface because the direct and ground-reflected waves cancel each other out to create the space wave.

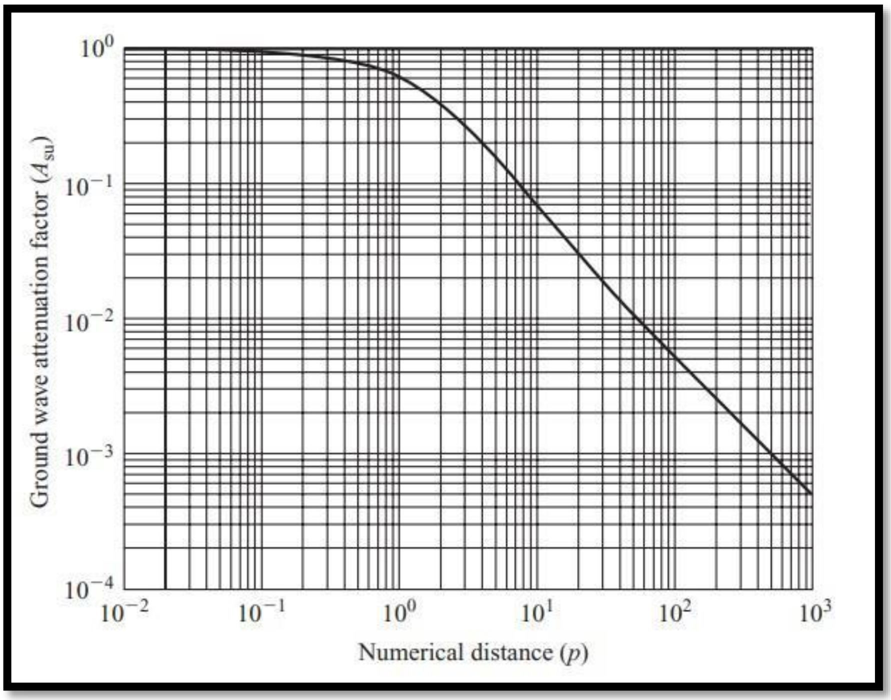

Fig 5.4: Ground wave attenuation factor as a function of numerical distance

Ref: https://khasimgriet.files.wordpress.com/2016/07/harish-a-r-_-sachidananda-m-antennas-and-wave-propagation-oxford-university-press-2007.pdf

The waves may then travel along the surface. Surface waves are the dominant mode of propagation for frequencies between a few kilohertz and a few megahertz.

A vertical monopole is employed to transmit in the MW frequency region in the AM broadcasting example. Due to their proximity to the ground, radio receivers pick up broadcast signals as surface waves. Several hundred kilometres of usable propagation may be achieved using the surface wave mode.The electrical qualities of the ground (relative permittivity and conductivity) across which the wave travels affect its attenuation factor, which in turn is a function of the distance between the transmitter and the receiver. The attenuation factor is sometimes referred to as the ground wave attenuation factor when measured at the Earth's surface.

A vertically polarised wave's electric field will be forward-slanted when it is close to Earth's surface. The conductivity and permittivity of the Earth affect the degree to which a wave is tilted. In most cases, the horizontal component is weaker and out of phase with the vertical part. This means that the electric field is elliptically polarised and relatively near the planet's surface.

5.6.3 WAVE TILT:

The wave front slows slightly as it travels, following the Earth's curvature. Increasing the angle reduces the electric field intensity of the wave. After a certain threshold of distance, the surface wave's energy is completely dissipated and vanishes.

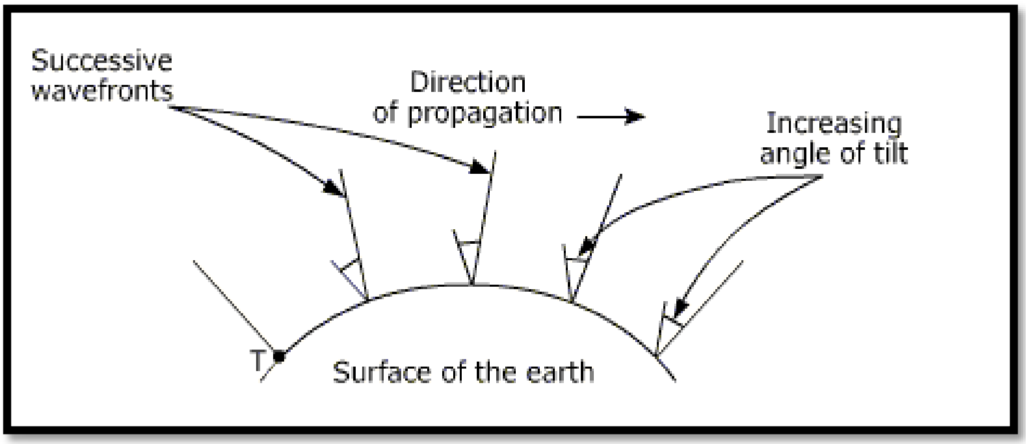

Fig 5.5: Wave Tilt

Ref: https://haygot.s3.amazonaws.com/questions/34764_13202_ans.PNG

When the vertically polarised ground wave at the surface of the Earth changes its orientation, this is known as a wave tilt. The phenomenon is caused by diffraction. Because of the slant, the electric field contains horizontal and vertical components that are out of phase with one another.

