LECTURE NOTES ON

WAVE PROPAGATION AND BROADBAND COMMUNICATION ENGG.

5th SEMESTER ETC

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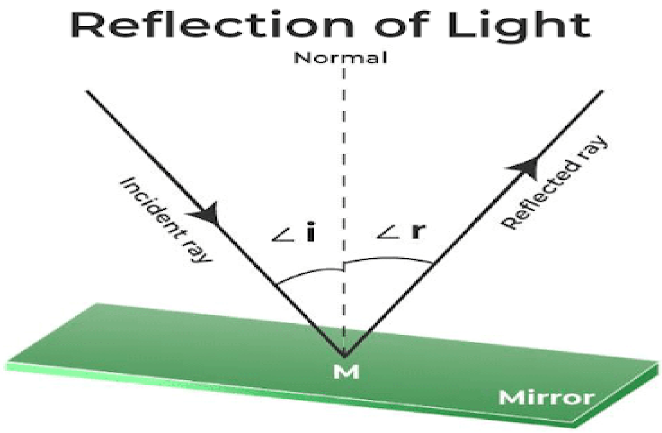
Ch-1 Wave propagation & antenna

Effects of Environment on Electromagnetic wave

Electromagnetic waves on the road are exposed to various environmental influences causing phenomena such as bending, reflection, refraction, absorption and multiple propagation.

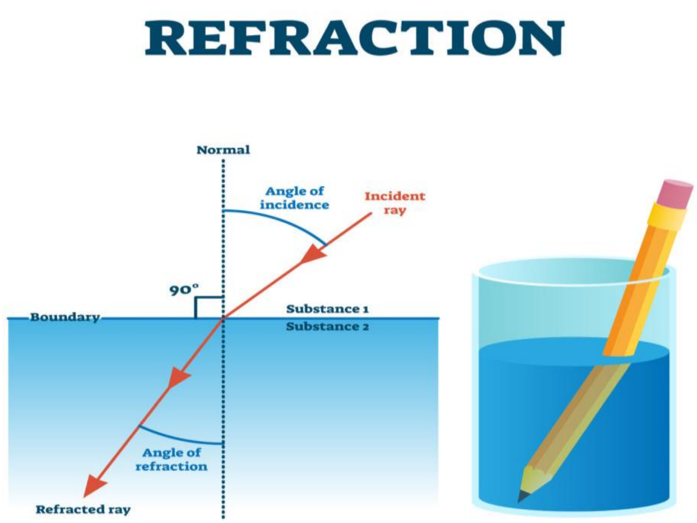
Reflection of electromagnetic wave

The reflection of electromagnetic radiation involves the returning or throwing back of the radiation by a surface upon which the radiation is incident. A reflecting surface is generally the boundary between two materials of different electromagnetic properties



Refraction of Electromagnetic waves

When an electromagnetic wave hits a boundary between different materials, some of the wave's energy is reflected back while the rest continues on through the second material, although the direction of the continuing wave may be somewhat different from the original wave's



