Basic Antenna Concepts

Antenna

An antenna is a device that transmits and or receives electromagnetic waves. Electromagnetic waves are often referred to as radio waves. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band that the radio system to which it is connected operates in, otherwise reception and/or transmission will be impaired.

Wavelength

We often refer to antenna size relative to wavelength. For example: a half-wave dipole, which is approximately a half-wavelength long. Wavelength is the distance a radio wave will travel during one cycle. The formula for wavelength is:

Length (in feet) = 984 * freq (in MHz)

Note: The length of an half-wave antenna is slightly less than the actual half-wavelength due to end effect. The speed of propagation in coaxial cable is slower than in air, so the wavelength in the cable is shorter. The velocity of propagation of electromagnetic waves in coax is usually given as a percentage of free space velocity, and is different for different types of coax. The formulas for calculating the length of two different wavelength antennas are listed below:

<u>Half-Wave</u>

Length (in feet) = 468 * freq (in MHz)

<u>Quarter-Wave</u>

Length (in feet) = 234 * freq (in MHz)

Impedance Matching

For efficient transfer of energy, the impedance of the radio, the antenna, and the transmission line connecting the radio to the antenna must be the same. Radios typically are designed for 50 ohms impedance and the coaxial cables (transmission lines) used with them also have 50-ohm impedance. Efficient antenna configurations often have impedance other than 50 ohms; some sort of impedance matching circuit is then required to transform the antenna impedance to 50 ohms. Radiall/Larsen antennas come with the necessary impedance matching circuitry as part of the antenna. We use low loss components in our matching circuits to provide the maximum transfer of energy between the transmission line and the antenna.

VSWR and Reflected Power

The Voltage Standing Wave Ratio (VSWR) is an indication of how good the impedance match is. VSWR is often abbreviated as SWR. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing.

A VSWR of 2.0:1 or less is considered good. Most commercial antennas, however, are specified to be 1.5:1 or less over some bandwidth. Based on a 100-watt radio, a 1.5:1 VSWR equates to a forward power of 96 watts and a reflected power of 4 watts, or the reflected power is 4.2% of the forward power.

Bandwidth

Bandwidth can be defined in terms of radiation patterns or VSWR/reflected power. The definition used in this book is based on VSWR. Bandwidth is often expressed in terms of percent bandwidth, because the percent bandwidth is constant relative to frequency. If bandwidth is expressed in absolute units of frequency, for example MHz, the bandwidth is then different depending upon whether the frequencies in question are near 150, 450, or 825 MHz.

Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting or to receive energy better from a particular direction when receiving. The relationship between gain and directivity: *Gain = efficiency/Directivity*. We see the phenomena of increased directivity when comparing a light bulb to a spotlight. A 100-watt spotlight will provide more light in a particular direction than a 100 watt light bulb, and less light in other directions. We could say the spotlight has more "directivity" than the light bulb. The spotlight is comparable to an antenna with increased directivity. An antenna with increased directivity is hopefully implemented efficiently, is low loss, and therefore exhibits both increased directivity and gain.

Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in "all" directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. An antenna gain of 2 (3 dB) compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires an adjustable dipole or a number of dipoles of different lengths. An antenna gain of 1 (0 dB) compared to a dipole antenna would be written as 0 dBd.

Gain Measurement

One method of measuring gain is by comparing the antenna under test against a known standard antenna. This is technically known as a gain transfer technique. At lower frequencies, it is convenient to use a 1/2-wave dipole as the standard. At higher frequencies, it is common to use a calibrated gain horn as a gain standard, with gain typically expressed in dBi.

Another method for measuring gain is the 3-antenna method. Transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance. The Friis transmission formula is used to develop three equations and three unknowns. The equations are solved to find the gain expressed in dBi of all three antennas.

Antenna manufacturers us both methods for measurement of gain. The method is selected based on antenna type, frequency, and customer requirement.

Use the following conversion factor to convert between dBd and dBi: 0 dBd = 2.15 dBi.

Antenna Placement

Correct antenna placement is critical to the performance of an antenna. An antenna mounted on the roof will function better than the same antenna installed on the hood or trunk of a car. Knowledge of the vehicle may also be an important factor in determining what type of antenna to use. You do not want to install a glass mount antenna on the rear window of a vehicle in which metal has been used to tint the glass. The metal tinting will work as a shield and not allow signals to pass through the glass.

Radiation Patterns

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a fixed or constant distance. The radiation pattern is a "reception pattern" as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but it is difficult to display the three-dimensional radiation pattern in a meaningful manner, it is also time consuming to measure a three-dimensional radiation pattern. Often radiation patterns are measured that are a slice of the three-dimensional pattern, which is of course a two-dimensional radiation pattern which can be displayed easily on a screen or piece of paper. These pattern measurements are presented in either a rectangular or a polar format.

