UNDER WHAT CONDITION RADIATION TAKES PLACE IN ANTENNAS: Radiation takes place in antennas when an alternating current (AC) is applied to the antenna. This AC current causes the electrons in the antenna to accelerate and decelerate, which in turn produces an electromagnetic field. As the electrons continue to oscillate, the electromagnetic field radiates outwards from the antenna into space as electromagnetic waves. In addition to these basic conditions, the radiation efficiency of an antenna can be affected by a number of factors, such as its shape, size, and proximity to other objects. Therefore, careful design and optimization of antenna parameters is important in order to achieve the desired radiation characteristics for a particular application.

HOW DOES AN ANTENNA RADIATE: • When an electrical signal is applied to an antenna, it creates a changing electric field around the antenna. This electric field causes electrons in the antenna to move back and forth. • As the electrons move back and forth, they create a corresponding changing magnetic field around the antenna. This magnetic field is perpendicular to the electric field. • The changing electric and magnetic fields together create an electromagnetic wave that propagates away from the antenna. This wave carries energy and information through space. • The direction and strength of the electromagnetic wave depend on the design of the antenna. Different types of antennas, such as dipole antennas, monopole antennas, and parabolic antennas, are designed to radiate in different patterns.

RADIATION RESISTANCE: Radiation resistance is the hypothetical resistance that would consume the same amount of power as that radiated by an antenna. It depends on the physical dimensions of the antenna and the wavelength of the radiation it radiates. The higher the radiation resistance, the higher the efficiency of the antenna. It can be calculated using the formula Rrad = (2 * pi^2 * L * I^2) / lambda^2, where L is the length of the antenna, I is the current flowing through the antenna, and lambda is the wavelength of the radiation.

RADIATION EFFICIENCY: Radiation efficiency refers to the fraction of input power to an antenna that is actually radiated as electromagnetic waves, rather than being dissipated as heat or stored in the antenna structure. It is a measure of how well an antenna converts electrical power into useful radiation. Radiation efficiency is affected by factors such as the electrical conductivity of the antenna material, the size and shape of the antenna, and the presence of any losses in the antenna circuit.

ANTENNA EFFICIENCY: The antenna efficiency that takes into account the reflection, conduction, and dielectric. The conduction and dielectric losses of an antenna are very difficult to compute and in most cases they are measured. Even with measurements, they are difficult to separate and they are usually lumped together to form the Ecd efficiency. The resistance Rl is used to represent the conduction-dielectric losses. The conduction-dielectric efficiency Ecd is defined as the ratio of the power delivered to the radiation resistance Rr to the power delivered to Rr and RL. the radiation efficiency can be written as

$$e_{cd} = \left[\frac{R_r}{R_L + R_r}\right]$$

APERTURE EFFICIENCY: Aperture efficiency is a measure of the effectiveness of an antenna in capturing electromagnetic radiation from a source. It is defined as the ratio of the power received by the antenna to the power incident on the antenna from a source that fills the entire aperture. In other words, aperture efficiency measures how much of the available radiation from a source is captured by the antenna. A high aperture efficiency indicates that the antenna is effective at capturing radiation, while a low efficiency indicates that some of the radiation is lost or scattered. Aperture efficiency depends on the physical dimensions and design of the antenna, as well as the frequency of operation and the properties of the surrounding environment. It is an important parameter to consider when designing and evaluating the performance of antenna systems.

RADIATION PATTERNS Radiation is the term used to represent the emission or reception of wave front at the antenna, specifying its strength. In any illustration, the sketch drawn to represent the radiation of an antenna is its **radiation pattern**. One can simply understand the function and directivity of an antenna by having a look at its radiation pattern. The energy radiated by an antenna is represented by the **Radiation pattern** of the antenna. Radiation Patterns are diagrammatical representations of the distribution of radiated energy into space, as a function of direction. The energy being radiated is represented by the patterns drawn in a particular direction. The arrows represent directions of radiation. The radiation patterns can be field patterns or power patterns.

Radiation Mechanisms In Single And Two Wire Antennas: The mechanism of radiation in a single wire antenna, such as a monopole or a dipole, is based on the principle of current acceleration. When an alternating current flows through the wire, it causes a periodic change in the direction of current flow, resulting in an acceleration of charges in the wire. This acceleration generates a changing electric field that propagates away from the antenna in the form of electromagnetic waves. As the waves propagate through space, they generate a perpendicular changing magnetic field, and the two fields oscillate at right angles to each other. The radiation pattern of a single wire antenna depends on its physical dimensions, frequency of operation, and surrounding environment. A short monopole antenna with a length less than one-tenth of the wavelength of the signal will radiate mostly in the vertical direction, while a dipole antenna with a length equal to half the wavelength of the signal will radiate most strongly in the horizontal direction perpendicular to the axis of the antenna. The radiation resistance of a single wire antenna is typically much smaller than its physical resistance, which means that only a small fraction of the power transmitted or received by the antenna is actually radiated as electromagnetic waves. The rest of the power is dissipated as heat in the wire.

The mechanism of radiation in a two-wire antenna, also known as a dipole antenna, is based on the principle of current oscillation. When an alternating current flows through the two wires, it causes a periodic oscillation of the charges in the wires, resulting in a changing electric field that propagates away from the antenna in the form of electromagnetic waves. The two-wire antenna is a balanced antenna, which means that the current in each wire is equal and opposite, resulting in a cancellation of the radiation from the wires in all directions except the plane perpendicular to the axis of the antenna. This perpendicular plane is known as the "H-plane" or "horizontal plane" of the antenna, where the radiation pattern of the antenna is strongest. The length of the two-wire antenna is typically equal to half the wavelength of the signal it is designed to transmit or receive. This length ensures that the oscillating currents in the wires are in phase and reinforce each other, resulting in maximum radiation in the H-plane. The radiation resistance of a two-wire antenna is typically larger than that of a single-wire antenna, resulting in a higher efficiency in converting the input power into radiated electromagnetic waves. The radiation pattern of a two-wire antenna can be further modified by the use of reflectors, directors, and other structures placed in front of or behind the antenna.

TYPES OF RADIATION PATTERNS: The common types of Radiation patterns are – • Omni-directional pattern (also called non-directional pattern): The pattern usually has a doughnut shape in three-dimensional view. However, in two-dimensional view, it forms a figure-of-eight pattern. • Pencil-beam pattern – The beam has a sharp directional pencil shaped pattern. • Fan-beam pattern – The beam has a fan-shaped pattern. • Shaped beam pattern – The beam, which is non-uniform and patternless is known as shaped beam.

DIFFERENT LOBES OF RADIATION PATTERNS: There are different lobes that can be observed in radiation patterns, including: • Main lobe: The main lobe is the central lobe of an antenna's radiation pattern, in which the majority of the antenna's radiation is concentrated. The main lobe is typically the most important part of the radiation pattern, as it determines the direction of maximum gain or sensitivity. • Side lobes: Side lobes are smaller lobes that are located on either side of the main lobe in an antenna's radiation pattern. They are the result of the antenna's radiation in directions other than the intended direction of maximum radiation. Side lobes can be a problem in some applications, as they can cause interference with other signals. • Back lobe: The back lobe is a lobe that is located on the opposite side of the main lobe, pointing in the opposite direction. It is the result of radiation from the back of the antenna, which can be caused by reflections or other effects. • Nulls: Nulls are areas of an antenna's radiation pattern where the signal strength is very low or zero. Nulls can be caused by interference or cancellation effects, and they can be a problem in some applications where signal strength is critical. • Beamwidth: Beamwidth refers to the angular width of the main lobe of the antenna radiation pattern. It is defined as the angle between the half-power points (the points at which the radiation intensity is half of the maximum) on either side of the main lobe. A narrow beamwidth corresponds to a high directivity, while a wide beamwidth corresponds to a lower directivity.

