Antenna Theory

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About the Tutorial

This tutorial is meant to provide the readers a detailed description of the antennas used in communication systems. After completing this tutorial, you will be able to calculate the parameters of an antenna and decide which antenna suits for which type of application and why.

Audience

This tutorial is meant for all the readers who are aspiring to learn the phenomenon of antennas used in communication systems, from the basic parameters of antennas, the types of antennas along with their characteristics and their design parameters.

Prerequisites

A learner who wants to go ahead with this tutorial needs to have basic concepts on Electromagnetic waves and a good hold on communication systems.

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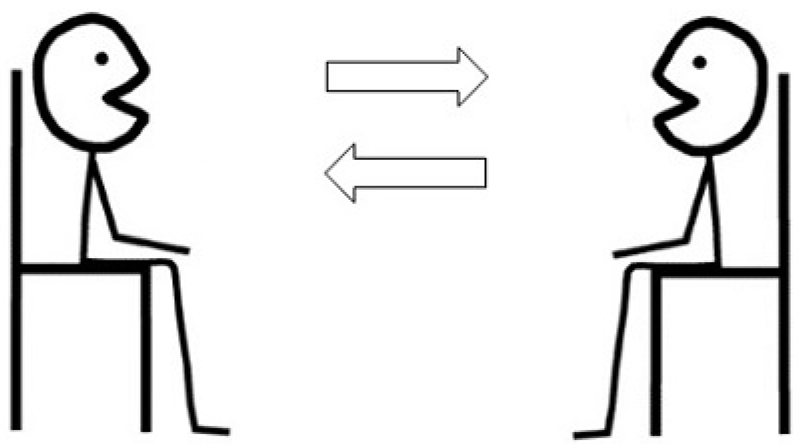
Antenna – Basic Terms

1. Antenna – Fundamentals

A person, who needs to convey a thought, an idea or a doubt, can do so by **voice communication.**

The following illustration shows two individuals communicating with each other. Here, communication takes place through sound waves. However, if two people want to communicate who are at longer distances, then we have to convert these sound waves into electromagnetic waves. The device, which converts the required information signal into electromagnetic waves, is known as an **Antenna.**



What is an Antenna

An Antenna is a transducer, which converts electrical power into electromagnetic waves and vice versa.

An Antenna can be used either as a **transmitting antenna** or a **receiving antenna**.

- A **transmitting antenna** is one, which converts electrical signals into electromagnetic waves and radiates them.
- A **receiving antenna** is one, which converts electromagnetic waves from the received beam into electrical signals.
- In two-way communication, the same antenna can be used for both transmission and reception.

Antenna can also be termed as an **Aerial**. Plural of it is, **antennae** or **antennas**. Now-a-days, antennas have undergone many changes, in accordance with their size and shape. There are many types of antennas depending upon their wide variety of applications.

Following pictures are examples of different types of Antennas.

In this chapter, you are going to learn the basic concepts of antenna, specifications and different types of antennas.

Need of Antenna

In the field of communication systems, whenever the need for wireless communication arises, there occurs the necessity of an antenna. **Antenna** has the capability of sending or receiving the electromagnetic waves for the sake of communication, where you cannot expect to lay down a wiring system. The following scenario explains this.

Scenario

In order to contact a remote area, the wiring has to be laid down throughout the whole route along the valleys, the mountains, the tedious paths, the tunnels etc., to reach the remote location. The evolution of wireless technology has made this whole process very simple. Antenna is the key element of this wireless technology.

In the above image, the antennas help the communication to be established in the whole area, including the valleys and mountains. This process would obviously be easier than laying a wiring system throughout the area.

Radiation Mechanism

The sole functionality of an antenna is **power radiation** or reception. Antenna (whether it transmits or receives or does both) can be connected to the circuitry at the station through a transmission line. The functioning of an antenna depends upon the radiation mechanism of a transmission line.

A conductor, which is designed to carry current over large distances with minimum losses, is termed as a **transmission line**. For example, a wire, which is connected to an antenna. A transmission line conducting current with uniform velocity, and the line being a straight one with infinite extent, **radiates no power**.