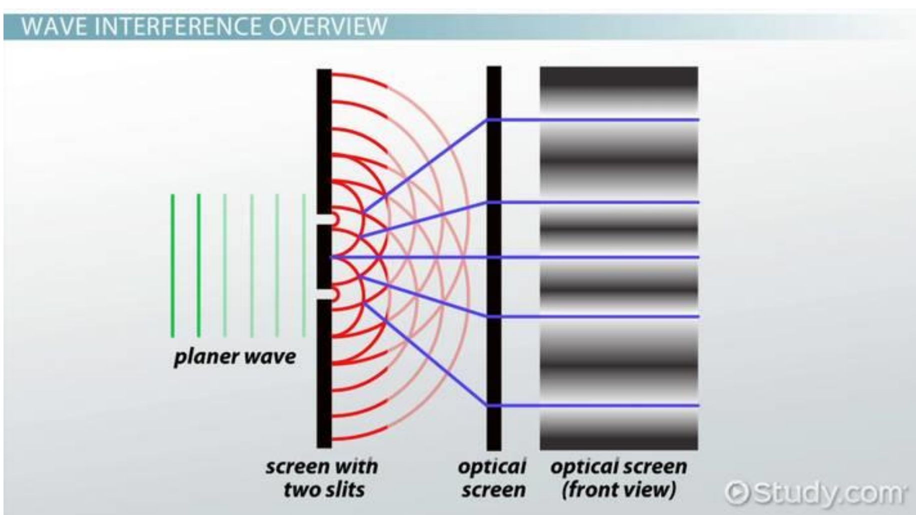
Absorption of electromagnetic waves

Electromagnetic radiation can be absorbed by any particle that carries electric charge. The absorption of electromagnetic radiation helps determine the visible appearance of objects. Absorption of electromagnetic radiation can occur only in quantized amounts. Heating, ionization, fluorescence, and other effects are triggered by the absorption of electromagnetic radiation.

Interference

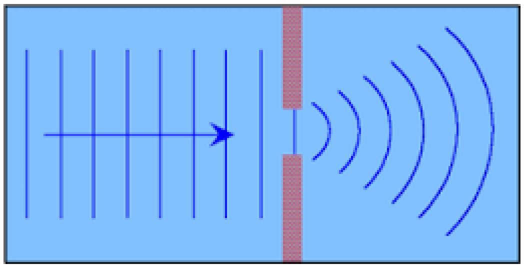
Interference is what happens when two or more waves meet each other. Depending on the overlapping waves' alignment of peaks and troughs, they might add up, or they can partially or entirely cancel each other. As per the interference definition, it is defined as. The phenomenon in which two or more waves superpose to form a resultant wave of greater, lower or the same amplitude.

The interference of waves results in the medium taking on a shape resulting from the net effect of the two individual waves. To better understand, let us consider the example of two pulses of the same amplitude travelling in different directions in the same medium. Let us consider each displaced upward by 1 unit at its crest and has the shape of a sine wave. As these sine pulses move towards each other, there will be a moment in time when they are completely overlapped. At this point, the shape of the medium would be an upward displaced sine wave with an amplitude of 2 units



Diffraction

Diffraction is the spreading out of waves as they pass through an aperture or around objects. It occurs when the size of the aperture or obstacle is of the same order of magnitude as the wavelength of the incident wave. For very small aperture sizes, the vast majority of the wave is blocked. For large apertures the wave passes by or through the obstacle without any significant diffraction.



Attenuation

When a wave travels through a medium, its intensity diminishes with distance. In idealized materials, the wave amplitude is only reduced by the spreading of the wave. Natural materials, however, all produce an effect which further weakens the wave. This further weakening results from scattering and absorption .Scattering is the reflection of the wave in directions other than its original direction of propagation. Absorptionis the conversion of the wave energy to other forms of energy. The combined effect of scattering and absorption is called **attenuation.**

Modes of Wave propagation:

Depending upon the frequencies, these waves propagation can be classified as:1.
Ground waves propagation
2.Skywave propagation
3.Free space propagation

Ground Wave propagation

Ground Wave propagation is a method of radio wave propagation that uses the area between the surface of the earth and the ionosphere for transmission, it. Ground wave propagation is also called surface wave propagation. The ground wave follows the contour of the earth and hence it can propagate considerable distances. Such a wave is called a direct wave. It exists below the 2 MHz frequency range. Ground wave propagation over the earth's surface can be propagated to a considerable distance by the ground wave, in the low frequency and medium frequency portion of the radio spectrum. Ground waves are mainly used for transmission between the surface of the earth and the ionosphere. These are made up of the number of constituent waves. Low frequencies of the electromagnetic spectrum were used. The collection of these radiations along the surface of the earth is known as ground wave propagation. The intensity of these radiations drops with distance due to their absorption by ground. 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 curvature of the earth is being followed by the waves, enabling them to cover beyond the horizon. The waves get blocked beyond the horizon, by the curvature of the earth and the signals are produced by the diffracted surface wave.