DIRECTIVITY : Directivity is a measure of how well an antenna concentrates radiation in a particular direction. It is defined as the ratio of the radiation intensity in the direction of maximum radiation to the average radiation intensity over all directions. Directivity is usually expressed in decibels (dB) relative to an isotropic radiator, which radiates equally in all directions. The ratio of radiation intensity in a given direction from an antenna to the radiation intensity averaged over all directions, is termed as directivity. The directivity of a non-isotropic antenna is equal to the ratio of the radiation intensity in a given direction to the radiation intensity of the isotropic source.

BEAMWIDTH: It refers to the angular width of the main lobe of the antenna radiation pattern. It is defined as the angle between the half-power points (the points at which the radiation intensity is half of the maximum) on either side of the main lobe. **Beam width** is the aperture angle from where most of the power is radiated. The two main considerations of this beam width are Half Power Beam Width **(HPBW)** and First Null Beam Width **(FNBW)**.

BEAM SOLID ANGLE AND BEAM EFFICIENCY: • Beam solid angle is a measure of the angular extent of a beam of radiation, such as that emitted by an antenna. It is defined as the ratio of the area of a portion of a sphere that is enclosed by the beam to the square of the radius of the sphere. The units of beam solid angle are steradians (sr). • Beam efficiency, on the other hand, is a measure of the effectiveness of an antenna in transmitting or receiving a signal in a particular direction. It is defined as the ratio of the power radiated in a particular direction to the total power radiated by the antenna. The higher the beam efficiency, the more effective the antenna is in transmitting or receiving signals in that direction. Beam efficiency is affected by various factors, including the shape and size of the antenna, the frequency of the radiation, and the properties of the surrounding environment.

VECTOR POTENTIAL: The vector potential is a mathematical construct used in electromagnetism to describe the behavior of electric and magnetic fields. It is a vector field that is defined in terms of the current density and its time derivative. The vector potential is related to the magnetic field by the curl operator, and it can be used to calculate the magnetic field in situations where the current density is known. The vector potential is a useful tool in electromagnetic theory because it simplifies the mathematical treatment of many problems involving electric and magnetic fields.

Significance of vector potentials. How can they be used to compute electric and magnetic fields from electric and magnetic sources: Vector potentials are mathematical constructs used in electromagnetic theory to simplify the computation of electric and magnetic fields. They are derived from the electric and magnetic sources that generate the fields, and are related to the electric and magnetic fields through Maxwell's equations. The significance of vector potentials lies in their ability to simplify the computation of electric and magnetic fields, particularly in cases where the sources of the fields are complex and difficult to analyze directly. By decomposing the sources into simpler components and using vector potentials to describe their effects, it becomes possible to obtain accurate and efficient solutions to electromagnetic problems. One way in which vector potentials can be used to compute electric and magnetic fields is through the method of retarded potentials. In this method, the vector potentials are first calculated from the sources, and then used to compute the electric and magnetic fields at any point in space and time. The retarded potentials take into account the time delay between the sources and the observation point, and allow for accurate modeling of time-varying electromagnetic fields. Another method for computing electric and magnetic fields using vector potentials is through the use of Green's functions. Green's functions are mathematical tools that describe the response of a system to a point source, and can be used to calculate the electric and magnetic fields from a distribution of sources. By expressing the sources in terms of vector potentials and using Green's functions to integrate over the distribution, it is possible to obtain an accurate and efficient solution to electromagnetic problems.

POLARIZATION AND DIFFERENT TYPES: Polarization refers to the orientation of the electric field of an electromagnetic wave with respect to a reference axis. Electromagnetic waves can have different polarization states depending on the orientation of their electric field. There are three main types of polarization: linear polarization, circular polarization, and elliptical polarization. • **Linear Polarization**: Linearly polarized waves have an electric field that oscillates in a single plane, perpendicular to the direction of propagation of the wave. The direction of the electric field is constant and does not change with time. Linear polarization can be further classified into horizontal polarization, vertical polarization, and diagonal polarization **Circular Polarization**: Circularly polarized waves have an electric field that rotates in a circular motion as the wave propagates. The direction of the electric field changes continuously with time, tracing out a helix. Circular polarization can be further classified into right-handed circular polarization (electric field rotates clockwise as viewed from the direction of propagation) and left-handed circular polarization (electric field rotates counterclockwise as viewed from the direction of propagation). • **Elliptical Polarization**: Elliptically polarized waves have an electric field that traces out an ellipse as the wave propagates. The direction of the electric field changes continuously with time, and the shape of the ellipse can be either circular or elongated. Elliptical polarization can be further classified into right-handed elliptical polarization and left-handed elliptical polarization.

FIELD PATTERN The field distribution can be quantifying in terms of field intensity is referred to as field pattern. That means, the radiated power from the antenna when plotted, is expressed in terms of electric field, E (v/m). Hence, it is known as **field pattern**. If it is quantified in terms of power (W), then it is known as **power pattern**. The field pattern can be classified as – • Reactive near-field region and Radiating near-field region – both termed as nearfield. • Radiating far-field region – simply called as far-field. The field, which is very near to the antenna is **reactive near field** or **non-radiative field** where the radiation is not pre-dominant. The region next to it can be termed as **radiating near field** or **Fresnel's field** as the radiation predominates and the angular field distribution, depends on the physical distance from the antenna. The region next to it is **radiating far-field** region. In this region, field distribution is independent of the distance from antenna. The effective radiation pattern is observed in this region.

PATTERN MULTIPLICATION: Pattern multiplication is a technique used to combine the radiation patterns of two or more antennas to form a new pattern with specific properties. This technique involves multiplying the complex field patterns of the antennas together to obtain the complex field pattern of the resulting combined antenna system. The resulting pattern will have characteristics that are a combination of the individual antenna patterns, and can be used to achieve desirable properties such as increased gain, directionality, or polarization. Pattern multiplication is commonly used in array antenna design, where multiple antennas are arranged in a specific configuration to achieve a desired radiation pattern.

EFFECTIVE AREA "**Effective area** is the area of the receiving antenna, which absorbs most of the power from the incoming wave front, to the total area of the antenna, which is exposed to the wave front." The whole area of an antenna while receiving, confronts the incoming electromagnetic waves, whereas only some portion of the antenna, receives the signal, known as the **effective area**. Only some portion of the received wave front is utilized because some portion of the wave gets scattered while some gets dissipated as heat. Hence, without considering the losses, the area, which utilizes the maximum power obtained to the actual area, can be termed as **effective area**.

GAIN: Gain of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically." Simply, gain of an antenna takes the directivity of antenna into account along with its effective performance. If the power accepted by the antenna was radiated isotropically (that means in all directions), then the radiation intensity we get can be taken as a referential. • The term **antenna gain** describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. • **Gain** is usually measured in **dB**.

• Unlike directivity, antenna gain takes the losses that occur also into account and hence focuses on the efficiency.