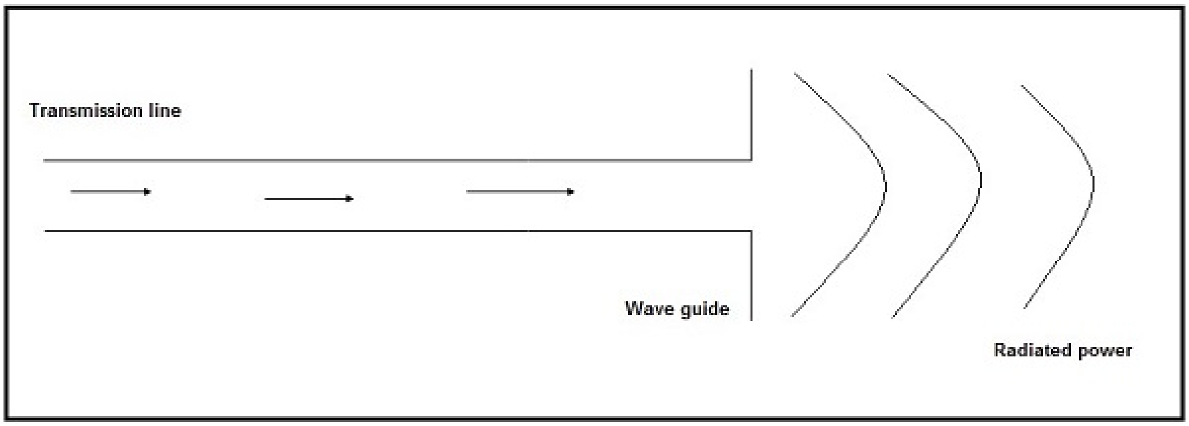
For a transmission line, to become a waveguide or to radiate power, has to be processed as such

- If the power has to be radiated, though the current conduction is with uniform velocity, the wire or transmission line should be bent, truncated or terminated.

- If this transmission line has current, which accelerates or decelerates with a time-varying constant, then it radiates the power even though the wire is straight.

- The device or tube, if bent or terminated to radiate energy, then it is called as **waveguide**. These are especially used for the microwave transmission or reception.

This can be well understood by observing the following diagram-



The above diagram represents a waveguide, which acts as an antenna. The power from the transmission line travels through the waveguide which has an aperture, to radiate the energy.

Basic Types of Antennas

Antennas may be divided into various types depending upon-

- The physical structure of the antenna.
- The frequency ranges of operation.
- The mode of applications etc.

Physical structure

Following are the types of antennas according to the physical structure. You will learn about these antennas in later chapters.

- Wire antennas
- Aperture antennas
- Reflector antennas
- Lens antennas
- Micro strip antennas
- Array antennas

Frequency of operation

Following are the types of antennas according to the frequency of operation.

- Very Low Frequency (VLF)
- Low Frequency (LF)
- Medium Frequency (MF)
- High Frequency (HF)
- Very High Frequency (VHF)
- Ultra High Frequency (UHF)
- Super High Frequency (SHF)
- Micro wave
- Radio wave

Mode of Applications

Following are the types of antennas according to the modes of applications-

- Point-to-point communications
- Broadcasting applications
- Radar communications
- Satellite communications

2. Antenna – Basic Parameters

The basic communication parameters are discussed in this chapter to have a better idea about the wireless communication using antennas. The wireless communication is done in the form of waves. Hence, we need to have a look at the properties of waves in the communications.

In this chapter, we are going to discuss about the following parameters-

- Frequency
- Wavelength
- Impedance matching
- VSWR & reflected power
- Bandwidth
- Percentage bandwidth
- Radiation intensity

Now, let us learn them in detail.

Frequency

According to the standard definition, "The rate of repetition of a wave over a particular period of time, is called as **frequency**."

Simply, frequency refers to the process of how often an event occurs. A periodic wave repeats itself after every '**T**' seconds (time period). **Frequency** of periodic wave is nothing but the reciprocal of time period (T).

Mathematical Expression

Mathematically, it is written as shown below.