5.6.4 CURVED EARTH REFLECTIONS:

Diffraction is the process by which electromagnetic waves are deflected around the corners and edges of objects along their path. Through diffraction, signals may get to areas beyond the barriers. The strength of the diffracted field at the receiver site may be sufficient to establish a communication connection even if the receiver is positioned behind an object such that the line-of-sight route is entirely impeded. The received signal intensity in the blocked or shadow zone is affected by the receiver's location and the geometry of the obstruction.The mathematical calculation of the intensity of the diffracted field of an object that is both complicated and irregular is challenging. To make the computation more accessible, the supplied terrain may be approximated in terms of regular geometries.This method provides an approximation of the diffracted fields with reasonable precision. When shadowing is brought on by a single hill or mountain, the diffracted field is calculated using a knife-edge diffraction model.

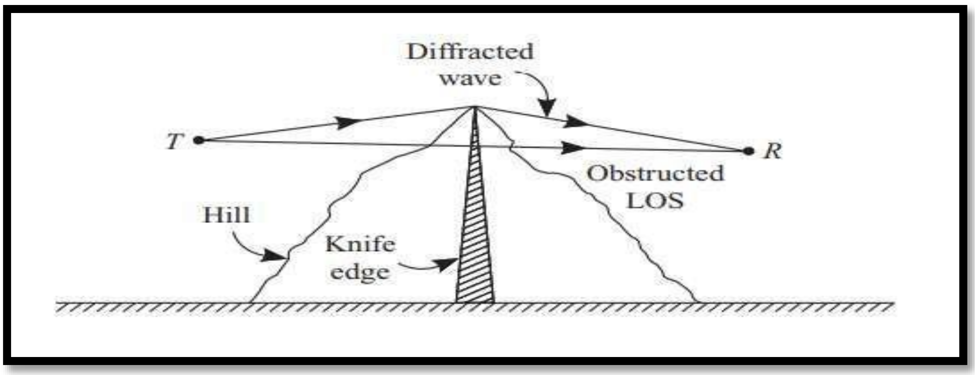

Fig 5.6: (a) Knife edge diffraction model

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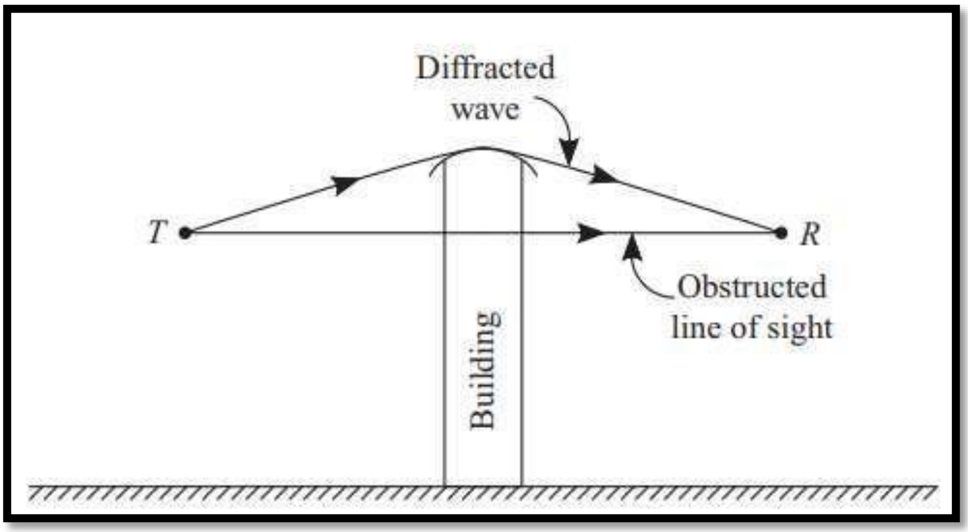

Fig 5.6: (b) Rounded-Surface Diffraction Model

Ref: https://khasimgriet.files.wordpress.com/2016/07/harish-a-r-_-sachidananda-m-antennas-and-wave-propagation-oxford-university-press-2007.pdf

SPACE WAVE PROPAGATION:

5.7 INTRODUCTION TO SPACE WAVE PROPAGATION:

The direct and reflected radio waves inside the troposphere (the lowest 20 km of the atmosphere) are considered space wave propagation. Because they may move unimpeded from the surface of the Earth to the surface of the troposphere, this kind of wave is sometimes referred to as tropospheric propagation. Since the signals travel straight from the transmitter to the receiver, this kind of propagation is sometimes called "line of sight."

The height of the antennas and the distance between them may be expressed as:

$$D_m = (2RH_t)^{-½} + (2RH_r)^{-½}$$

5.7.1 SUPER REFRACTION:

When the radar beam is bent more than it would be in a Standard Atmosphere due to atmospheric circumstances, this phenomenon is known as "super-refraction" (Figure 5.7). A more extended operating range is achieved when the environment is relatively steady compared to the Standard Atmosphere. To the extent that the super-refractive layer is based on a surface, radar coverage may be increased by as much as 150%. Detection of low-altitude precipitation echoes, generally below a conventional refracted beam, is possible if the shaft is not bent enough to contact the Earth's surface.