Advantages of Ground Wave Propagation

As it uses lower frequencies, interference occurs due to atmospheric noise only. That's why the absorption of EM waves at lower frequencies is less. Hence it can cover longer distances. However, the path loss increases as the distance from the transmitter increases. These waves are more efficient and also these are not affected by the change in atmospheric conditions, due to the bending around the corners or obstructions during propagation.They are vertically polarized in order to prevent short circuits of the electric field (E) component.

Disadvantages of Ground Wave Propagation

1.High-frequency waves cannot be transmitted as the energy losses are more because of the absorption of energy in the earth’s atmosphere.

2.These are used to cover short ranges and also involve attenuation of waves as they interact with the eddy currents produced by the surface of the earth.

3.If the polarization of the ground wave is affected, E field components are short-circuited with the ground.

Applications Ground Wave Propagation

1.To provide the local radio communications coverage, we generally use ground wave propagation, especially by radio broadcast stations that are required to cover a particular locality

2.Ground wave propagation can be used for one-way communication from the military to submerged submarines as they penetrate to a significant depth into seawater.AM, FM, and television broadcasting can be done with the help of ground waves.

3.Ground wave propagation of radio signals is ideal for relatively short distance propagation on these frequencies during the daytime.

Sky Wave Propagation

Sky wave propagation is a kind of radio wave propagation. This wave propagation helps in communicating at long distances in the frequency ranges from a few MHz to 30 MHz or 40 MHz. In Sky wave propagation, radio waves were reflected by the ionosphere or ionised layer back towards the earth. The ionosphere can reflect the waves because of the presence of a large number of charged particles or ions. This sphere extends from 65 km height from the earth to 400 km above. Sky wave propagation is used by the services for shortwave broadcasts. Skip is another name for Sky wave propagation.

The mathematical representation for the sky wave propagation is:

fc=9Nmax

Where,

fc = critical frequency in Hz

Nmax = max. Electron density per m3

Skip Distance is the minimum distance from the radio signal transmitted to the surface of the earth.

Skip distance can be given by

Dskip= 2h (fmuffc)2-1

Where,

fmuf is max. usable frequency

Dskip is skip distance

h is the height from where the reflection happened fc= critical frequency

Sky Wave Propagation Advantages

1. It supports propagation at large distances.
2. Loss of radio waves or debilitation is low due to atmospheric conditions.
3. The frequency range of operation is high.
4. It provides continuous support in different types of communication.
5. Sky wave propagation is a simple mode of propagation.

Sky Wave Propagation Disadvantages

1. There is variation in the signal transmission in day and night time due to the presence of ionosphere near during night and far during night time.
2. There is a requirement of big sized antennas for long-distance or sky wave propagation.
3. Sky wave propagation travels between multiple hops before reaching the receiver which in turn reduces the strength of the waves considerably.

Sky Wave Propagation Applications

This type of radio wave propagation is usually used in satellite and mobile communication.

Space Wave Propagation

Space wave propagation can be described as a type of radio wave propagation. In this propagation, the radio waves are being transmitted either from one antenna to another antenna directly or getting reflected from the ground. Space wave propagation is achieved in the atmosphere's tropospheric region. Thus, Tropospheric wave propagation is another name for space wave propagation. The frequencies are usually greater than 30 or 40 MHz. The troposphere is extended up to 20 km above the surface of the earth.

To calculate the height and distance between the antenna to prevent the loss of signal can be given as:

Dm = (2RHt)–12 + (2RHr)–12

Where,

R = earth's radius

Ht = height of transmitting antenna

Hr = height of receiving antenna

Dm = Distance between the antennas

Space wave propagation advantages

1. To overcome the limitations of other wave propagations, i.e. sky wave propagation and ground wave propagation

2. Allows a large range of frequencies.

Space Wave Propagation disadvantages

1. Space wave propagation happens in the line of sight distance
2. Signals get affected due to the earth curvature.

Space Wave Propagation Applications

This type of radio wave propagation is usually used in satellite and radar communication. Space wave propagation can also be used in microwave linking applications.

