Pulse Electronics / LARSEN ANTENNAS

Antenna Basic Concepts

ANTENNA

An antenna is a device to transmit and/or receive 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 (matched) to the same frequency band as the radio system to which it is connected, otherwise reception and/or transmission will be impaired.

WAVELENGTH

We often refer to antenna size relative to wavelength. For example: a 1/2 wave dipole is approximately half a wavelength long. Wavelength is the distance a radio wave travels during one cycle. The formula for wavelength is:

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

Where:

λ is the wavelength expressed in units of length, typically meters, feet or inches
c is the speed of light (11,802,877,050 inches/second)
f is the frequency

For example: wavelength in air at 825 MHz is $\frac{11.803 \text{ X } 109 \text{ in./sec}}{825 \text{ x } 106 \text{ cycles/sec.}}$ = 14.307 inches

Note: The physical length of a half-wave dipole is slightly less than half a 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.

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 Ohms impedance. Efficient antenna configurations often have an impedance other than 50 Ohms. Some sort of impedance matching circuit is then required to transform the antenna impedance to 50 Ohms. 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

Voltage Standing Wave Ratio (VSWR) is an indication of the quality of the impedance match. VSWR is often abbreviated as SWR. A high VSWR is an indication 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 often considered acceptable. Most commercial antennas 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 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 MHz, 450 MHz or 825 MHz.

Percentage bandwidth is defined as: $\frac{F_H - F_L}{F_C}$

$BW = 100$

F_H is the highest frequency in the band
F_L is the lowest frequency in the band
F_C is the center frequency of the band

$$F_C = \frac{F_H + F_L}{2}$$

Example: If you need an antenna to operate in the 150 to 156 MHz band, you need an antenna covering at least a $\frac{156 - 150}{153}$ 3.9% bandwidth.

$100 = 3.9\%$

The problem might need to be worked in a different way. If the antenna is tuned to 460 MHz and provides a VSWR bandwidth of 5%, what are F_L and F_H? The equations above can be solved for F_L and F_H:

$$F_H = F_C \left(1 + \frac{BW}{200}\right) \text{ and } F_L = F_C \left(1 - \frac{BW}{200}\right)$$

Plugging the numbers into the equations, the answers are:

$$F_H = 460 \left(1 + \frac{5}{200}\right) = 471.5 \text{ MHz}$$

$$F_L = 460 \left(1 - \frac{5}{200}\right) = 448.5 \text{ MHz}$$

Antenna Basic Concepts

DECIBELS

Decibels (dB) are the accepted method of describing a gain or loss relationship in a communication system. The beauty of dB is they may be added and subtracted. A decibel relationship (for power) is calculated using the following formula.

$$\text{dB} = 10 \log \frac{\text{Power A}}{\text{Power B}}$$

"A" might be the power applied to the connector on an antenna, the input terminal of an amplifier or one end of a transmission line. "B" might be the power arriving at the opposite end of the transmission line, the amplifier output or the peak power in the main lobe of radiated energy from an antenna. If "A" is larger than "B", the result will be a positive number or gain. If "A" is smaller than "B", the result will be a negative number or loss.

Example:

At 1700 MHz, one fourth of the power applied to one end of a coax cable arrives at the other end. What is the cable loss in dB?

$$\text{Loss in dB} = 10 \log \frac{1}{4} = 10 \text{ X } (-)\ 0.602$$

$$\text{Loss} = (-)\ 6.02 \text{ dB}$$

In the above case, taking the log of 1/4 (0.25) automatically results in a minus sign, which signifies negative gain or loss.

It is convenient to remember these simple dB values which are handy when approximating gain and loss:

Power Gain	**Power Loss**
3 dB = 2X power	- 3 dB = 1/2 power
6 dB = 4X power	- 6 dB = 1/4 power
10 dB = 10X power	-10 dB = 1/10 power
20 dB = 100X power	-20 dB = 1/100 power

In the case of antennas, passive structures cannot generate power. dB is used to describe the ability of these structures to focus energy in a part of space.

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. There is a relationship between gain and 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. Gain is the practical value of the directivity. The relation between gain and directivity includes a new parameter (η) which describes the efficiency of the antenna.

$$G = \eta \bullet D$$

For example an antenna with 3 dB of directivity and 50% of efficiency will have a gain of 0 dB.

Antenna Basic Concepts

GAIN MEASUREMENT

One method of measuring gain is to compare the antenna under test against a known standard antenna. This is 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 powers at the antenna terminal are 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.