Define a radian sphere. Compare the features of near field, intermediate field and far field of an antenna:

A radiation sphere, also known as a "spherical wavefront", is a hypothetical sphere surrounding an antenna at a specific distance, where the electromagnetic fields emitted by the antenna are considered to be uniform and spherical in shape. The radiation sphere is used as a reference point to calculate various antenna parameters, such as gain, directivity, and radiation pattern.

Near field, intermediate field, and far field are three regions surrounding an antenna where the electromagnetic fields have distinct characteristics: **Near field**: This region is closest to the antenna and is characterized by a strong electric field component and a significant magnetic field component. The near field is further divided into two regions: the reactive near field, where the fields are predominantly reactive and store energy, and the radiating near field, where the fields begin to radiate away from the antenna. **Intermediate field**: This region is farther away from the antenna than the near field and is characterized by a mixture of radiating and reactive fields. In the intermediate field, the radiated fields begin to dominate over the reactive fields. **Far field:** This region is the farthest away from the antenna and is characterized by a nearly uniform distribution of the electromagnetic fields, with the electric and magnetic fields at right angles to each other and perpendicular to the direction of propagation. In the far field, the radiated fields are dominant and propagate as plane waves.

ELEMENTARY DIPOLE AND HOW DOES IT DIFFER FROM INFINITESIMAL DIPOLE: An elementary dipole is a model used to represent a tiny object that has a separation of positive and negative charges. It is an idealized dipole that has a finite size and can be considered as a fundamental building block for more complex systems. It is commonly used to describe the behavior of molecules, atoms, and subatomic particles. On the other hand, an infinitesimal dipole is a mathematical model used to represent a point-like object that has a separation of positive and negative charges. It is a theoretical construct that has zero size, but has a finite electric dipole moment. Infinitesimal dipoles are often used in mathematical descriptions of electromagnetic fields and radiation. The main difference between an elementary dipole and an infinitesimal dipole is their size. An elementary dipole has a finite size, whereas an infinitesimal dipole is a theoretical construct with zero size. Additionally, the behavior of an elementary dipole is more complex than that of an infinitesimal dipole, as it can experience higher-order effects such as induced dipoles and dipole-dipole interactions.

Define the array factor of an n element isotropic array. What is its significance in predicting the array pattern: The array factor of an N-element isotropic array is a mathematical function that describes the radiation pattern of the array. It is given by the equation:

AF(theta, phi) = sum from n=1 to N of exp(jk(nd cos(theta) + m phi))

where k is the wave number, d is the spacing between adjacent array elements, n and m are integers representing the element indices, and theta and phi are the angles defining the direction of radiation.

The significance of the array factor in predicting the array pattern is that it represents the interference pattern caused by the individual elements of the array. When the array factor is multiplied by the single-element radiation pattern, the resulting pattern is the radiation pattern of the entire array. The array factor is therefore a crucial component in the design and analysis of antenna arrays, as it allows engineers to predict the radiation pattern of an array based on the geometry and spacing of its elements. By adjusting the element spacing and geometry, the array factor can be used to optimize the array pattern for a particular application.

BROAD SIDE AND END FIRE ARRAYS: • A broadside array consists of multiple antenna elements arranged in a straight line, perpendicular to the direction of maximum radiation. This type of array radiates equally in all directions perpendicular to the array axis, with the maximum radiation occurring in the direction perpendicular to the array axis. The radiation pattern of a broadside array is symmetric, and the directivity is relatively low. • An end-fire array, on the other hand, consists of multiple antenna elements arranged in a straight line, parallel to the direction of maximum radiation. The spacing between the elements is less than half the wavelength of the signal. This type of array radiates primarily in the direction of the array axis, with the maximum radiation occurring in that direction. The radiation pattern of an end-fire array is highly directional, and the directivity is much higher than that of a broadside array. The main differences between these two types of arrays are as follows: • **Array Structure**: • A broadside array consists of a linear array of identical elements that are oriented perpendicular to the direction of maximum radiation. •An end-fire array consists of a linear array of identical elements that are oriented parallel to the direction of maximum radiation, with the spacing between the elements being less than half the wavelength of the signal. **Radiation Pattern:** • A broadside array produces a radiation pattern that is symmetric about the perpendicular axis, with the maximum radiation occurring in the perpendicular direction. • An end-fire array produces a radiation pattern that is focused along the axis parallel to the direction of the elements, with the maximum radiation occurring in that direction. **Directivity**: • The directivity of a broadside array is relatively low, typically less than 3 dB, because the radiation is spread out over a wide angle. • The directivity of an end-fire array is much higher, typically greater than 5 dB, because the radiation is concentrated in a narrow beam along the axis of the array.

Grating Lobes In Radiation Pattern And How Can They Be Avoided: Grating lobes refer to secondary radiation lobes that occur in the radiation pattern of an antenna array. These lobes occur at angles other than the main lobe and can cause unwanted interference in the communication system. Grating lobes can be avoided by ensuring that the spacing between the antenna elements is less than half of the wavelength of the signal being transmitted. This ensures that the signals from each element add constructively in the direction of the main lobe, while cancelling out in other directions, thereby minimizing the occurrence of grating lobes. Additionally, choosing an appropriate antenna array design, such as a uniformly spaced linear array or a planar array, can also help to reduce the occurrence of grating lobes.

Principle Used To Find The Radiation Pattern Of An Array Antenna: The radiation pattern of an array antenna can be found by applying the principle of superposition. This involves adding the individual radiation patterns of each antenna element, taking into account the phase and amplitude of the signals at each element. The radiation pattern of each individual element can be determined using electromagnetic theory or experimentally measured using an anechoic chamber or other testing facility. The resulting pattern is then combined with the patterns of the other elements in the array, taking into account the relative positions and orientations of the elements. The resulting radiation pattern of the array is the superposition of all the individual patterns, and can be visualized as a plot of the radiated power density as a function of direction. This pattern can be used to determine the directional characteristics and performance of the antenna array, including gain, beamwidth, and side lobe levels.

YAGI-UDA ANTENNA• -its an array antenna which consists of one active element and a few parasitic elements. • The active element consists of a folded dipole whose length is λ/2. • The parasitic elements consists of one reflector and few directors. • The length of the reflector is greater than λ/2.It is located behind the active element. • The length of each director is less than λ/2 and is placed in front of the active element. • The spacing between each element is not identical and hence it is considered as non-linear array. • The number of directors in antenna depends on the gain requirements. • The impedance of the active element is resistive. • The impedance of the reflector is inductive. • The impedances of directors are capacitive. **Folded dipole is used in Yagi antenna** because it has 4 times more radiation resistance than ordinary dipole antenna. It also has high input impedance which causes free space and transmission line matching. **Salient features of Yagi-Uda antenna 1**. It consists of a driven element, a reflector and one or more directors. 2. Driven element is usually a folded dipole which is excited. Director is a straight conductor placed in front of the driven element towards transmitter. Reflector is also a straight conductor placed behind the driven element. 3. Directors and reflector are called parasitic elements. 6. Its radiation pattern is almost uni-directional and gives a gain of about 7 dB. 7. It is used as a transmitting antenna at HF and used for TV reception at VHF. 8. Back lobe can be reduced by bringing the elements closer. This reduces the input impedance of the antenna and hence there will be a mismatch. 9. The effect of parasitic elements depends on their distance and tuning. In other words, the effect depends on the magnitude and phase of the current induced in them. In recent years the bandwidths as large as 40:1 are introduced. Such antennas are called **frequency independent antenna.** The conditions for an antenna to be frequency independent include: • The antenna must be designed with a wide bandwidth. • The antenna must have a consistent radiation pattern across the frequency range of interest. • The antenna must have a consistent impedance over the frequency range of interest. • The antenna must have low levels of distortion and noise over the frequency range of interest. • The antenna must have a high efficiency.