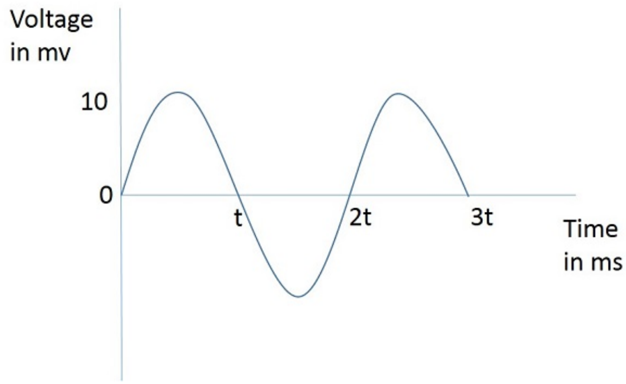
$$f = \frac{1}{T}$$

Where

- f is the frequency of periodic wave.
- T is the time period at which the wave repeats.

Units

The unit of frequency is **Hertz**, abbreviated as **Hz**.



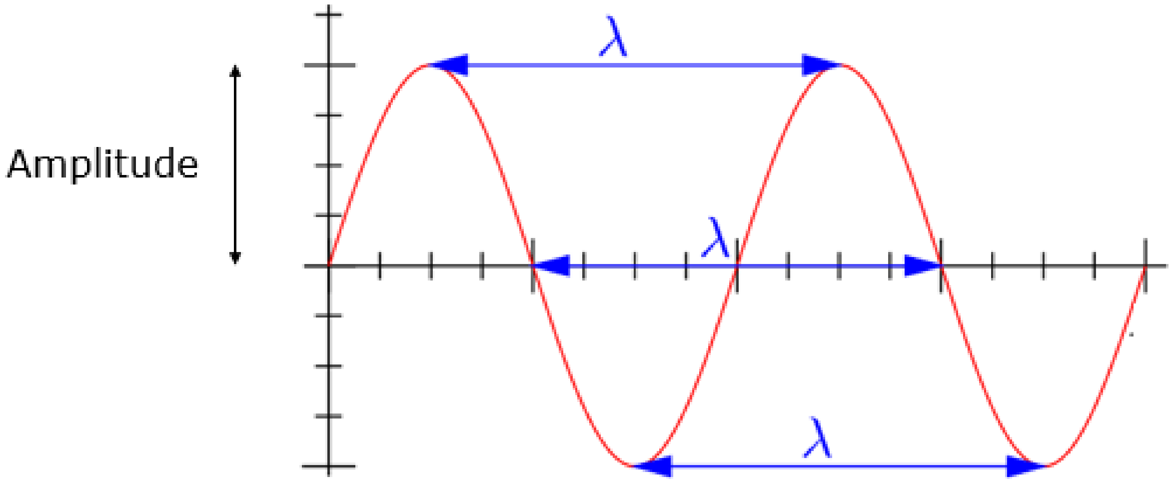
The figure given above represents a sine wave, which is plotted here for Voltage in millivolts against time in milliseconds. This wave repeats after every 2t milliseconds. So, time period, T=2t milliseconds and frequency, f = $\frac{1}{2t} K\ Hz$.

Wavelength

According to the standard definition, "The distance between two consecutive maximum points (crests) or between two consecutive minimum points (troughs) is known as the **wavelength.**"

Simply, the distance between two immediate positive peaks or two immediate negative peaks is nothing but the length of that wave. It can be termed as the **Wavelength**.

The following figure shows a periodic waveform. The **wavelength (λ)** and amplitude are denoted in the figure. The higher the frequency, the lesser will be the wavelength and vice versa.



Mathematical Expression

The formula for wavelength is,

$$\lambda = \frac{c}{f}$$

Where-

- **λ** is the wavelength
- **c** is the speed of light (3×10^8 meters/second)
- **f** is the frequency

Units

The wavelength **λ** is expressed in the units of length such as meters, feet or inches. The commonly used term is **meters.**

Impedance Matching

According to the standard definition, "The approximate value of impedance of a transmitter, when equals the approximate value of the impedance of a receiver, or vice versa, it is termed as **Impedance matching**."

Impedance matching is necessary between the antenna and the circuitry. The impedance of the antenna, the transmission line, and the circuitry should match so that **maximum power transfer** takes place between the antenna and the receiver or the transmitter.

Necessity of Matching

A resonant device is one, which gives better output at certain narrow band of frequencies. Antennas are such **resonant devices** whose impedance if matched, delivers a better output.

- The power radiated by an antenna, will be effectively radiated, if the **antenna impedance** matches the free space impedance.