- Super refraction or beam entrapment often happens in a variety of contexts, including but not limited to the following:
- The combination of a significant drop in humidity with altitude and a night-time low-level temperature inversion formed.
- The lower levels of the atmosphere are cooled and moistened when a flow of warm, dry air adverts over a colder surface, which is most effective if the more excellent surface is water.
- The formation of a sea breeze is characterised by the movement of cold, moist air inland underneath a warm, dry continental air mass.
- The rain-cooled outflow from a thunderstorm creates a surface-based temperature inversion.
- When the tropo-pause, where the lapse rate decreases significantly with height, may be found.

Radar height estimations are inflated when super-refraction occurs. An elevated observation angle of a precipitation target is seen during super-refraction. The antenna has to be elevated to a larger elevation angle than usual to locate the top of an echo since the beam is lower to the ground than the typical charts based on the environment.

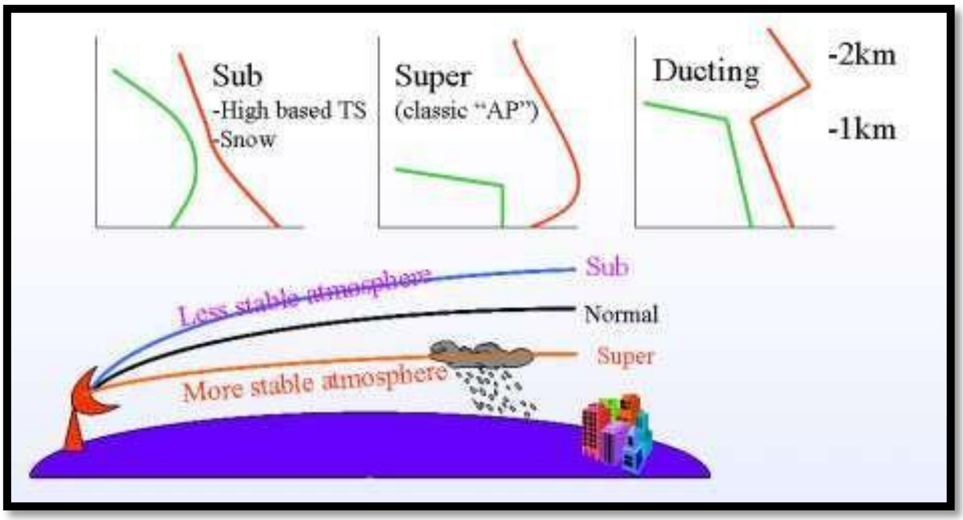

Fig 5.7: Typical sounding profiles sub- and super refraction and ducting

Ref:https://courses.comet.ucar.edu/pluginfile.php/3704/mod_imscp/content/1/ducting2.gif

When operating a radar system, the effects of super-refraction are more noticeable to the operator than those of sub-refraction. As was previously noted, the lowered beam detects low-altitude objects that would otherwise be below the shaft.Unfortunately, other range-folded echoes may be caught due to super-refraction. These echoes arise when objects beyond the radar's unambiguous range are detected due to the radar beam bent by super-refraction. It tends to follow the Earth's curvature for extended distances. In the lesson on Radar Theory, we covered the topic of a radar's precise detection range.

Another drawback is that radar's ability to see things that aren't precipitation at more significant distances is hindered by super-refraction. Super-refractive circumstances amplify ground clutter, a highly reflective echo pattern often produced by terrain features and other objects near the radar. When the radar beam is curved and travels close to the ground or bounces around the basis for a great distance, surface characteristics may be detected and prevented from far away.

To distinguish it from precipitation echoes, radar operators often use the term "anomalous propagation" (AP) to describe the enlarged ground clutter pattern. Radical effectiveness is often reduced due to difficulties differentiating ground return from precipitation targets.

5.7.2 DUCT PROPAGATION:

A radar "beam" becomes "ducted" when it encounters a stable layer or temperature inversion, a unique super refractive state. Even though this causes the beam to slant lower than usual, it seldom makes contact with the ground and suffers little attenuation.

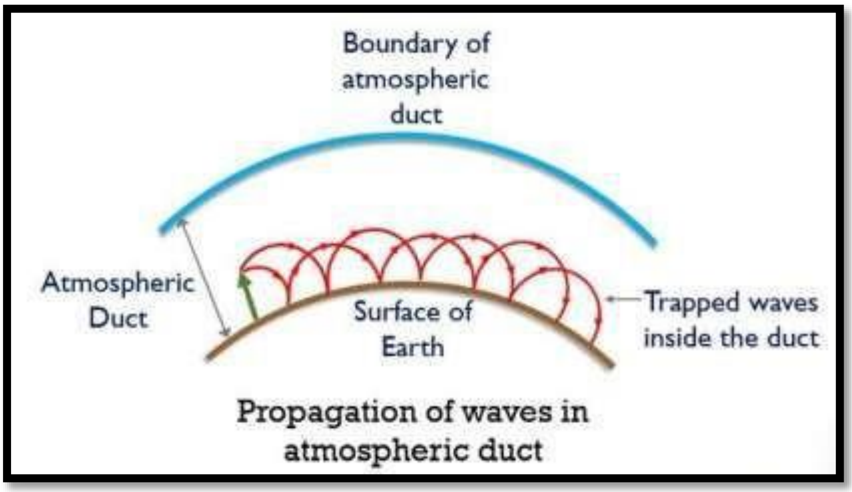

Fig 5.8: Duct propagation

Ref: https://electronicsdesk.com/wp-content/uploads/2020/01/propagation-of-waves-in-duct.jpg