6 ELEMENT YAGI UDA ANTENNA: In a 6-element Yagi-Uda antenna, the reflector is the longest element and is placed behind the driven element. The directors are shorter than the driven element and are placed in front of it. The number and length of directors can vary depending on the desired gain and beamwidth of the antenna. The radiation pattern of a Yagi-Uda antenna is highly directional, with the maximum radiation occurring in the direction perpendicular to the plane of the antenna. The direction of maximum radiation, also known as the main lobe, can be steered by adjusting the length and spacing of the elements. The pattern also has minor lobes on either side of the main lobe, which can be used for sidelobe suppression.

Design A 3 Element Yagi Uda Antenna Operating At 10mhz: λ = c/f where c is the speed of light (3x10^8 m/s) and f is the frequency (10MHz)

λ = 30 meters
L = λ/2
L = 15 meters
length of the reflector would be: Lr = 1.05 x L = 15.75 meters
length of the director would be: Ld = 0.95 x L = 14.25 meters
spacing between the elements would be: S = 0.2 x λ = 6 meters
assemble the three elements (driven, reflector, and director) onto a boom (support structure) in the following order: Reflector - Driven element – Director. The distance from the end of the reflector to the start of the driven element should be S/2, and the distance from the end of the driven element to the start of the director element should also be S/2.

HELICAL ANTENNA: • It is an antenna which is in the shape of a helix. • Its polarization and radiation properties depend on the diameter, pitch, number of turns, wavelength, excitation and spacing between helical loops. • Helical antenna consists of helical loops made of thick conductor which have the appearance of a screw thread. It is associated with a ground plane made of the conductor. • The ground plane is often made of screen or sheet or of radial and concentric conductors. • This antenna is fed by a coaxial cable. This can be operated in normal and axial modes. The common antenna parameters are: C = circumference of helix a = pitch angle S = loop separation La = axial length = NR. In **normal mode**, the radiation is maximum in the broadside direction. This can be called broadside mode. This mode happens if NL << l, that is, the dimensions of the helix are small. In this, beam width is small and efficiency is low. These two parameters can be increased if the helix is large. Axial ratio for elliptical polarisation is given by $\text{Axial ratio, AR} = \frac{2S\lambda}{\pi^2 D_h^2}$ In **axial mode,** radiation is maximum along the axis of the helix. It can be considered as end-fire mode. In this mode, polarisation is almost circular. This mode can be obtained when Dh and S are of the order of l. Circular polarisation occurs when C /lambda = 1 and S = lambda/4 . **Salient features of helical antenna** 1. Helical antenna is a simple antenna for circular polarisation. 2. It is used in VHF and UHF bands. 3. It is most popularly used in axial mode. 4. In normal mode, beam width and efficiency are small. 5. It is a wide band antenna in axial mode. 6. It is used for extra-terrestrial communications, satellites and space probe communications, radio astronomy and so on. 7. It is not preferred in normal mode. **Pitch angle** is the angle between a line tangent to the helix wire and plane normal to the helix axis. **Applications of helical antenna** 1. It is used to transmit and receive VHF waves for ionospheric propagation. • Satellite , space communication • Space telemetry at hf and vhf bands • Radio astronomy. **Advantages** • Simple design • Highest directivity • Wider bandwidth • Can achieve circular polarization • Can be used at HF & VHF bands also **Disadvantages** • Antenna is larger and requires more space • Efficiency decreases with number of turns

LOG-PERIODIC ANTENNA It is an array antenna which has structural geometry such that its impedance is periodic with the logarithm of the frequency. It is a non-linear array in which the spacing of the elements as well as their dimensions are unequal. However, excitation is uniform. It is basically called a frequency-independent antenna. It can be used to receive a good number of TV channels without any deterioration of the received field strength. **Salient features:** 1. It is a frequency-independent antenna. 2. The input impedance variation of the antenna with the log of frequency is periodic. 3. It is an array of non-identical dipoles which are all excited equally. 4. It is a non-uniform array where the spacing between the elements is unequal. 5. Its impedance, directional patterns and directivity are constant with frequency. 6. The gain of a well designed antenna lies between 7.5 and 12 dB. 7. It is a broad band antenna. **3 Regions:** 1. Capacitive - elements shorter than lamda/2. Currents leads applied voltage by 90. small back ward radiation. 2. Resistive - dipoles are of lamda/2 and are resistive. current in phase with voltage. small forwd radiation. 3. Inductive - elements are greater than lamda/2. currents lags voltage by 90. reflects wave in backward direction

LOG PERIODIC PRINCIPLE USING LOG PERIODIC DIPOLE ARRAY: A log-periodic dipole array (LPDA) is a type of antenna that operates over a wide frequency range, typically several octaves, with relatively constant characteristics such as impedance and radiation pattern. The LPDA is based on the log-periodic principle, which is a mathematical pattern that repeats itself over a range of scales. The LPDA consists of a series of dipoles of varying length arranged in a specific pattern along a support structure. The dipoles are connected to a transmission line, which feeds the antenna with the desired signal. The length and spacing of the dipoles are designed to vary logarithmically with frequency, so that the antenna exhibits a constant characteristic impedance over a wide frequency range. The key to the operation of an LPDA is the fact that the dipoles are designed to resonate at different frequencies. As the frequency of the signal changes, different dipoles in the array become resonant and contribute to the overall radiation pattern. The LPDA can therefore operate over a wide frequency range while maintaining a consistent radiation pattern and impedance. The LPDA is commonly used in applications such as television and radio broadcasting, where it is important to transmit signals over a wide frequency range. The LPDA is also used in scientific research, such as in radio astronomy and particle accelerators. In summary, the log-periodic principle is used in the design of the LPDA to create an antenna that operates over a wide frequency range with consistent characteristics. The LPDA consists of a series of dipoles of varying length arranged in a specific pattern, which resonate at different frequencies to provide a constant radiation pattern and impedance over a wide range of frequencies

Structure And Radiation Characteristics Of Log Periodic Antenna: The structure of a log periodic antenna consists of a boom or support structure, which holds the dipole elements. The dipole elements are arranged in a repeating pattern, with each element being slightly longer or shorter than the previous one. The spacing between the elements also varies according to a logarithmic scale. The pattern of the dipole elements and their spacing is carefully designed to ensure that the antenna has a consistent radiation pattern over a wide frequency range. The radiation characteristics of a log periodic antenna are determined by its design. The antenna is designed to have a consistent radiation pattern over a wide frequency range, which makes it useful for a variety of applications, such as communication, broadcasting, and radar. The radiation pattern of the antenna is directional, with the highest gain being in the direction of the main lobe. The main lobe is the direction in which the antenna is most sensitive to incoming signals. The radiation pattern also has side lobes, which are areas of lower gain to the sides of the main lobe. The width and shape of the main lobe and side lobes depend on the design of the antenna.