Critical Frequency

Critical frequency is defined as the frequency which divides the synchrotron radiation power spectrum into two equal parts

MUF (Maximum Usable Frequency)

MUF is the **maximum frequency which can be reflected for given distance of transmission**. MUF is usually 3 to 4 times of critical frequency

Skip distance

The skip distance is the distance over the Earth's surface between the point where a radio signal is transmitted, and the point where it is received having travelled to the ionosphere, and been refracted back by the ionosphere.

Fading

Fading in wireless communication is defined as the fluctuation in the strength of the signal received at the receiver. These are basically unwanted variations introduced at the time when the signal propagates from an end to another by taking multiple paths.

Duct Propagation

At a height of around 50 mts from the troposphere, a phenomenon exists; the temperature increases with the height. In this region of troposphere, the higher frequencies or microwave frequencies tend to refract back into the Earth's atmosphere, instead of shooting into ionosphere, to reflect. These waves propagate around the curvature of the earth even up to a distance of 1000km.

This refraction goes on continuing in this region of troposphere. This can be termed as **Super refraction** or **Duct propagation**.

Tropospheric Scatter Propagation:

Tropospheric Scatter Propagation is a means of beyond-the-horizon propagation for UHF signals. Tropospheric Scatter Propagation uses certain properties of the troposphere, the nearest portion of the atmosphere (within about 15 km of the ground).

Antenna Maxwell's Equations

Maxwell's Equations are a set of four vector-differential equations that govern all of electromagnetics (except at the quantum level, in which case we as antenna people don't care so much). They were first presented in a complete form by James Clerk Maxwell back in the 1800s. He didn't come up with them all on his own, but did add the displacement current term to Ampere's law which made them complete.

The four equations (written only in terms of **E** and **H**, the electric field and the magnetic field), are given below.

$$\nabla \cdot \mathbf{E} = \frac{\rho_v}{\varepsilon} \qquad \text{(Gauss' Law)}$$

$$\nabla \cdot \mathbf{H} = 0 \qquad \text{(Gauss' Law for Magnetism)}$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \qquad \text{(Faraday's Law)}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \qquad \text{(Ampere's Law)}$$

In Gauss' law, ρ_v is the volume electric charge density, **J** is the electric current density (in Amps/meter-squared), ε is the permittivity and μ is the permeability.

The good news about this is that all of electromagnetics is summed up in these 4 equations. The bad news is that no matter how good at math you are, these can only be solved with an analytical solution in extremely simple cases. Antennas don't present a very simple case, so these equations aren't used a whole lot in antenna theory (except for numerical methods, which numerically solve these approximately using a whole lot of computer power).

The last two equations (Faraday's law and Ampere's law) are responsible for electromagnetic radiation. The curl operator represents the spatial variation of the fields, which are coupled to the time variation. When the E-field travels, it is altered in space, which gives rise to a time-varying magnetic field. A time-varying magnetic field then varies as a function of location (space), which gives rise to a time varying electric field. These equations wrap around each other in a sense, and give rise to a wave equation.

Directivity Gain

It can be defined as the ratio of maximum radiation intensity of a test antenna to the radiation intensity of an isotropic antenna or reference antenna which is radiating the same power in total. Directivity can be denoted by D.

Directivity of antenna shows, how it able to radiates the energy in one or more specific direction. The radiation pattern of an antenna determines its directivity value. Then, Directivity D = maximum radiation intensity of a test antenna/radiation intensity of an isotropic antenna. Here, the isotropic antenna is an ideal antenna, which radiates its power equally or uniformly in all direction to space.