This is a rare but possible operational scenario of super refraction that may lead to the identification of objects much beyond the normal operating R-max.

DUCTING PROPERTIES:

- The beam is deflected toward the planet and then rebounds from inside the trapping layer.
- Significantly extended usable range

- Consequences: a severe inversion with a steep drop in humidity with altitude
- Shocking night-time flip
- Moving hot air over cold water
- Calming effects of the ocean air
- The Flow of a Thunderstorm
- Tropopause

5.7.3 FADING AND PATH LOSS CALCULATIONS:

How the signal spreads and the amount of loss it experiences along the way may be used as building blocks for more intricate signal propagation models. To be sure, the free space propagation model describes how a radio signal would travel across space when not affected by any of the many external factors that might affect propagation.

The amplitude of the wave's decreases as they spread outward, eventually becoming imperceptible. Unlike the two-dimensional pond, radio waves have room to spread out in all three dimensions during propagation.

Signal strength in free space:

The strength of the signal decreases with distance from its source, as illustrated in fig (5.9).

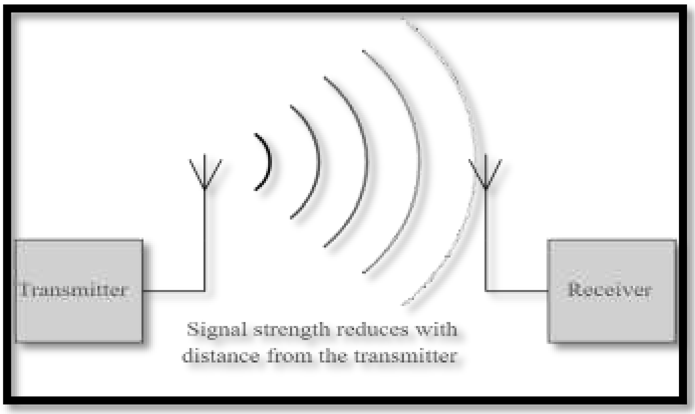

Fig 5.9: Path loss of signal strength

Ref: https://www.electronics-notes.com/images/propagation-free-space-path-loss-01.svg

Its descent velocity is inversely related to the square of the distance from its source.

$$\text{Signal level} = \frac{\mathrm{k}}{d^2}$$

Where:

k = constant

d = distance from the transmitter

A simple illustration of this is that a transmission's signal strength is reduced by a factor of four while moving from a distance of one metre to two.

The fundamental formula may be modified when a radio signal is affected by external influences. The exponent is changed to reflect reality better. The route loss exponent may reach values as high as 4 or 6 inside buildings, stadiums, and other enclosed spaces. Several mobile phone companies use a terrestrial signal attenuation of around inverse-square-root-fourth power for their computations. However, tunnels may serve as waveguides, leading to route loss exponent values lower than 2.

PATH LOSS IN FREE SPACE:

Path loss between a sender and a receiver may be computed. As seen above, the path loss is proportional to the square of the distance between the transmitter and receiver and the square of the operating frequency.Path loss in free space may be calculated in terms of wavelength or frequency. In the following, you'll find both equations:

In terms of wavelength:

$$\mathbf{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2$$

In terms of frequency:

$$\text{FSPL} = \left(\frac{4\pi d f}{c}\right)^2$$

Where:

FSPL = Free space path loss

d = distance from the transmitter to the receiver (metres)

λ = signal wavelength (metres)

f = signal frequency (Hz)

c = speed of light (metres per second)

FREE SPACE LOSS FORMULA FREQUENCY DEPENDENCY:

Dependence of the Free Space Loss Formula on Frequency, The preceding formulae for free space loss show that the loss varies with frequency or wavelength. The actual attenuation due to the vastness of space is independent of frequency or wavelength and is constant.

When examining the equations describing the loss of signal along a free-space route, it is clear that the outcome is reliant on two factors:

- As the area of the sphere across which the energy is dispersed grows, the first effect follows. The rule of diminishing squares provides a good description of this phenomenon.
- The antenna aperture change causes the second effect, which varies with physical size and operating wavelength. This makes the element frequency-dependent since it influences the antenna to pick up signals.
- One part of the equation for free space path loss is independent of frequency, but the other part is; therefore, the whole thing depends on wavelength or frequency.