PARABOLIC REFLECTOR: It is a reflector antenna which has the shape of paraboloid and employs the properties of parabola. It can also be defined as a reflector which is part of a paraboloid of revolution. The parabola, it is a plane curve obtained by the locus of a point which moves so that its distance from another point, called the focus, plus its distance from a straight line, called directrix, is constant. A paraboloid is a three dimensional surface obtained by revolving the parabola about its axis. The paraboloid is called the parabolic reflector or dish antenna. **Operation of parabolic reflector:** If a feed antenna is placed at the focus, all the waves are incident on the reflector and they are reflected back, forming a plane wave front. By the time the reflected waves reach the directrix, all of them will be in phase, irrespective of the point on the parabola from which they are reflected. Hence the radiation is very high and is concentrated along the axis of the parabola. At the same time, waves will be cancelled in other directions as a result of path and phase differences. The main purpose of the parabolic reflector is to convert a spherical wave into a plane wave. **Salient features of paraboloid reflectors:** 1. The directional beam has a sharp main lobe surrounded by several side lobes. 2. The three dimensional shape of the main lobe resembles a fat cigar in the direction of the axis of the paraboloid. 3. If the primary antenna is non-directional,

$$\text{BWFN} = 140\left(\frac{\lambda}{D_a}\right)$$

and $\quad \text{HPBW} = 70\left(\frac{\lambda}{D_a}\right)$

4. The gain of the antenna with parabolic reflector is influenced by aperture ratio

$\left(\frac{D_a}{\lambda}\right)$ and type of illumination

RADIATION MECHANISM OF PARABOLIC ANTENNA: The radiation mechanism of a parabolic antenna involves several steps: **Feed horn**: The feed horn is a small antenna that generates an electromagnetic wave. **Reflector**: The curved surface of the parabolic reflector reflects the incoming wave, causing it to converge towards a focal point in front of the dish. **Focal point**: The electromagnetic wave emitted by the feed horn is focused at the focal point of the dish, where it forms a high-intensity beam. **Radiation pattern**: The shape and direction of the radiation pattern of the antenna depend on the size and shape of the reflector and the position of the feed horn. The radiation pattern is typically highly directional, with a narrow beamwidth that allows the antenna to communicate with distant points while rejecting unwanted signals from other directions. Parabolic antennas can be fed using various mechanisms, including: **Prime focus feed**: This is the most common feed mechanism, where the feed horn is located at the focal point of the parabolic reflector. **Offset feed**: This mechanism is similar to the prime focus feed, but the feed horn is located off-center of the dish, allowing for a larger range of elevation angles. **Cassegrain feed**: This mechanism uses a secondary reflector to reflect the signal from the primary reflector to the feed horn, allowing for a smaller feed horn size and reducing the effects of spillover. **Gregorian feed**: This mechanism uses a concave secondary reflector to direct the signal from the primary reflector to the feed horn, improving the radiation pattern and reducing the effects of blockage. **Applications:** Satellite communication, Radio astronomy, Radar systems.

HORN ANTENNA: It is a radiating element which has the shape of a horn. It is a waveguide one end of which is flared out. A waveguide, when excited at one end and open at the second end, radiates. However, radiation is poor and non-directive pattern results because of the mismatch between the waveguide and free space. The mouth of the waveguide is flared out to improve the radiation efficiency, directive pattern and directivity. Types of horns: • Sectoral horn • Pyramidal horn • Conical horn. Sectoral horn is of two types: (a) Sectoral H plane horn (b) Sectoral E-plane horn. Sectoral horn is a horn in which flaring exists only in one direction. If flaring is along the direction of electric field, it is called sectoral E-plane horn. If flaring is along the direction of magnetic field, it is called sectoral H plane horn. If flaring is along E and H, the horn is called pyramidal horn. It has the shape of a truncated pyramid. If the walls of a circular waveguide are flared out, a conical horn is obtained.

The **aperture** distribution determines how the electromagnetic waves are coupled into the horn and how they propagate through it. In particular, the amplitude and phase of the electric field across the aperture determine the phase and direction of the radiated waves. Therefore, any variation in the aperture distribution will affect the radiation pattern of the horn antenna. For example, if the aperture distribution is uniform, the radiation pattern of the horn antenna will be symmetric and have a well-defined main lobe. On the other hand, if the aperture distribution is tapered, the radiation pattern will have a narrower main lobe and lower sidelobes. This is because the tapered aperture acts as a phase shifter, causing the radiated waves to interfere constructively in the main lobe direction and destructively in the sidelobe directions.

Reasons For The Broadband Characteristics Of A Horn Antenna: • Aperture size: The size of the horn aperture is an important factor in determining the operating bandwidth of the antenna. Larger apertures can support a wider range of frequencies, which can result in a broader bandwidth. • Tapered structure: The horn antenna's tapered structure helps to reduce reflections and improve impedance matching, which can improve its bandwidth. • Low-loss materials: Horn antennas are often constructed using low-loss materials such as metal or dielectric materials.

Applications of horns: 1. Horns are used at microwave frequencies where moderate gains are sufficient. 2. They are used as feed elements. 3. They are often used in laboratories for the measurement of different antenna parameters. **Salient features of horns** 1. Horn becomes small if the flare angle is small. Its radiation pattern is directive, wave front is spherical, mouth area is small and its directivity is small. 2. Flare angle is related to axial length. 4. Directivity of pyramidal horn is more as the flare is in more than one direction. 5. Its directivity is not as high as that of paraboloid. 6. It is used as radiator. 7. It is easy to use with the waveguide. 8. It is used as primary antenna for paraboloid.

MICROSTRIP OR PATCH ANTENNAS: These are antennas made from patches of conducting material on a dielectric substrate above a ground plane. Construction It consists of a very thin (l << l) metallic strip called a patch placed above a ground plane. The strip and ground plane are separated by a dielectric sheet called substrate as shown in Fig. 7.45. The radiating element and feed lines are usually photoetched on the dielectric substrate. The wide use of printed circuits led to the construction of radiating elements and inter-connecting transmission lines using similar technology.

RADIATION MECHANISM: When an AC voltage is applied to the feed line of a microstrip antenna, an alternating current flows on the patch, generating an electric field that is tangential to the surface of the patch. The electric field induces a magnetic field, which is perpendicular to the electric field and parallel to the ground plane. The magnetic field, in turn, generates an electric field that is perpendicular to the magnetic field and tangential to the patch surface. As a result of this interaction between the electric and magnetic fields, electromagnetic waves are excited on the radiating patch. These waves propagate away from the antenna in the form of a plane wave, which can be approximated as a combination of two orthogonal modes: the dominant mode and the higher-order modes. The dominant mode is the lowest-frequency resonant mode of the patch, which generates a broadside radiation pattern with a maximum radiation intensity perpendicular to the surface of the patch. The higher-order modes are excited at higher frequencies and generate radiation patterns with more complex shapes and multiple lobes.

Advantages 1. Small size. 2. Low weight. 3. Low cost. 4. Ease of installation. 5. It does not give rise to aerodynamic drag when used in aircrafts. 6. These are low profile antennas. 7. These antennas can be flush mounted to a metallic conductor or to other surfaces. They do not require space for feed line. The feed line can be placed behind the ground plane. **Disadvantages** 1. Their efficiency is less. 2. Their band width is small and is typically a few percent. Shapes of patch antennas 1. Square 2. Circular 3. Elliptical 4. Rectangular 5. Triangular 6. Diamond. For microstrip line where w Ú t is small, the fringing effect is accounted for by approximately adding two cells. This gives more accurate formula for the impedance of the microstrip line. That is given by Methods of band width control It is a narrow band width antenna. However, **band width can be increased by**: 1. increasing the thickness of parallel plate transmission line 2. cutting holes or slot in the patch. (These holes or slots increase its inductance) 3. using high dielectric constant (Er) substance 4. adding reactive component to the patch. (This reduces VSWR).