Aperture Concept

Aperture of an Antenna is the area through which the power is radiated or received. Concept of Apertures is most simply introduced by considering a Receiving Antenna .The effective antenna aperture is the ratio of the available power at the terminals of the antenna to the power flux density of a plane wave incident upon the antenna, which is matched to the antenna in terms of polarization. If no direction is specified, the direction of maximum radiation is implied. Effective Aperture (Ae) describes the effectiveness of an Antenna in receiving mode, It is the ratio of power delivered to receiver to incident power density

Input Impedance of Antenna

The input impedance of antenna is basically the impedance offered by the antenna at its terminals. It is defined as the ratio of voltage to the current across the two input terminals of the antenna

Bandwidth

According to the standard definition, “A band of frequencies in a wavelength, specified for the particular communication, is known as bandwidth.” The signal when transmitted or received, is done over a range of frequencies. This particular range of frequencies are allotted to a particular signal, so that other signals may not interfere in its transmission. Bandwidth is the band of frequencies between the higher and lower frequencies• over which a signal is transmitted. The bandwidth once allotted, cannot be used by others.• The whole spectrum is divided into bandwidths to allot to different transmitters.• The bandwidth, which we just discussed can also be called as Absolute Bandwidth.

AntennaEfficiency

According to the standard definition, “Antenna Efficiency is the ratio of the radiated power of the antenna to the input power accepted by the antenna.” Simply, an Antenna is meant to radiate power given at its input, with minimum losses. The efficiency of an antenna explains how much an antenna is able to deliver its output effectively with minimum losses in the transmission line. This is otherwise called as Radiation Efficiency Factor of the antenna.

RadiationPattern 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.

1.The radiation patterns can be field patterns or power patterns. The field patterns are plotted as a function of electric and magnetic fields. They• are plotted on logarithmic scale.

2.The power patterns are plotted as a function of square of the magnitude of electric and magnetic fields. They are plotted on logarithmic or commonly on dB scale.

Types of Radiation patterns

The common types of Radiation patterns are- 1.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.

2.Pencil-beam pattern: The beam has a sharp directional pencil shaped pattern.

3. Fan-beam pattern: The beam has a fan-shaped pattern.

4.Shaped beam pattern: The beam, which is non-uniform and patternless is known as shaped beam.

Antenna

An antenna is a specialized transducer that converts radio-frequency (RF) fields into alternating current (AC) or vice-versa. There are two basic types: the receiving antenna, which intercepts RF energy and delivers AC to electronic equipment, and the transmitting antenna, which is fed with AC from electronic equipment and generates an RF field.

Type of antenna	**Examples**	**Applications**
Wire Antennas	Dipole antenna, Monopole antenna, Helix antenna, Loop antenna	Personal applications, buildings, ships, automobiles, space crafts
Aperture Antennas	Waveguide (opening), Horn antenna	Flush-mounted applications, air-craft, space craft
Reflector Antennas	Parabolic reflectors, Corner reflectors	Microwave communication, satellite tracking, radio astronomy
Lens Antennas	Convex-plane, Concave-plane, Convex-convex, Concaveconcave lenses	Used for very highfrequency applications
Micro strip Antennas	Circular-shaped, Rectangularshaped metallic patch above the ground plane	Air-craft, space-craft, satellites, missiles, cars, mobile phones etc.
Array Antennas	Yagi-Uda antenna, Micro strip patch array, Aperture array, Slotted wave guide array	Used for very high gain applications, mostly when needs to control the radiation pattern

Dipole

The radiation of energy when done through such a bent wire, the end of such transmission line is termed as dipole or dipole antenna. The reactance of the input impedance is a function of the radius and length of the dipole. The smaller the radius, the larger the amplitude of the reactance. It is proportional to the wavelength. Hence, the length and radius of the dipole should also be taken into consideration. Normally, its impedance is around 72Ω.