SKY WAVE PROPAGATION:

5.8 INTRODUCTION TO SKY WAVE PROPAGATION:

When the distance the wave must travel is excellent, sky wave propagation is the method of choice. Here, the wave is sent upward and reflected down to Earth.This illustration accurately depicts how sky waves travel. Here, we see how radio waves may be broadcast from a central hub and picked up by several distant nodes. As such, it is an illustration of the medium of broadcasting.

The ionosphere acts as a mirror, reflecting the waves toward the transmitter antenna. The charged particles that make up these layers extend from 30 to 250 miles above Earth's surface. Sky wave propagation refers to the process by which a radio signal is sent from a transmitter to the ionosphere and then back to Earth. The ionosphere is the outer layer of Earth's atmosphere where radio waves may travel through the atmosphere.

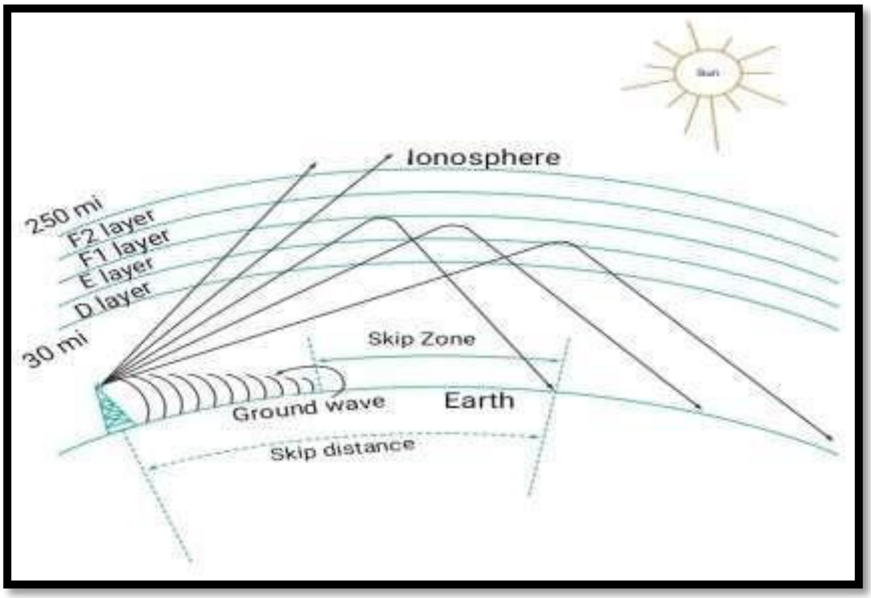

Fig 5.10: Sky Wave Propagation

Ref: https://www.mphysicstutorial.com/2021/01/what-is-sky-wave-propagation-advantages-and-disadvantages.html

5.8.1 STRUCTURE OF IONOSPHERE:

This is the part of Earth's atmosphere where ionisation is most noticeable. In addition to providing thermal energy, the Sun's rays also generate positive and negative ions in this area. This layer promotes the ionisation of particles because of the Sun's continual UV radiation and the low air pressure.

IMPORTANCE OF IONOSPHERE:

Because of these factors, the ionosphere layer is very vital during the wave propagation phase:

- Air particles are more significant, and UV light is weaker at the layer below the ionosphere.
- Because of this, there are more collisions and less consistent ionisation of particles.
- When it comes to air particles, the layer above the ionosphere has an insufficient quantity, and the ionisation density is also relatively low. Therefore, ionisation is inappropriate.
- The ionosphere is characterised by a high concentration of UV light and a moderate air density, neither significantly altering the ionisation process.
- As a result, the propagation of Skywaves is primarily affected by this layer.

Different gases in the ionosphere have varying pressures. These are ionised at various heights by various ionising agents. The ionosphere comprises many distinct layers due to the multiple gases present at each altitude.