VARIOUS TYPES OF FEEDING STRUCTURES USED IN MICROSTRIP PATCH ANTENNAS

Microstrip line feed: This is the most common type of feeding structure used in microstrip patch antennas. In this method, a microstrip transmission line is used to feed the patch antenna. **Proximity feed**: In this method, a coaxial probe is placed near the patch antenna to feed it. The center conductor of the coaxial probe is connected to the patch antenna, while the outer conductor is connected to the ground plane. **Aperture-coupled feed**: In this method, the patch antenna is coupled to the feed line through a small aperture in the ground plane. **Coaxial feed**: In this method, a coaxial cable is used to feed the patch antenna. The center conductor of the coaxial cable is connected to the patch antenna, while the outer conductor is connected to the ground plane. **Inset feed**: In this method, a rectangular slot is made in the patch antenna, and a microstrip line is inserted into the slot to feed the antenna. **Proximity-coupled feed**: In this method, a microstrip line is placed parallel to the patch antenna, and the two are coupled through a small gap between them. **Slot-coupled feed**: In this method, a slot is made in the ground plane under the patch antenna, and a microstrip line is used to feed the patch antenna through the slot.

A **BICONICAL ANTENNA** consists of an arrangement of two conical conductors, which is driven by potential, charge, or an alternating magnetic field (and the associated alternating electric current) at the vertex. The conductors have a common axis and vertex. The two cones face in opposite directions. It is used to produce wide bandwidths, i.e when coverage over a broad range of frequencies is required. **Main features:** • From 75 MHz to 400 MHz. • Excellent azimuth pattern symmetry. • Low loss, high efficiency. Generally, **propagation characteristics** of the layers are described in terms of the following parameters: 1. Virtual height, hv 2. Critical frequency, fc 3. Maximum Usable Frequency, MUF 4. Skip distance 5. Lowest Usable Frequency, LUF 6. Critical angle, qc 7. Optimum working frequency, OWF or frequency of optimum traffic (FOT).

1. Virtual height (hv): It is defined as the height that is reached by a short pulse of energy which has the same time delay as the original wave. Virtual height of the layer is always greater than the actual height. Virtual height of the layer is useful to find the angle of incidence required for the wave to return to earth at a specified point.

2. Critical frequency (fc) for a given layer is defined as the highest frequency that will be reflected to earth by that layer at vertical incidence. It is also defined as the limiting frequency below which a wave is reflected and above which it penetrates through an ionospheric layer, when the waves are incident on the layer normally. Frequencies above the critical frequencies will penetrate through the layer. The critical frequency, fc is given by, fc = 9 sqrt(N). fc is not fixed but depends on electron density. It also differs from time to time during the day.

3. Maximum usable frequency (MUF): It is the highest frequency of wave that is reflected by the layer at an angle of incidence other than normal. MUF depends on time of day, distance, direction, season and solar activity. MUF is the highest frequency that can be used for sky-wave communication between transmitter and receiver. The common values of MUF range between 8 to 30 MHz. However, it may even be 50 MHz at times.

4. Skip distance (ds): It is defined as the shortest distance from the transmitter that is covered by a fixed frequency (> fc). When the angle of incidence is large, ray 1 (Fig. 9.24) returns to ground at a long distance from the transmitter. If the angle is reduced, ray 2 returns to a point closer to the transmitter. So there is always a possibility that short distances may not be covered by sky-wave propagation under certain conditions. The transmission path is limited by the skip distance and curvature of the earth. The longest single-hop distance is achieved when the transmitted ray is tangential to the surface of the earth. The skip distance, ds is found from ds = 2h/tan (theta)c.

5. Lowest usable frequency (LUF): At certain low frequencies, the combination of ionospheric absorption, atmospheric noise, miscellaneous static and receiver S N requirements conspire to reduce radio communications. The lowest frequency that can be used for communication is called LUF.

6. Critical angle (θc): Critical angle, qc is defined as the angle of incidence of a wave at which the wave will not be reflected when q > qc and it will be reflected when q < qc. It depends on the thickness of layer, height and frequency of the wave.

7. Optimum working frequency (OWF) or frequency of optimum traffic (FOT) The frequency of wave which is normally used for ionospheric communication is known as optimum working frequency. It is generally chosen to be about 15% less than the MUF. It is always desirable to use as high a frequency as possible since the attenuation is inversely proportional to the square of the frequency.

Actual height: The height at a point above the surface at which the wave bends down to the earth is called actual height

The **SKIP ZONE** is a zone of silence between the point where the ground wave becomes too weak for reception and the point where the sky wave is first returned to Earth. The size of the skip zone depends on the extent of the ground wave coverage and the skip distance. When the ground wave coverage is great enough or the skip distance is short enough that no zone of silence occurs, there is no skip zone. Occasionally, the first sky wave will return to Earth within the range of the ground wave. If the sky wave and ground wave are nearly of equal intensity, the sky wave alternately reinforces and cancels the ground wave, causing severe fading. This is caused by the phase difference between the two waves, a result of the longer path travelled by the sky wave.

THE MAIN EFFECT OF EARTH'S CURVATURE: 1. The field strength at the receiver becomes small as the direct ray may not be able to reach the receiving antenna (Fig. 9.9). The earth-reflected rays diverge after their incidence on the earth. 2. The curvature of the earth creates shadow zones. These are the regions where no signal reaches. Shadow zones are also called diffraction zones. 3. It reduces the possible distance of transmission. 4. The field strength that is available at the receiver becomes small. When an EM wave travels from the transmitter to the receiver, there are **several factors that influence the propagation.** The factors are: 1. Earth's characteristics in terms of conductivity, permittivity and permeability. 2. Frequency of operation. 3. Polarisation of transmitting antenna. 4. Height of the transmitting antenna. 5. Transmitter power. 6. Curvature of the earth. 7. Obstacles between the transmitter and receiver. 8. Electrical characteristics of the atmosphere in the tropospheric region. 9. Moisture content in the troposphere. 10. Characteristics of the ionosphere. 11. Earth's magnetic field. 12. Refractive index of troposphere and ionosphere. 13. Permittivity of the tropospheric and ionospheric regions. 14. The distance between the transmitter and receiver. 15. Roughness of the earth. 16. Type of earth like hilly terrain, forest, sea water or river water.

The **SPACE WAVE FIELD STRENGTH is affected by** the following: 1. Curvature of the earth. 2. Earth's imperfections and roughness. 3. Hills, tall buildings and other obstacles. 4. Height above the earth. 5. Transition between ground and space wave. 6. Polarisation of the waves.

GROUND WAVE PROPAGATION: Ground wave propagation is a type of radio propagation which is also known as a surface wave. These waves propagate over the earth's surface in low and medium frequencies. These are mainly used for transmission between the surface of the earth and the ionosphere. These are made up of several constituent waves. It is known as a ground wave because it is the sum of the waves that are reflected by the earth's surface or any hills. The waves follow the earth's curvature, enabling them to cover beyond the horizon. Beyond the horizon, the waves get blocked by the earth's curvature, and the signals are produced by the diffracted surface wave. **Advantage:** These waves have the tendency to bend around the corners or obstructions during propagation which makes them more efficient and, these are not affected by the change in atmospheric conditions. **Disadvantage:** • High-frequency waves cannot be transmitted as the energy losses are more because of the energy absorption in the earth's atmosphere. • These are used to cover short ranges and also involves attenuation of waves as they interact with the eddy currents produced by the surface of the earth.