Monopole antennas

Monopole antennas constitute a group of derivatives of dipole antennas.Only half of the dipole antenna is needed for operation. A metal ground plane (ideally of infinite size) is used, with respect to which the excitation voltage is applied to the half structure. The half structure for a regular dipole antenna is called a monopole antenna, in reference to the presence of only one physical side. A similar half structure for a folded dipole antenna is called a folded monopole antenna. The presence of the ground plane allows the monopole antenna to operate as electrically equivalent to a dipole antenna. The ground plane equivalently replaces the lower half by an imaging principle, similar to creating an optical image through a mirror. For the currents in the monopole and dipole structures to be the same, one needs the source voltage of the equivalent dipole antenna to be twice that of the monopole antenna. As a result, the input impedance of the monopole structure is half that of the corresponding dipole structure:

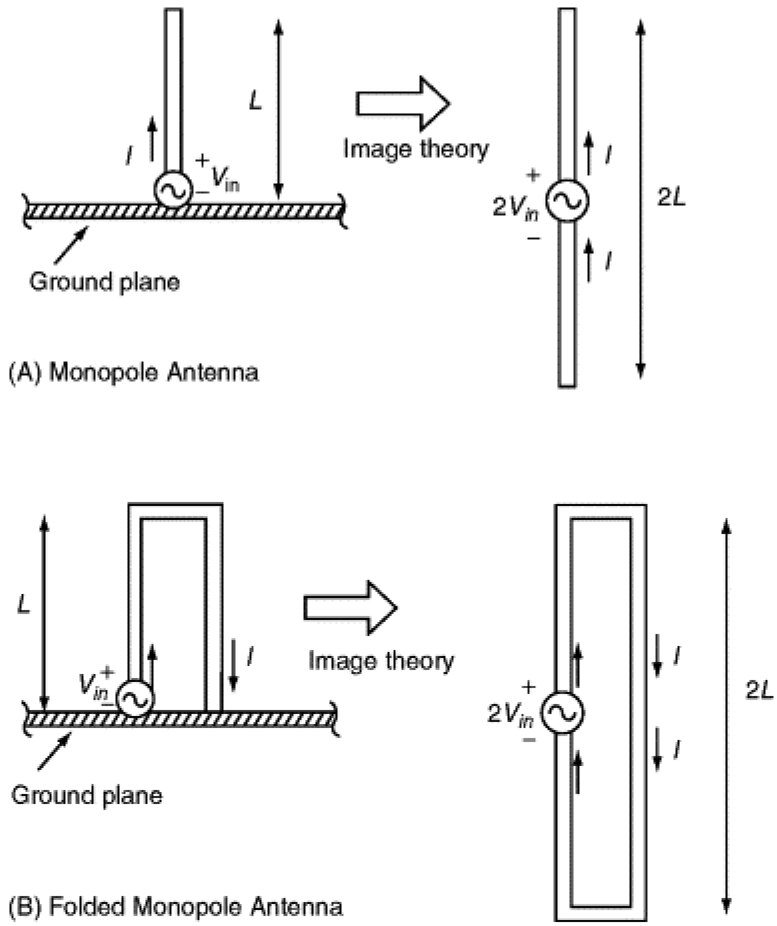


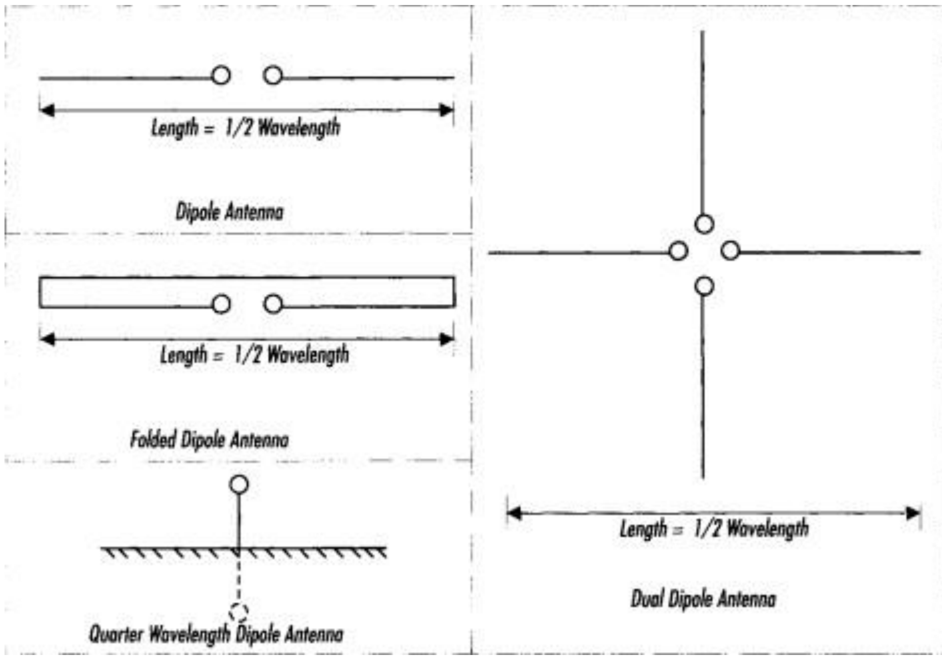
FIGURE . The Corresponding Equivalent Dipole Structures Employing Image Theory

For example, if the length of the monopole antenna $L - \lambda_0/4$, such that the corresponding length of the equivalent dipole antenna is $\lambda_0/2$, the following values of the radiation impedances result:

Due to the imaging principle, the polarization of radiation and radiation patterns of a monopole antenna is the same as that of its equivalent dipole antenna. However: the monopole antenna has a field only in the top half of the space, having zero radiation below the ground plane. In contrast, the equivalent dipole structure has fields in both sides, with the radiation to the bottom side symmetric to that above. In this situation, the expression of the directive gain functions in equations 6.141, 6.142, 6.159, and 6.160 (Das, 2004) can be used to show that the directivity *D* of a monopole antenna is twice that of its equivalent dipole structure.

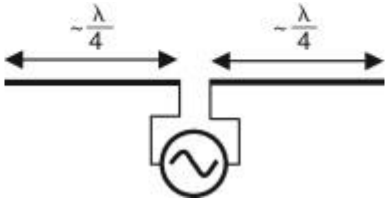
Dipole Antennas