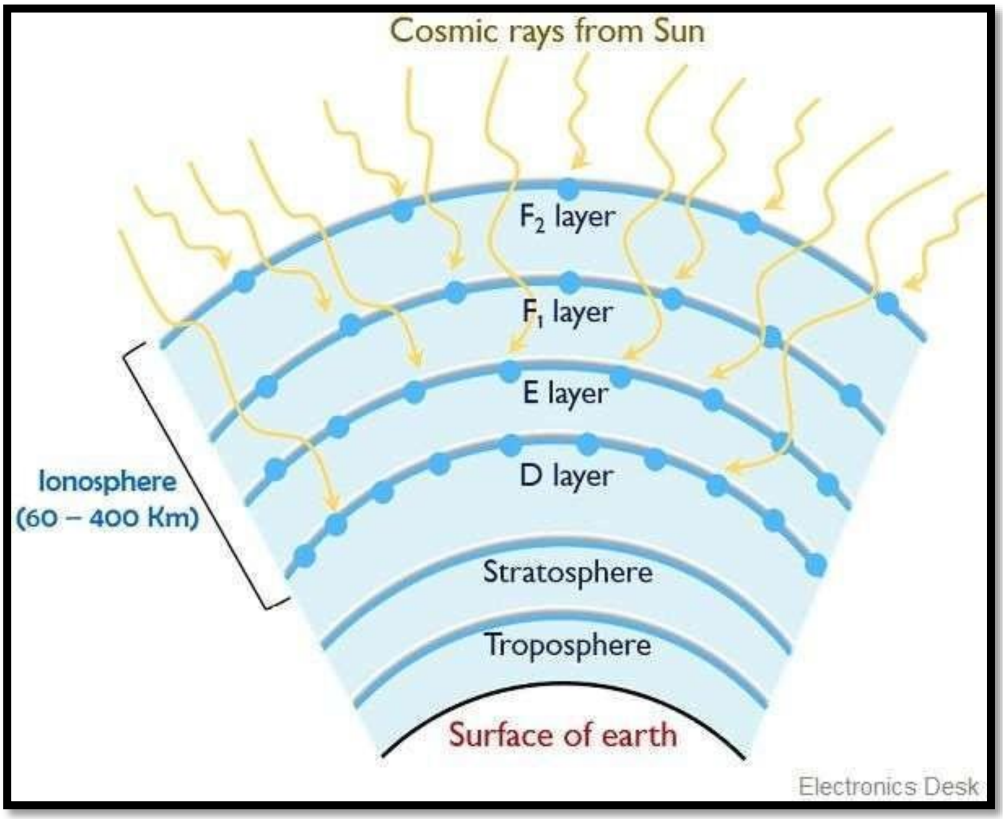

Fig 5.11: Structure of the Ionosphere.

Ref: https://electronicsdesk.com/wp-content/uploads/2020/01/cosmic-rays-reaching-ionospheric-region-in-sky-wave-propagation.jpg

Molecular constituents of atmospheric gases are ionised by cosmic radiation, especially solar energy. The term "ionosphere" refers to the ionised layer that begins at an altitude roughly 90 kilometres above the Earth's surface and continues for several thousand kilometres into space. The ionising radiation is powerful at these altitudes above Earth's surface, yet there are also relatively few molecules. Therefore, this area's ionisation density (the number of electrons or ions per unit volume) is low. When altitude is dropped, atmospheric pressure rises, signifying a more significant number of molecules in the air. As a result, there is a greater ionisation density at the Earth's surface.

Though the total number of molecules will always be more significant at lower altitudes, the ionisation density will decrease as the ionisation energy from the ionising radiation is used up. Therefore, there is a maximum ionisation density neither at the Earth's surface nor the ionosphere's outer border.

5.8.2 REFRACTION AND REFLECTION OF SKY WAVES BY IONOSPHERE:

The ionospheric reflections result from the wave's refraction as it travels through the ionosphere. The ionosphere is an area of the upper atmosphere rich in positively and negatively charged ions and electrons, which combine to produce an ionised gas or plasma.The ionosphere can reflect radio signals toward Earth because ionised atmospheric gases may refract high-frequency (HF or shortwave) radio waves. Radio waves may get back to Earth from beyond the horizon when sent at an inclination into the sky.

When a beam of light travels from a denser material into a lighter one, it deviates from its regular direction and curves upwards. The phenomenon is caused by refraction. The refracted light becomes parallel to the surface at a certain angle. A crucial angle has been reached.

The light is reflected into the denser medium if the angle is larger than this. Total internal reflection (TIR) describes this phenomenon. There is a layer of charged particles in the air at greater heights from the surface of the Earth. The ionosphere is the name given to this layer. Radio signals of a given frequency may be reflected to Earth after undergoing TIR when they pass through this layer.This technique of communication is possible. Skywave communication refers to the use of these waves for transmission.

5.8.2 RAY PATH:

The route or direction that wave energy takes as it travels through the Earth. The ray path in isotropic media is orthogonal to the local wavefront. Ray tracing can be used to determine the ray path. Seismic energy can propagate through diffraction and moves through material with varied anisotropy, which makes it difficult to determine ray paths.

5.8.3 CRITICAL FREQUENCY:

Each ionospheric layer has a maximum frequency at which radio waves can be vertically transmitted and refracted back to Earth at any one time. The Critical Frequency is the name given to this frequency. It is a phrase that is frequently used while talking about the spread of radio waves.

Radio waves broadcast at frequencies greater than the layer's critical frequency will pass through the layer and disappear into space, but if the same waves enter an upper layer with a higher critical frequency, they will be refracted back to Earth. If radio waves are not absorbed or have been refracted from a lower layer, they will also be reflected back to Earth at frequencies below the critical frequency. The faster a radio wave is refracted by a given level of ionisation, the lower its frequency must be. the simultaneous entry of three distinct waves with different frequency into an ionospheric layer. Observe how severely the 5-megahertz wave is refracted. The 20-megahertz pulse returns to Earth at a greater distance and with less abrupt refractive error. The 100-megahertz pulse passes into space instead of being refracted because it is manifestly above the critical frequency for that ionised layer.

5.8.4 MUF, LUF, OF:

MAXIMUM USABLE FREQUENCY:

As we previously discussed, the rate of refraction by an ionised layer decreases with increasing radio wave frequency. As a result, there is a maximum frequency that can be used for communications between two specific places for a certain angle of incidence and time of day. The Maximum Usable Frequency is the name for this frequency (MUF).Waves with frequencies above the MUF are typically refracted so slowly that they either pass through the ionosphere and are lost, or they return to Earth beyond the desired point. However, you should be aware that using an existing MUF does not ensure effective communication between a broadcasting site and a receiving site. The present MUF may rise or fall at any time due to variations in the ionosphere. This is especially true for radio waves that the extremely changeable F2 layer is bending. Around noon, when the sun's UV light rays are at their peak intensity, the MUF is at its highest. Then, as recombination starts, it declines very abruptly.