SKY WAVE PROPAGATION: It is preferred when the wave has to travel a longer distance. Here the wave is projected onto the sky and it is again reflected back onto the earth. The sky wave propagation is well depicted in the above picture. Here the waves are shown to be transmitted from one place and where it is received by many receivers. Hence, it is an example of broadcasting. The waves, which are transmitted from the transmitter antenna, are reflected from the ionosphere. It consists of several layers of charged particles ranging in altitude from 30- 250 miles above the surface of the earth. Such a travel of the wave from transmitter to the ionosphere and from there to the receiver on Earth is known as Sky Wave Propagation. Ionosphere is the ionized layer around the Earth's atmosphere, which is suitable for sky wave propagation. **Applications:** International broadcasting, Long-range communication, Amateur radio communication, Emergency communication, Navigation

SPACE WAVE PROPAGATION: Space wave propagation refers to the propagation of electromagnetic waves in free space or through the atmosphere without any reflection or refraction from the Earth's surface or any other obstacles. The space wave propagation is commonly used in point-to-point communication systems, such as satellite communication, microwave communication, and terrestrial radio communication. In these systems, the transmitter and the receiver are placed at high elevations, such as tall buildings, towers, or satellites, to increase the line-of-sight distance and reduce the effects of obstacles on the propagation of the waves. The propagation of space waves is influenced by several factors, including the frequency of the waves, the distance between the transmitter and the receiver, and the atmospheric conditions. As the frequency of the waves increases, the attenuation and absorption of the waves by the atmosphere also increase, limiting the propagation range of the waves. The distance between the transmitter and the receiver also affects the propagation of the waves, as the signal strength decreases with distance due to spreading and absorption effects. The atmospheric conditions, such as temperature, pressure, and humidity, can also affect the propagation of the waves, by causing scattering, reflection, and refraction of the waves.

TROPOSPHERIC PROPAGATION: The tropospheric region extent from surface of earth to a height of 10km at poles and 18km at equator. The propagation through the troposphere takes place die to mechanisms such as diffraction, normal refraction, abnormal reflections and refraction and tropospheric scattering in troposphere slight bending of radio waves occur and cases signal to return to earth beyond geometric horizon.it is most useful in VHF and UHF regions. Radio signals happen in troposphere travel a longer distance than normal before coming back to earth surface. The normal refraction is the main mechanism for tropospheric propagation, the dielectric constant of the earth atm, which varies above the earth Is a primary factor in the tropospheric refraction

PATH LOSS (PL) refers to the loss or attenuation a propagating electromagnetic signal (or wave) encounters along its path from transmitter to the receiver. As a result of path loss, the received signal power level is several orders below the transmitted power level. The received power level is dependent on factors such as transmission power, antenna gains, frequency of operation and the distance between the transmitter and the receiver. Like any other gain or attenuation, path loss is also expressed in decibel (dB). We can relate the received power level and the path loss but before that, let's know the expression of path loss

TROPOSPHERIC REFRACTION: As the atmospheric conditions, expressed in terms of radio refractivity, can considerably influence the performance of radio communication links and radar systems, there is a need for reliable prediction of refractivity structure in the lower atmosphere. The usual methods of direct refractive index measurement by means of radio sounding and refractometers can usually only give a rough idea of the refractivity distribution. The basic disadvantage of the radiosonde, resulting from its occasional, although regular, launching, is that it is not able to provide a detailed idea of refractivity structure time development. In recent years, matched field processing methods representing indirect methods of refractivity structure sounding have turned out to be suitable alternative to direct means of measurement. These methods have been used in the electromagnetic domain to estimate the refractivity structure in the troposphere. In tropospheric propagation, measurement values at a vertical receiver array are usually compared with values obtained by simulation with various refractivity profiles as an environmental parameter. The refractivity estimation is determined by the parameter that gives the best fit between the measurement and the simulation. Similar estimation techniques exist relying on fitting simulation results and measurement data from radar.

RADIO WAVE PROPAGATION: In Radio communication systems, we use wireless electromagnetic waves as the channel. The antennas of different specifications can be used for these purposes. The sizes of these antennas depend upon the bandwidth and frequency of the signal to be transmitted.

The mode of propagation of electromagnetic waves in the atmosphere and in free space may be divided in to the following three categories – •Line of sight (LOS) propagation • Ground wave propagation • Sky wave propagation

In ELF (Extremely low frequency) and VLF (Very low frequency) frequency bands, the Earth, and the ionosphere act as a wave guide for electromagnetic wave propagation. In these frequency ranges,

RADIO HORIZON: It is the maximum distance to which radio waves can be transmitted and received without any obstruction due to the curvature of the Earth's surface or any other obstacles. The radio horizon is determined by the height of the transmitting and receiving antennas above the ground, the frequency of the radio waves, and the refractive index of the atmosphere. The radio horizon assumes that the propagation of radio waves is affected by atmospheric refraction, which can bend the waves and cause them to follow the curvature of the Earth's surface, allowing radio waves to travel beyond the optical horizon.

MECHANISM OF RADIO WAVE BENDING IN THE IONOSPHERE: Radio waves bend in the ionosphere due to the variation in the refractive index of the ionized gas or plasma present in this layer of the atmosphere. The refractive index is a function of the electron density and the frequency of the radio waves. When a radio wave enters the ionosphere, it experiences a change in the refractive index and is refracted or bent towards the normal, which is the line perpendicular to the surface of the ionosphere. The degree of bending depends on several factors, including the angle of incidence, the frequency of the radio wave, the electron density, and the height of the ionospheric layer. The ionospheric refraction plays a significant role in long-distance radio communication but can also cause distortion and fading of the radio signals.

TRANSMISSION PATH LOSS: Transmission path loss refers to the reduction in signal strength that occurs as a radio signal propagates through space. It is caused by several factors, including the distance between the transmitter and receiver, the frequency of the signal, obstacles or obstructions in the signal path, and environmental factors such as atmospheric absorption and scattering. Path loss can be mitigated by using higher power transmitters, directional antennas, and lower frequencies, or by removing obstacles in the signal path. Path loss is a critical consideration in wireless communication systems, where it can affect the range and reliability of the communication link.

EFFECT OF MULTIPATH IN WAVE PROPAGATION: Multipath in wave propagation occurs when a signal takes multiple paths to reach the receiver, resulting in multiple copies of the same signal arriving with different phases and amplitudes. The effect of multipath can result in fading, interference, delay spread, and frequency selective fading. Fading is caused by the interference between multiple copies of the signal, while interference is caused by the interference between the signal and other signals transmitted on the same frequency. Delay spread refers to the spread of the signal in time due to the different distances traveled by each copy of the signal. Frequency selective fading occurs when different frequency components of the signal fade differently, leading to signal distortion. Overall, the effect of multipath can reduce the quality and reliability of wireless communication systems.

communication signals practically propagate around the world. The channel band widths are small. Therefore, the information is transmitted through these channels has slow speed and confined to digital transmission.

