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An Insight into Antenna Classification and Applications

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***Abstract*—Antenna is an important part of any wireless communication system as it converts the electronic signals (propagating in the RF Transreceiver) into Electromagnetic Waves (Propagating in the free space) efficiently with minimum loss. This paper discusses the performance, characteristics and applications of antennas in modern wireless communication systems. Five different types of antennas are discussed. The basic equations and principles of antenna theory are presented. The characteristics of each type of antenna are discussed. This paper has a selection of antenna applications from the low-frequency ELF system to high frequency wireless applications.**

***Index Terms*— Antennas, Classification, Applications of Antenna.**

I. INTRODUCTION

Antennas are basic components of any electric system and are connecting links between the transmitter and free space or free space and the receiver. These are employed in different systems in different forms. That is, in some systems the operational characteristic of the system are designed around the directional properties of the antennas or in some others systems, the antennas are used simply to radiate electromagnetic energy in an omni-directional or finally in some systems for point-to-point communication purpose in which increased gain and reduced wave interference are required.

The broadest definition of an antenna is that it is a transducer—it changes energy from one form into another. An antenna is the component of a radio system that is used to send or receive a radio signal. A radio frequency (RF) signal that has been generated in a radio transmitter travels through a transmission line (coaxial cable) to an antenna. An antenna connected to a transmitter is the device that releases RF energy (in the form of an electromagnetic field) to be sent to a distant receiver. The receiving antenna picks up the RF energy. As the electromagnetic field strikes the receiving antenna, a voltage is induced into the antenna, which serves as a conductor. The induced RF voltages are then used to recover the transmitted RF information. A receiving antenna changes electromagnetic energy into electric or magnetic energy. A transmitting antenna changes the energy from electric or magnetic into electromagnetic energy. Current flowing in the antenna induces the electric and magnetic fields. Antennas have been used for over a century in a variety of applications. They can transmit over a massive range of frequencies, from a fraction of a kilohertz to over one hundred gigahertz. This paper will give a brief introduction to antenna principles, and then discuss various antenna types and their applications.

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II. BASIC ANTENNA PRINCIPLES

A. Antenna Parameters

There are five basic parameters that one must understand to determine how an antenna will operate and perform. The first is the characteristic of radiation resistance. The radiation resistance (R_{rad}) of an antenna relates the power supplied (P_{rad}) to the antenna and the current (I) flowing into the antenna. The equation for radiation resistance is given in (1). As can be seen, the greater the radiation resistance, the more energy is radiated or received by the antenna. When the radiation resistance of the antenna matches the resistance of the transmitter or receiver, the system is optimized. Antennas also have ohmic or loss resistance which decreases the efficiency. It can be shown that an efficient antenna must be comparable to a wavelength in size.

$$R_{rad} = \frac{P_{rad}}{I^2} \qquad (1)$$

A second parameter of antennas is the antenna pattern. This gives a distribution of radiated power as a function of direction in space. Generally, planar sections of the radiation pattern will be shown instead of the complete three-dimensional surface. The most important views are those of the principal E-plane and H-plane patterns. The E-plane pattern contains the plane in which the electric field lies. Similarly, the H-plane pattern is a sectional view in which the magnetic field lies. An example of each type is shown in Fig. 1, which gives the antenna pattern for a half-wave dipole orientated in the z-direction.

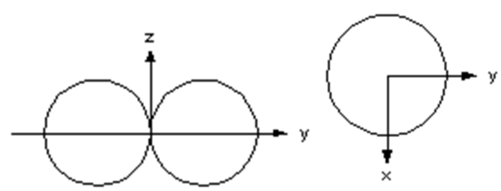


Fig. 1 (a) Dipole Principal E-plane Pattern (b) Dipole Principal H-plane Pattern

Most antennas do not radiate uniformly, as seen in Fig. 1 (a). This implies that there is some directivity, which is the third parameter. Closely related to this is the gain of the antenna. The directivity is a measure of the ability of an antenna to concentrate the radiated power in a given direction. The gain is similarly defined. Usually given in decibels, it is the ratio of power radiated to input power. Thus, using an antenna with a higher gain would require less input power. Gain is a more significant parameter in practice than the directivity.