A *dipole antenna* is an antenna with a center-fed driven element for transmitting or receiving radio frequency energy. From a physics viewpoint, this type of antenna is the simplest practical antenna. It consists of a straight electric conductor, made of conducting metal such as copper, interrupted at the center, therefore making two poles.



Dipole Antennas

The *dipole antenna* is one of the simple and widely used antennas This antenna consists of two wires (or traces on a PCB board). The size of each wire is approximately a quarter of the wavelength of the desired frequency of operation. For example, for the 2.4 GHz ISM band with a wavelength of approximately 12 cm, the size of each wire is about 3 cm. Since the total length of this antenna is about half a wavelength, it is also known as a *half-wave* dipole antenna.



A dipole antenna consists of a conductor broken in the middle to allow it to be fed from a balanced transmission line. The total length of the dipole is normally one-half wavelength though other lengths are used in certain cases

Omnidirectional and Directional Antennas

Omnidirectional antennas receive signals equally from all directions. Directional antennas pull in signals better from one direction. In this direction, they can detect a weaker or more distant signal than an equivalent omnidirectional antenna. The trade-off is that they do this by decreasing their ability to pull in signals from other directions.

omnidirectional antennas are easy to identify, because they are generally a vertical wire similar and contained in a vertical housing called a *radome.* A radome is a cover that is transparent to the radio waves. Dipole Antennas

Commonly known as an *omnidirectional* antennas, all *dipole antennas* have a generalized radiation pattern. The donut-shaped elevation pattern shows that a dipole antenna is best used to transmit and receive from the broadside of the antenna and is very sensitive to matching horizontal positioning and any movement away from a perfectly vertical position. At about 45 degrees from perfect verticality, the omni's signals, both received and transmitted, will degrade to more than half.