- For a **receiver antenna**, antenna's output impedance should match with the input impedance of the receiver amplifier circuit.

- For a **transmitter antenna**, antenna's input impedance should match with transmitter amplifier's output impedance, along with the transmission line impedance.

Units

The unit of impedance (**Z**) is **Ohms**.

VSWR & Reflected Power

According to the standard definition, "The ratio of the maximum voltage to the minimum voltage in a standing wave is known as **Voltage Standing Wave Ratio**."

If the impedance of the antenna, the transmission line and the circuitry do not match with each other, then the power will not be radiated effectively. Instead, some of the power is reflected back.

The key features are-

- The term, which indicates the impedance mismatch is **VSWR**.
- **VSWR** stands for Voltage Standing Wave Ratio. It is also called as **SWR**.
- The higher the impedance mismatch, the higher will be the value of **VSWR**.
- The ideal value of VSWR should be 1:1 for effective radiation.
- Reflected power is the power wasted out of the forward power. Both reflected power and VSWR indicate the same thing.

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**.

Percentage Bandwidth

According to the standard definition, "The ratio of absolute bandwidth to the center frequency of that bandwidth can be termed as **percentage bandwidth**."

The particular frequency within a frequency band, at which the signal strength is maximum, is called as **resonant frequency**. It is also called as **center frequency (f_C)** of the band.

- The higher and lower frequencies are denoted as f_H and f_L respectively.
- The absolute bandwidth is given by- $f_H - f_L$.
- To know how wider the bandwidth is, either **fractional bandwidth** or **percentage bandwidth** has to be calculated.

Mathematical Expression

The **Percentage bandwidth** is calculated to know how much frequency variation either a component or a system can handle.

$$\text{Percentage bandwidth} = \frac{\text{absolute bandwidth}}{\text{center frequency}} = \frac{(f_H - f_L)}{f_C}$$

Where

- f_H is higher frequency
- f_L is lower frequency
- f_C is center frequency

The higher the percentage bandwidth, the wider will be the bandwidth of the channel.

Radiation Intensity

"**Radiation intensity** is defined as the power per unit solid angle"

Radiation emitted from an antenna which is more intense in a particular direction, indicates the maximum intensity of that antenna. The emission of radiation to a maximum possible extent is nothing but the radiation intensity.

Mathematical Expression

Radiation Intensity is obtained by multiplying the power radiated with the square of the radial distance.

$$U = r^2 \times W_{rad}$$

Where

- **U** is the radiation intensity
- **r** is the radial distance
- $\mathbf{W_{rad}}$ is the power radiated.

The above equation denotes the radiation intensity of an antenna. The function of radial distance is also indicated as **Φ**.

Units

The unit of radiation intensity is **Watts/steradian** or **Watts/radian²**.

3. Antenna – Parameters

Radiation intensity of an antenna is closely related to the direction of the beam focused and the efficiency of the beam towards that direction. In this chapter, let us have a look at the terms that deal with these topics.

Directivity

According to the standard definition, "The ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, radiating the same total power is called the **directivity**."

An Antenna radiates power, but the direction in which it radiates matters much. The antenna, whose performance is being observed, is termed as **subject antenna**.

Its **radiation intensity** is focused in a particular direction, while it is transmitting or receiving. Hence, the antenna is said to have its **directivity** in that particular direction.

- The ratio of radiation intensity in a given direction from an antenna to the radiation intensity averaged over all directions, is termed as directivity.
- If that particular direction is not specified, then the direction in which maximum intensity is observed, can be taken as the directivity of that antenna.
- 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.

Mathematical Expression

The radiated power is a function of the angular position and the radial distance from the circuit. Hence, it is expressed by considering both the terms **θ** and **Ø**.

The mathematical expression for directivity is as follows-

$$\text{Directivity} = \frac{\text{Maximum radiation intensity of subject antenna}}{\text{Radiation intensity of an isotropic antenna}}$$

$$D = \frac{\Phi\ (\theta,\Phi)_{max}\ (from\ subject\ antenna)}{\Phi_0\ (from\ an\ isotropic\ antenna)}$$

Where

- $\Phi\ (\theta, \Phi)_{max}$ is the maximum radiation intensity of subject antenna.
- Φ_0 is the radiation intensity of an isotropic antenna (antenna with zero losses).