Bandwidth is another important antenna parameter. This refers to the inclusive frequencies available outside the center frequency. For example, a 10 MHz transmitter with a 10% bandwidth could send information on frequencies from 9 MHz to 11 MHz. This is important to Frequency Modulated (FM) signals, as they require modulation about the carrier frequency in order to send data.

The final antenna parameter is the signal-to-noise ratio. This is the relationship between the desired information signal and the noise[1]. If this ratio does not exceed unity, information will not be transferred. Noise can be caused by obstructions, large distances between antennas, and environmental RF noise, such as power supplies and digital switching devices.

B. Electromagnetic Energy Calculations

An antenna's electric and magnetic fields can be calculated at any point, but the equations are not simple. A short current filament generates the fields shown in (2), (3), and (4), given in spherical coordinates. Because of the complexity of these equations, most problems involving antennas are solved by experimental rather than theoretical methods.

$$H_{\phi s} = \frac{I_0 d}{4\pi} \sin\theta e^{-j2\pi \cdot r/\lambda} \left(j\frac{2\pi}{\lambda r} + \frac{1}{r^2} \right) \qquad (2)$$

$$E_{rs} = \frac{I_0 d\eta}{2\pi}\cos\theta e^{-j2\pi\cdot r/\lambda}\left(\frac{\lambda}{j2\pi\cdot r^3}+\frac{1}{r^2}\right) \quad (3)$$

$$E_{\theta s} = \frac{I_0 d\eta}{4\pi}\sin\theta e^{-j2\pi\cdot r/\lambda}\left(j\frac{2\pi}{\lambda r}+\frac{1}{r^2}+\frac{\lambda}{j2\pi\cdot r^3}\right) \quad (4)$$

Despite the complexity of these equations, some observations can be made. The exponential factor in each equation is the same. This indicates wave propagation outward from the origin in the positive r direction. The wavelength is equal to λ, and d is the length of the current filament. Also as expected, the strength of the fields is related directly to the peak current, I0. The factor η is equal to 120πΩ in free space.

At radial distances 10 or more wavelengths away from the oscillating current element, these equations can be simplified [4]. All terms except the 1/r term may be neglected, and the radiation fields are given in (5), (6), and (7). Assuming a vertical orientation of the current element, plotting Eθs against θ for a constant r will result in a graph similar to Figure 1a, called the vertical pattern. Plotting Hϕs shows the variation of field intensity with ϕ, often referred to as the horizontal pattern, such as in Fig. 1 (b).

$$H_{\phi s} = j\frac{I_0 d}{2\lambda r}\sin\theta e^{-j2\pi\cdot r/\lambda} \quad (5)$$

$$E_{\theta s} = j\frac{I_0 d\eta}{2\lambda r}\sin\theta e^{-j2\pi\cdot r/\lambda} \quad (6)$$

$$E_{rs} = 0 \quad (7)$$

III. Types of Antennas

A. Diploes and Monopoles

The world's most popular antenna is the half-wave dipole. Shown in Figure 2, the total length of the antenna is equal to half of the wavelength. The relationship between wavelength and frequency is f = c / λ , where $c = 3\times 10^8$ m/s in free space. Dipoles may be shorter or longer than half of the wavelength, but this fraction provides the best antenna efficiency. The radiation resistance is calculated as 73.1 Ω.

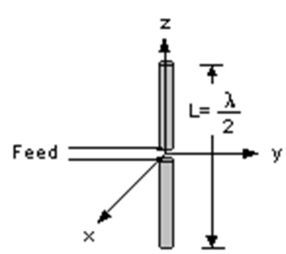


Fig. 2 Dipole Antenna, 1/2 Wave

The dipole antenna is fed by a two-wire line, where the two currents in the conductors are equal in amplitude but opposite in direction[3]. Since the antenna ends are essentially an open circuit, the current distribution along the length of the half-wave dipole is sinusoidal, shown in Figure 3. This produces the antenna pattern shown in Figure 1. This pattern shows that when the antenna is vertical, it radiates the most in the horizontal direction and very little out the ends of the antenna. A typical gain for a dipole antenna is 2dB, and the bandwidth is generally around 10%.