Pulse-Larsen uses 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.
Example: 3.6 dBd + 2.15 dB = 5.75 dBi

RADIATION PATTERNS

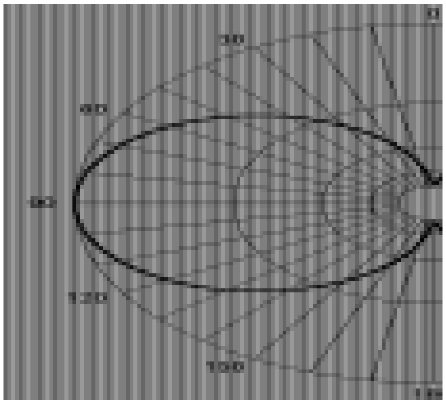
Radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna at a constant distance. The radiation pattern is a "reception pattern" as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, 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 measured are a slice of the three-dimensional pattern, resulting in 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.

ANTENNA PATTERN TYPES

Omnidirectional Antennas

For mobile, portable and some base station applications the type of antenna needed has an omnidirectional radiation pattern. Omnidirectional antennas radiate and receive equally well in all horizontal directions. The gain of an omnidirectional antenna can be increased by narrowing the beamwidth in the vertical or elevation plane. 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 located in higher places. Therefore they are more useful in mountainous and metropolitan areas with tall buildings. A 3 dBd gain antenna is a good compromise for use in suburban and general settings. A 5 dBd gain antenna radiates more energy toward the horizon compared to the 0 and 3 dBd antennas. This allows the signal to reach radio communication sites further apart and less obstructed. Therefore they are best used in deserts, plains, flatlands and open farm areas.



Directional Antennas

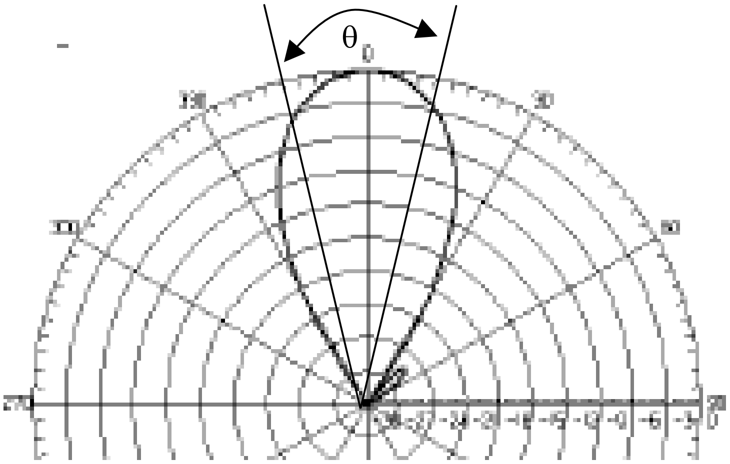
Directional antennas focus energy in a particular direction. Directional antennas are used in some base station applications where coverage over a sector by separate antennas is desired. Point-to-point links also benefit from directional antennas. Yagi and panel antennas are directional antennas.

Antenna Basic Concepts

BEAMWIDTH

Beamwidth describes the angular aperture where the most important part of the power is radiated. In general, we talk about the 3 db beamwidth which represents the aperture (in degrees) where more than 90% of the energy is radiated.

For example, for a 0 dB gain antenna, 3 db beamwidth is the area where the gain is higher than –3 dB.



Value of θ in degree = 3 dB beamwidth.

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 existing 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 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:

$$r_{min} = \frac{2D^2}{\lambda}$$

Where:
r_{min} is the minimum distance from the antenna
D is the largest dimension of the antenna
λ is the wavelength

Antenna Basic Concepts

ANTENNA POLARIZATION

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Two often-used special cases of elliptical polarization are linear polarization and circular polarization. Initial polarization of a radio wave is determined by the antenna launching the waves into space. The environment through which the radio wave passes on its way from the transmit antenna to the receiving 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 system 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 satellite applications such as GPS. Circular polarization can also be used to reduce multipath.

DETERMINING WHIP LENGTH

In general, whip length is defined as a fraction of the wavelength and depends on the electrical characteristics you want to achieve. Theoretically, a whip provides an omnidirectional pattern in the horizontal plane and a dipolar pattern in the elevation plane. When you increase the whip length by a fraction of a wavelength (commonly /14 wavelength), you increase the gain of the structure by reducing the aperture in the elevation plane.