TROPOSPHERIC SCATTER - make use of the scattering of radio waves in the troposphere to propagate signals in the 250MHZ – 5GHZ rage. It produces undesirable noise and fading which may be minimized do certain extent by diversity reception. The field strength received is usually on the order of or d1/8 where d-distance between transmitter and receiver, high gain antennas are required for reception since signal strength is weak. **Tropospheric scatter can affect space wave propagation** by causing scattering, attenuation, and multipath interference of the radio waves as they travel through the Earth's atmosphere. This can result in signal degradation, fading, and signal loss, especially at higher frequencies. The scattering of the radio waves occurs due to the variation in temperature, pressure, and moisture content in the atmosphere, which can cause the waves to deviate from their original path and scatter in different directions. The attenuation of the radio waves occurs due to the absorption and reflection of the waves by the water vapor and other atmospheric constituents, which can reduce the power of the waves. The multipath interference occurs due to the reflection of the waves by the Earth's surface and the atmosphere, which can cause the waves to arrive at the receiver at different times and with different phases, leading to interference and distortion of the signal.

DIRECT WAVE: when the transmitter and receiver antenna are on the earth there can be multiple paths for communication. It the transmitter and receiver antennae AC IN LOS, then direct path exists. The propagating wave is called Direct wave.

SURFACE WAVE: When Em waves encounters on interface between two dissimilar media a part of energy flow along the interface known as surface waves.

SPACE WAVE: Interaction with one object on ground will manifest as Reflection, refraction, diffraction, scattering. These waves are collectively called as space wave.

STRUCTURE OF IONOSPHERE: The ionized layer extends above 50km above the Surface of the earth to several thousand kilometres Is known as ionosphere. The ionization density increases closer to the surface of the earths, very closer to earth ionization density reduces because of the energy in the radiation been used up or absorbed to create ions. Ionosphere is divided in to 3 layers: d-layer, f-layer, e-layer. F layer is also called as Appleton layer and it is ionized during day time as well as night time. E- layer is called as Kenney-Heavyside layer. d-lager is present only during day time, does not reflect high frequency EM wave but attenuates the waves through it. E and F layer, which are present during both day and night, make long distance communication possible by reflecting radio waves in range of 2-30mhz.along e-layer it has ionization density. the region lower to d-region, where peak of electron density is called d-layer. **Reflection and refraction** of radio waves occur in the ionosphere due to the variation in the refractive index of the ionized gas or plasma present in this layer of the Earth's upper atmosphere. Reflection occurs when the radio wave encounters an abrupt change in the refractive index, such as the transition from the ionosphere to space or the Earth's surface. When the angle of incidence of the radio wave is greater than the critical angle, the radio wave is reflected back towards the Earth's surface. Refraction occurs when the radio wave enters a region of the ionosphere with a different refractive index, causing it to change direction. The degree of refraction depends on several factors, including the angle of incidence, the frequency of the radio wave, the electron density of the ionosphere, and the height of the ionospheric layer.

MECHANISM OF RADIO WAVE PROPAGATION IN EVAPORATION DUCTS: Radio wave propagation in evaporation ducts occurs due to the bending or refraction of radio waves as they pass through layers of moist air with different refractive indices. An evaporation duct is a type of atmospheric duct formed when there is a temperature inversion, which occurs when a layer of warm and moist air is trapped beneath a layer of cooler and drier air. This creates a duct-like structure where the refractive index decreases with height. When a radio wave travels through such a duct, it is refracted towards the surface of the earth due to the decrease in refractive index with height. The degree of refraction depends on the density and temperature of the layers of air through which the radio wave passes. If the refractive index decreases rapidly with height, then the radio wave will be refracted back to the surface of the earth, resulting in a surface wave that can travel for long distances along the surface of the earth. This is known as ducting, and it is commonly observed over the ocean, particularly in areas with high temperatures and humidity, such as the tropics. The presence of an evaporation duct can affect radio communications, particularly at frequencies above 2 GHz. In some cases, the evaporation duct can act as a waveguide, allowing the radio waves to travel for long distances with little attenuation. However, in other cases, the evaporation duct can cause signal fading and multipath interference, which can degrade the quality of the communication link.

REFRACTION BY THE IONOSPHERE: When a radio wave is transmitted into an ionized layer, refraction or, bending of wave occurs. Refraction is caused by an abrupt change in the velocity at the upper part of radio wave, as it shrikes or enters a new medium. The amount of refraction. that occurs depends on three main factors: 1. density of ionization of the layer. 2. frequency of the radio wave. 3. Angle of incidence which wave enter layer

HIGH FREQUENCY WAVES IN SKY-WAVE PROPAGATION- The ionosphere is a region extending to around 400km above the earth. in these regions radiations from the sun causes the molecules to become ionised. the ionisation varies at different levels these levels are peaks in ionisation. within these regions it is primarily the free electron that vibrate with the incoming signals and cause them to be refracted or attenuated according to their frequency. low frequency signals do not reach the higher hence ionospheric propagation takes place for high frequency waves only.

Characteristics of D-layer- •lowest layer of the ionosphere. • thickness of about 10km. exist only in day-time • disappear at night. • ionisation properties depend on altitude of the sun above the horizon. • not useful for HF communication. • reflect some VLF and LF waves and it absorbs MF and HF waves to some extent. • electron density is 400 electron/cc. • critical frequency of the layer is 100khz. **Characteristics of E-layer**- • It exists next to D-layer at an average height of 100km. • its thickness is about 25km. • it reflects some HF waves in day-time. • Its electron density is 5*10^5 electrons/cc. • Its critical frequency is 4MHZ.

FACTORS THAT EFFECT RADIO WAVE PROPAGATION: Frequency: Radio waves of different frequencies propagate differently in the atmosphere. Lower frequency waves (below 2 MHz) follow the curvature of the earth and can propagate for very long distances via ground wave propagation. Higher frequency waves (above 30 MHz) propagate via line-of-sight propagation and are affected by obstacles such as buildings and mountains. **Terrain**: The topography of the terrain, including the height and density of trees, buildings, and mountains, affects the propagation of radio waves. Obstacles can cause reflection, diffraction, and absorption of radio waves, which can affect the strength and quality of the received signal. **Distance**: The distance between the transmitter and receiver affects the strength of the received signal. As the distance increases, the signal strength decreases due to free-space loss, which is the natural attenuation of radio waves as they travel through space. **Weather:** The weather can affect the propagation of radio waves, particularly at higher frequencies. Rain, fog, and snow can absorb and scatter radio waves, while atmospheric conditions such as ionization and atmospheric ducting can affect the propagation of radio waves. **Polarization**: The polarization of the radio wave can affect its propagation. When the polarization of the transmitter and receiver antennas is aligned, the signal strength is maximized, while when the polarization is orthogonal, the signal strength is minimized. Antenna height and orientation: The height and orientation of the transmitting and receiving antennas can affect the propagation of radio waves. Antennas positioned high above the ground can increase the range of the signal, while directional antennas can focus the signal in a specific direction.

OPTICAL HORIZON: It is the visual distance that can be seen from a given height without any obstruction due to the curvature of the Earth's surface. The optical horizon is determined by the observer's height above the ground and the curvature of the Earth's surface, which is approximately 8 inches per mile squared (12.9 cm per km squared) or about 1/12th of the Earth's diameter. The optical horizon assumes that the propagation of light occurs in a straight line and is not affected by atmospheric refraction, which can cause the apparent position of distant objects to be displaced.