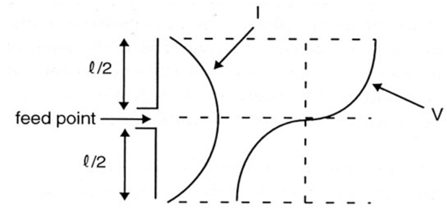


Fig. 3 Current and Voltage Distributions for a Half-Wave Dipole Antenna

A monopole antenna is one-half a dipole plus a perfectly conducting plane. It behaves in a similar way to the dipole, but most of its parameters are halved. Figure 4 shows a quarter-wave monopole, also known as the vertical whip antenna.

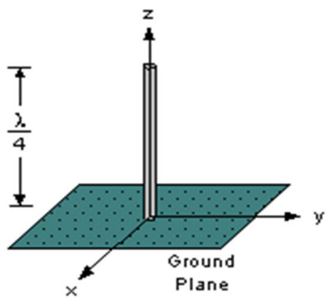
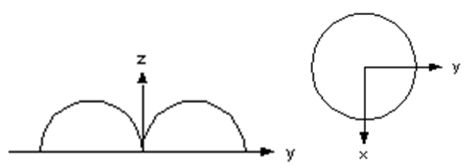


Fig. 4 Monopole Antenna, 1/4 Wave

The radiation resistance is 36.5Ω, half that of a dipole. The total power radiated is also half that of a dipole, and the radiation pattern is shown in Figure 5. A typical gain for a monopole antenna is 2 to 6dB, and the bandwidth is also around 10%.

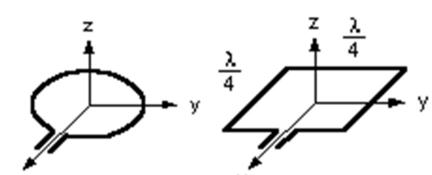


(a) (b)

Fig. 5 (a) Monopole Principal E-plane Pattern (b) Monopole Principal H-plane Pattern

B. Loop Antennas

The loop antenna is a conductor bent into the shape of a closed curve, such as a circle or square, with a gap in the conductor to form the terminals. Figure 6 shows a circular and a square loop. These antennas may also be found as multi-turn loops or coils, designed with a series connection of overlaying turns. There are two sizes of loop antennas: electrically small and electrically large. If the total conductor length is small compared with a wavelength, it is considered small. An electrically large loop typically has a circumference approaching one wavelength.



(a) (b)

Fig. 6 (a) Circular Loop Antenna (b) Square Loop Antenna

The current distribution on a small loop antenna is assumed to be uniform. This allows it to be simply analyzed as a radiating inductor. Used as transmitters, loop antennas have a pattern that follows Figure 7. Loop antennas can have a gain from –2dB to 3dB and a bandwidth of around 10%.

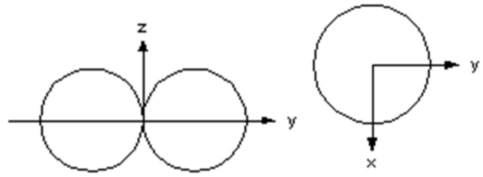


Fig. 7 (a) Loop Antenna Principal E-plane Pattern (b) Loop Antenna Principal H-plane Pattern

Loop antennas have found to be very useful as receivers. For low frequencies—where dipoles would become very large—loop antennas can be used. While the efficiency of a small loop antenna is not good, a high signal-to-noise ratio makes up for it. A common method to increase loop antennas' performance is to fill the core with a ferrite. This has the effect of increasing the magnetic flux through the loop and increasing radiation resistance.