Absolute and Relative Patterns

Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative pattern measurements, and then the gain transfer method is then used to establish the absolute gain of the antenna.

Near-Field and Far Field Patterns

The radiation pattern in the region close to the antenna is not exactly the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna; the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. The near-field is called the induction field (although it also has a radiation component).

Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is:

> Note: When extremely high power is being radiated (as from some modern radar antennas), the near-field pattern is needed to determine what regions near the antenna, if any, are hazardous to human beings.

Beamwidth

Depending on the radio system in which an antenna is being employed there can be many definitions of beamwidth. A common definition is the half power beamwidth. The peak radiation intensity is found and then the points on either side of the peak represent half the power of the peak intensity are located. The angular distance between the half power points traveling through the peak is the beamwidth. Half the power is —3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth.

Antenna Pattern Types

Omni-directional Antennas

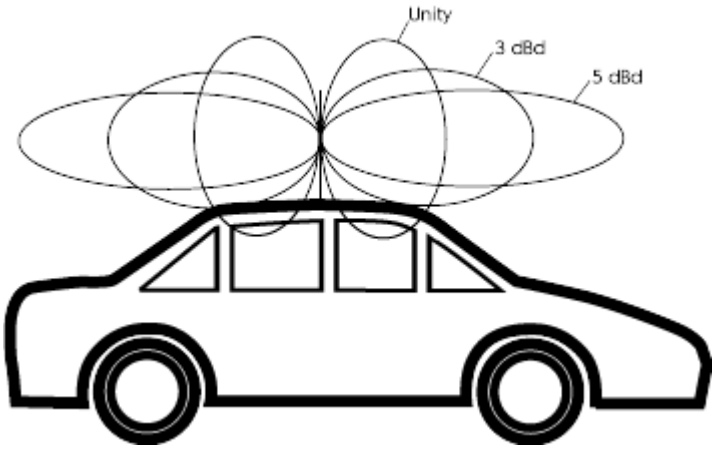
For mobile, portable, and some base station applications the type of antenna needed has an omni-directional radiation pattern. The omni-directional antenna radiates and receives equally well in all horizontal directions. Narrowing the beamwidth in the vertical or elevation plane can increase the gain of an omnidirectional antenna. The net effect is to focus the antenna’s energy toward the horizon.

Selecting the right antenna gain for the application is the subject of much analysis and investigation. Gain is achieved at the expense of beamwidth: higher-gain antennas feature narrow beamwidths while the opposite is also true.

Omnidirectional antennas with different gains are used to improve reception and transmission in certain types of terrain. A 0 dBd gain antenna radiates more energy higher in the vertical plane to reach radio communication sites that are located in higher places. Therefore they are more useful in mountainous and metropolitan areas with tall buildings. A 3 dBd gain antenna is the compromise in suburban and general settings. A 5 dBd gain antenna radiates more energy toward the horizon compared to the 0 and 3 dBd antennas to reach radio communication sites that are further apart and less obstructed. Therefore they are best used in deserts, plains, flatlands, and open farm areas.

Directional Antennas

Directional antennas focus energy in a particular direction. Directional antennas are used in some base station applications where coverage over a sector by separate antennas is desired. Point to point links also benefit from directional antennas. Yagi and panel antennas are directional antennas.



Antenna Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. An ellipse in general describes polarization. Two often-used special cases of elliptical polarization are linear polarization and circular polarization. The antenna that launches the waves into space determines the initial polarization of a radio wave. The environment through which the radio wave passes on its way from the transmit antenna to the receive antenna may cause a change in polarization.

With linear polarization the electric field vector stays in the same plane. In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. The rotation may be right-hand or left-hand.

Choice of polarization is one of the design choices available to the RF system designer. For example, low frequency (< 1 MHz) vertically polarized radio waves propagate much more successfully near the earth than horizontally polarized radio waves, because horizontally polarized waves will be cancelled out by reflections from the earth. Mobile radio systems waves generally are vertically polarized. TV broadcasting has adopted horizontal polarization as a standard. This choice was made to maximize signal-to-noise ratios. At frequencies above 1 GHz, there is little basis for a choice of horizontal or vertical polarization, although in specific applications, there may be some possible advantage in one or the other. Circular polarization has also been found to be of advantage in some microwave radar applications to minimize the "clutter" echoes received from raindrops, in relation to the echoes from larger targets such as aircraft. Circular polarization can also be used to reduce multi-path.