LESS THAN USEFUL FREQUENCY:

There is a minimum operating frequency as well as a maximum operating frequency that can be employed for communications between two sites. The LOWEST USABLE FREQUENCY is this (LUF). The rate of refraction rises as a radio wave's frequency decreases. In order to avoid this, a wave with a frequency below the established LUF is refracted back to Earth at a closer distance than planned.

The transmission path that is produced by the rate of refraction is merely one of the variables that affect the LUF. The radio wave is more readily absorbed as frequency is decreased. A wave with a frequency that is too low gets absorbed to the point where it is too feeble to be picked up. A low frequency radio wave may have an inadequate signal-to-noise ratio since ambient noise is also more intense at lower frequencies. The LUF for effective communication between two points depends on the ionosphere's refraction characteristics, absorption factors, and the level of ambient noise present for a specific angle of incidence and set of ionospheric circumstances.

OPTIMUM WORKING FREQUENCY:

The MUF and LUF are not usable operational frequencies. The signal-to-noise ratio at the luf is still much lower than at the higher frequencies, and the likelihood of multipath propagation is significantly higher even though radio waves at the LUF can be refracted back to Earth at the targeted position.

When operating at or close to the MUF, the transmission path's length can change due to ionospheric changes, which can lead to frequent signal fading and dropouts. The operating frequency that you can depend on with the fewest number of issues is the most practical one. It should be high enough to prevent the multipath, absorption, and noise issues that arise at lower frequencies, but not so high as to cause the unfavourable consequences of quick ionosphere shifts. The OPTIMUM WORKING FREQUENCY is a frequency that has been determined and satisfies the aforementioned requirements. The French terms for optimal working frequency, "frequency optimum travail," are abbreviated as "FOT" instead. The FOT makes up around 85% of the MUF, however the exact proportion fluctuates and can be significantly higher or lower than 85%.

5.8.5 VIRTUAL HEIGHT AND SKIP DISTANCE:

SKIP DISTANCE:

the connection between the skip zone, skip distance, and ground wave coverage. The distance between the transmitter to the location where the sky wave is first returned to Earth is known as the "SKIP DISTANCE." The frequency of the wave, the angle of incidence, and the level of ionisation present all affect how far the wave skips.

A period of quiet known as the "SKIP ZONE" occurs between the time at which the ground wave is too feeble to be picked up and the point at which the sky wave is first sent back to Earth. The extent of the ground wave coverage and the skip distance both affect how big the skip zone is.There is no skip zone when the ground wave coverage is sufficient or the skip distance is small enough to prevent the occurrence of a zone of silence. On occasion, the ground wave's range will overlap with the initial sky wave's return to Earth. When the sky wave and ground wave are almost equally strong, the sky wave alternately strengthens and cancels the ground wave, severely weakening the signal. Due to the sky wave's longer course and resulting phase difference between the two waves, this occurs.

$$Dskip = 2h \sqrt{[(fmuf / fc)2-1]}$$

HIGHT VIRTUAL:

- The height to which a brief energy pulse is sent vertically upward.
- It will never be the same height as the real height.
- It is simple to determine the angle of incidence necessary for the wave to return at a specific spot if it is known.
- In most cases, an instrument called an ionosonde is used to measure virtual height.
- H = CT/2, where CT is the round-trip time and C is the light speed.

VIRTUAL HIGHT MEASUREMENT METHOD:

Transmit a signal that is made up of brief RF energy pulses. Both the direct and reflected signals are picked up by a receiver that is close to the transmitter. The height of the layer can be calculated from the distance between these signals on the time axis of the CRO. useful for calculating transmission paths.

5.8.6 RELATION BETWEEN MUF AND SKIP DISTANCE:

What we mean when we talk about "MUF," or "Maximum Usable Frequency," is the highest frequency at which sky wave propagation is possible, or the highest frequency that the ionosphere will reflect. When talking about the distance between a transmitter and the earth's return point, the term "skip distance" is used.Top frequency for practical use. According to the International Telecommunication Union (ITU), the maximum usable frequency (MUF) is the highest radio frequency that can be used to transmit between two sites at a certain time via reflection from the ionosphere (skywave or "skip" propagation).

Radio waves typically make a jump via the ionosphere, which adds a certain amount of distance to the total trip. A skip distance is the horizontal distance between two places on Earth. When the ionosphere is at its peak, at night, the greatest skip distance is achieved.Commercial AM radio broadcasts on shortwave frequencies are commonly associated with this word. When the frequency of an electromagnetic wave exceeds a particular threshold, the ionosphere ceases reflecting it. As a result, the highest frequency that is reflected back from the ionosphere at a given angle of incidence is known as the maximum useable frequency. ('Secant Law' explains the connection between the two).