C. Microstrip Antennas

The microstrip or patch antenna is often manufactured directly on a printed circuit board, where the patch is a rectangular element that is photoetched from one side of the board (Figure 8)[11]. Most microstrip elements are fed by a coaxial conductor which is soldered to the back of the ground plane. The dielectric substrate between the microstrip and the ground plane is simply the printed-circuit substrate.

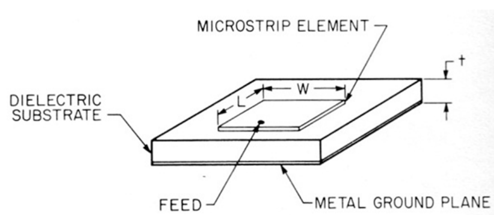


Fig. 8 Rectangular Microstrip-Antenna Element

Despite its low profile, the microstrip antenna has an efficient radiation resistance. The source of this radiation is the electric field that is excited between the edges of the microstrip element and the ground plane. The equation for the radiation resistance is a function of the desired wavelength (λ) and the width (W) of the microstrip:

$$R_{rad} = \frac{120\lambda}{W} \qquad (8)$$

Microstrip antennas are generally built for devices that require small antennas, which lead to high frequencies, typically in the Gigahertz. Most microstrip elements are very efficient, anywhere from 80 to 99 percent. Factors that affect efficiency are dielectric loss, conductor loss, reflected power, and the power dissipated in any loads involved in the elements.

D. Helical Antennas

The basic helical antenna consists of a single conductor wound into a helical shape, shown in Figure 9. Helical antennas are circularly polarized, that is, the radiated electromagnetic wave contains both vertical and horizontal components [10]. This is unlike the dipole, which only radiates normal to its axis. Like the monopole, a ground plane must be present.

The antenna shown in Figure 9 has a gain of about 12dB. It operates in the 100 to 500 MHz range and is fed with a coax where the center conductor is fed through the center of the ground plane. The spacing of the turns is 1/4-wave and the diameter of the turns is 1/3-wave. This is just one example of a helical antenna; they can be scaled to other frequencies of operation as well.

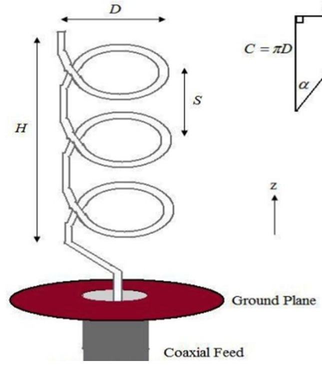


Fig. 9 Helical Antenna

Other modifications can be made; nonuniform-diameter helical structures can widen the bandwidth and improve radiation performance.

E. Horn Antennas

Horn antennas are made for the purpose of controlling one or more of the fundamental antenna properties: gain, antenna pattern, and radiation resistance. A horn antenna works in conjunction with a waveguide—a tube that channels energy from one location to another. Horn antennas can have several shapes, depending on their function. Several are shown in Figure 10.

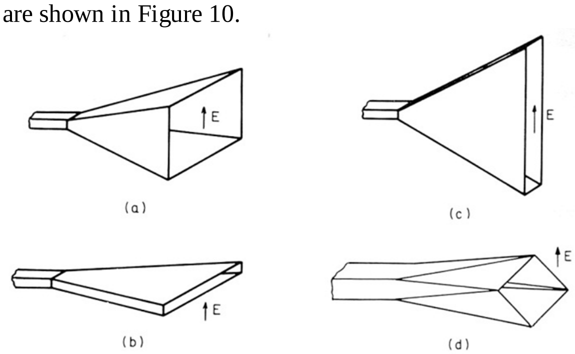


Fig. 10 Rectangular –Waveguide Horns (a) Pyramidal (b) Sectoral H-plane (c) Sectoral E-plane (d) Diagonal

The pyramidal horn in Figure 10a is used to maximize the gain, since the antenna is flared in both the H-plane and E-plane. This obviously gives the antenna a fixed directivity, and it will radiate principally in the direction of the horn's axis. Figures 10b and 10c are special cases of the pyramidal horn, where either the H-plane or E-plane is flared thus and maximized.