Physically, dipole antennas are cylindrical and are usually limited in power gain due to their widespread coverage. They are most commonly used in mobility applications. The dipole antenna is not a directive antenna, since its power is radiated 360 degrees around the antenna (one of the reasons for FCC power gain limitations). Dipole antennas are also the most common culprits in interference issues, due to their widespread radiated pattern. A mobility device requires a dipole antenna, since there is no way of telling where the next AP will be for connectivity. If a mobile unit discovers an AP north of its current position, the antenna continues to radiate 360 degrees in all directions, creating noise and/or interference for any other AP in the area attempting to use the same frequencies and channels.

Directional High Frequency Antenna:

Directional High Frequency Antenna are likely to differ from lower-frequency ones for two reasons. These are the HF transmission/reception requirements and the ability to meet them. Since much of HF communication is likely to be point-to-point, the requirement is for fairly concentrated beams instead of omnidirectional radiation. Such radiation patterns are achievable at Directional High Frequency Antenna, because of the shorter wavelengths. Antennas can be constructed with overall dimensions of several wavelengths while retaining a manageable size.

Yagi-Uda antenna:

A Yagi-Uda antenna is an array consisting of a driven element and one or more parasitic elements. They are arranged collinearly and close together, as shown in Figure together with the optical equivalent and the radiation pattern.

Since it is relatively unidirectional, as the radiation pattern shows, and has a moderate gain in the vicinity of 7 dB, the Yagi antenna is used as an Directional High Frequency Antenna. It is also employed at higher frequencies, particularly as a VHF television receiving antenna. The back lobe of Figure may be reduced, and thus the front-to-back ratio of the antenna improved, by bringing the radiators closer. However, this has the adverse effect of lowering the input impedance of the array, so that the separation shown, 0.1λ, is an optimum value.

The precise effect of the parasitic element depends on its distance and tuning, i.e., on the magnitude and phase of the current induced in it. As already mentioned, a parasitic element resonant at a lower frequency than the driven element (i.e., longer) will act as a mild reflector, and a shorter parasitic will act as a mild "director" of radiation. As a parasitic element is brought closer to the driven element, it will load the driven element more and reduce its input impedance. This is perhaps the main reason for the almost invariable use of a folded dipole as the driven element of such an array.

The Yagi antenna admittedly does not have high gain, but it is very compact, relatively broadband because of the folded dipole used and has quite a good unidirectional radiation pattern. As used in practice, it has one reflector and several directors which are either of equal length or decreasing slightly away from the driven element. Finally, it must be mentioned that the folded dipole, along with one or two other antennas, is sometimes called a supergain antenna, because of its good gain and beamwidth per unit area of array.

Nonresonant Antennas—The Rhombic:

A major requirement for Directional High Frequency Antenna is the need for a multi-band antenna capable of operating satisfactorily over most or all of the 3- to 30-MHz range, for either reception or transmission. One of the obvious solutions is to employ an array of nonresonant antennas, whose characteristics will not change too drastically over this frequency range.

A very interesting and widely used antenna array, especially for point-to-point communications, is shown in Figure . This is the **rhombic antenna**, which consists of nonresonant elements arranged differently from any previous arrays. It is a planar rhombus which may be thought of as a piece of parallel-wire transmission line bowed in the middle. The lengths of the (equal) radiators vary from 2 to 8 λ, and the radiation angle, Φ, varies from 40 to 75°, being mostly determined by the leg length.

Because the rhombic is nonresonant, it does not have to be an integral number of half-wavelengths long. It is thus a broadband antenna, with a frequency range at least 4 : 1 for both input impedance and radiation pattern. The rhombic is ideally suited to Directional High Frequency Antenna transmission and reception and is a very popular antenna in commercial point-to-point communications.