The crucial frequency, layer height, and skip distance are all related via the following expression:

$$D_{skip} = 2h\sqrt{(\frac{f_{MUF}}{f_C})^2 - 1}$$

5.8.7 MULTI - HOP PROPAGATION:

A reflection from the F2 zone can travel up to about 4000 km, but reflections from other parts of the ionosphere can travel only a fraction of that distance. Using a simple reflection from the ionosphere is insufficient to explain how messages might reach from the other side of the world via ionospheric propagation. This is feasible because of the several reflections that signals go through. It has been discovered that signals from the ionosphere are reflected by the surface of the Earth and sent back into the ionosphere. Here, the ionosphere reflects them back to Earth at almost double the distance from the transmitter as a single reflection.

As was to be predicted, the signal suffers further attenuation. When a signal is reflected multiple times by the Earth, it suffers attenuation each time. The amount of these losses is strongly influenced by the Earth's surface at the point of reflection.

As may be predicted, salt water is a fantastic reflector, but dry desert is abysmal. Because of this, echoes off the Atlantic Ocean are likely to be louder than those off a desert.

The signal also experiences attenuation in the ionosphere, in addition to the reflection at the Earth's surface. When the signal travels through the D area, it gets further weakened each time. If the signal takes more than one hop, it will go through the D layer multiple times, so minimising the number of times it does so is crucial. The attenuation, as was indicated before, decreases with increasing frequency. In addition to the low reflections and loss experienced by the high frequency path due to its use of the F2 layer, the high frequency path also benefits from the lower attenuation experienced by its passage through the D layer. If both frequencies can allow propagation, then a signal on 28 MHz, for instance, will be stronger than one on 14 MHz.

Keep in mind that if you employ very steep angles of radiation, the path length for a multiple reflection signal will exceed the great circle distance around the world. This will further degrade the signal quality because signal loss scales directly with cable length.

CHORDAL HOP:

The ionosphere, and the F2 area in particular, can shift orientation at irregular intervals. If this occurs, the signal might not be reflected back to Earth. In its place, it is reflected such that it travels between the Earth and the ionosphere, only to return to the ionosphere and be reflected back to Earth. This method of propagation has substantially fewer losses and so can offer stronger signals because it does not rely on a reflection from Earth's surface. It has been hypothesised in certain studies that this mode of propagation could be responsible for global echoes.Chordal Hop propagation is only possible when the ionosphere is at a specific angle, usually around sunrise and sunset and across the equator. Since the equatorial anomaly is oriented north to south, most propagation follows that direction (or south-north direction).

It has been determined that the F2 zone is at its highest across the equator, and that on either side of this it tilts, allowing the signals to be reflected over the surface of the globe.

SIGNAL PATHS:

A wide range of systems exist for the transmission of messages. With long-distance propagation, the route may be an intricate synthesis of multiple hops that make use of multiple regions. Due to variations in ionosphere conditions, signals of the same frequency may be reflected using the F region in one part of the world but the E region in another. It is noteworthy to note that the MUFs for this mode of propagation are greater than the identical path utilising a double hop, possibly because signals can become stuck between the F and E areas where there is a trough in the amount of ionisation.

A system of nomenclature has been developed in order to classify the many possible directions of travel. Locations of reflection are denoted; for example, the hyphen between g and r indicates a ground reflection. A single hop using the F area is indicated by a F whereas an E-F indicates that the signal is reflected by the E region back to Earth, where it is then reflected again up to the F region, and finally returns to Earth at the receiver.

5.9 EFFECT OF EARTH'S MAGNETIC FIELD:

In prior paragraphs, we analysed how electromagnetic waves travel through an ionised material. Ionosphere electrons and the field exchange energy because of the free charges present there. This impact is modelled in the medium as a complex permittivity, which is represented as a complex permittivity in the broadest meaning. Therefore, there is both a real and an imaginary component to the propagation constant.So far, the presence of Earth's magnetic field has been disregarded in the analysis. When a magnetic field B0 is present, free electrons travelling at a speed v perpendicular to B0 will experience a force F equal to v multiplied by B0, causing them to spiral in a circle.

The force equation specifies the direction of the electron's revolution. Now, picture an electromagnetic wave with a circular polarisation that travels in the direction of the earth's magnetic field. Whether or not the electron and the electric field vector are rotating in the same direction affects the electromagnetic wave's interaction with the particle. Because of this, the effective permittivity's, and hence the propagation constants, for the left and right circularly polarised waves are distinct.

When an electromagnetic wave's electric field vector is aligned with B0 and travelling in a direction perpendicular to Earth's magnetic field, the magnetic field has no effect on the wave's propagation. To rephrase, the wave's propagation constant is unaffected by the presence or absence of Earth's magnetic field. The ordinary wave is the most common type of wave.

The electromagnetic wave is no longer linearly polarised and cannot be thought of as a plane wave if it propagates perpendicular to B0 with its electric field also perpendicular to B0. It is because of this interaction that the electric field has a component in the direction of propagation, causing the electric field vector's tip to trace an ellipse in a plane perpendicular to the direction of propagation. The incredible wave describes this tidal surge.