IV. Antenna Applications

Only a handful of antennas have been introduced in the previous section. There are numerous variations on these basic antennas, as well as many different shapes. This section will discuss some of the more familiar antenna applications.

A. Indian Navy's ELF System

In the futuristic scenario painted by Gen S Padmanabhan in his book reviewed on one very pertinent and potent future weapon for India in 2017 — the use of submarines both conventional and nuclear powered, with the stated 'second strike' capability. It is quite likely that an Indian nuclear submarine will be in operation by then with sister submarines, as India's second strike. The General discussed the ALH, Vajra a laser based weapon, advanced Akash AA systems and others in the book for the 2017 scenario but failed to include futuristic submarines and their communications. Several reports have suggested that the Indian Navy will have an operational nuclear powered submarine by about 2006. In such a scenario it is pertinent to shift focus to underwater VLF/ELF (Very Low Frequency/Extremely Low Frequency) and laser communications for effective coordination of the submarines with the National Command Authority. The Indian Navy had anticipated the importance of VLF (Very Low Frequency) underwater transmissions long ago. As part of an ambitious naval modernization program, during the mid-1980s the Indian Navy had constructed a VLF (Very Low Frequency) broadcasting station in Tamil Nadu. Although not publicly declared, it was reported that the United States actively collaborated in the project, which was completed in September 1986.

The operational VLF facility can primarily be used by the Indian Navy to communicate with its SSKs (Submarine, Conventional powered hunter-killer). When nuclear submarines become operational, the VLF facility will permit Indian National Command Authority to issue launch orders to submerged subs at depths of several metres. VLF waves propagate almost a quarter of the globe away and are generally immune to atmospheric disturbances caused by nuclear detonations.

ELF systems work on the principle that the attenuation of electromagnetic waves in seawater increases with frequency. The Navy's ELF system operates at only 76 Hz, allowing signals to penetrate to depths of hundreds of feet. The ELF system is virtually jam proof from both natural and man-made interference. When frequencies are this low, the earth and ionosphere behave like conducting mediums—like two spherical shells. The locations of the transmitters were chosen based on geological factors. In each site, the bedrock present has a low conductivity.

B. VHF and UHF Antennas

The very-high-frequency (VHF) and ultra-high-frequency (UHF) bands are used for private and public-access services carrying speech and data. There are a wide variety of applications and many different types of antennas. For a typical base-station antenna, such as for a television or radio station, the transmitter must be large to achieve the desired frequency and provide a large range of coverage. The VHF and UHF bands cover frequencies from 3 MHz to 3000 MHz and include television and FM radio broadcasting. It is common that antennas will share a tower, resulting in a candelabra structure.

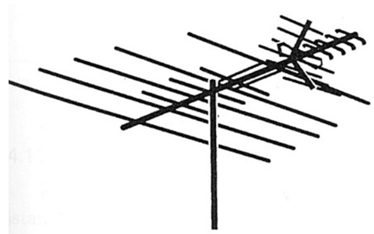


Fig. 11 UHF/VHF/FM Antenna

V. CONCLUSIONS

Antennas are devices that change electromagnetic energy into electric or magnetic energy or vice versa. The equations describing antenna behavior are complicated, and engineers use experimental measurements and data in most antenna design work. There are many different types of antennas, and this paper introduced just a few of the basic shapes: dipoles, monopoles, loops, microstrips, helicals, and horns. Each type of antenna has certain characteristics that are important to determine its behavior: radiation resistance, antenna pattern, directivity and gain, bandwidth, and the signal-to-noise ratio. Antennas are used in numerous applications. A few were mentioned in this paper, such as the Navy's ELF system, VHF and UHF antennas, TV and FM receiving antennas, and some wireless applications.

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