DETERMINING GROUND PLANE SIZE

For many types of antennas the theoretical analysis is based on the use of an infinite ground plane. In practice, this condition is never achieved. Common effects of reduction of the size of the ground plane are:

- Electrical tilt: The maximum energy is not radiated in the expected direction.
- Beamwidth Increased: The aperture of the radiating element is modified, and the gain of the antenna is decreased.

In conclusion, we could say the bigger the ground plane, the better the control of the electrical performance of the antenna.

BASIC ANTENNA TYPES

The following discussion of antenna types assumes an “adequate” ground plane is present.

1/4 Wave

A single radiating element approximately 1/4 wavelength long. Directivity 2.2 dBi, 0 dBd.

Loaded 1/4 Wave

The loaded 1/4 wave antenna looks electrically like a 1/4 wave antenna but the loading allows the antenna to be physically smaller than a 1/4 wave antenna. Quite often this is implemented by placing a loading coil at the base of the antenna. Gain depends upon the amount of loading used. Directivity 2.2 dBi, 0 dBd.

1/2 Wave

A single radiating element 1/2 wavelength long. Directivity 3.8 dBi, 1.6 dBd. A special design is the end fed 1/2 wave.

5/8 Wave

A single radiating element 5/8 wavelength long. Directivity 5.2 dBi, 3.0 dBd.

Antenna Basic Concepts

Collinear

Two or three radiating elements separated by phasing coils for increased gain. Four common styles are:

1) 5/8 over 1/4: The top element is 5/8 wave and the bottom element is 1/4 wave. Directivity 5.4 dBi, 3.2 dBd.
2) 5/8 over 1/2: The top element is 5/8 wave and the bottom is 1/2 wave. Directivity 5.6 dBi, 3.4 dBd.
3) 5/8 over 5/8 over 1/4: The top 2 elements are 5/8 wave and the bottom element is 1/4 wave. Directivity 7.2 dBi, 5.0 dBd.
4) 5/8 over 5/8 over 1/2: The top 2 elements are 5/8 wave and the bottom element is 1/2 wave. Directivity 7.6 dBi, 5.4 dBd.

Using more than three radiating elements in a base-fed collinear configuration does not significantly increase gain. The majority of the energy is radiated by the elements close to the feed point of the collinear antenna so there is only a small amount of energy left to be radiated by the elements which are farther away from the feed point.

Please note the directivity is given above for common antenna configurations. Gain depends upon the electrical efficiency of the antenna. Here is where the real difference between antenna manufacturers is seen. If you cut corners in building an antenna, the gain may be significantly lower than the directivity. Larsen uses low-loss materials to minimize the difference between the gain and the directivity in our antennas.

Whip

The vertical portion of the antenna assembly acting as the radiator of the radio frequency

GPS

Active GPS antennas include an amplifier circuit in order to provide better reception of the satellite signal. This active stage generally includes a low noise amplifier and a power amplifier.

Combi GPS/Cellular structures include several antennas in one radome to allow reception and transmission in different frequency bands.

Dipole

An antenna - usually 1/2 wavelength long - split at the exact center for connection to a feed line. Dipoles are the most common wire antenna. Length is equal to 1/2 of the wavelength for the frequency of operation. Fed by coaxial cable.

Sleeve Dipoles are realized by the addition of a metallic tube on a coaxial structure.

Printed Dipoles have a radiation structure supported by a printed circuit.

Embedded Omni

Embedded omni antennas are generally integrated on a base for applications such as access points. This structure could be externally mounted (ex: sleeve dipole) or directly integrated on the PC board of the system (ex: printed dipole).

Yagi

A directional, gain antenna utilizing one or more parasitic elements. A yagi consists of a boom supporting a series of elements which are typically aluminum rods.

Antenna Basic Concepts

Panel

Single Patch describes an elementary source obtained by means of a metallic strip printed on a microwave substrate. These antennas are included in the radiating slot category.

Patch Arrays are a combination of several elementary patches. By adjusting the phase and magnitude of the power provided to each element, numerous forms of beamwidth (electric tilt, sectoral, directional . . .) can be obtained.

Sectoral antennas can be depicted like a directive antenna with a beamwidth greater than 45°. A 1 dB beamwidth is generally defined for this kind of radiating structure.

Omni Ceiling Mount

Omni ceiling mount antennas are used for the propagation of data in an in-building environment. In order to provide good coverage, these antennas are vertically polarized and present an omnidirectional pattern in the horizontal plane and a dipolar pattern in the vertical plane.

Parabolic

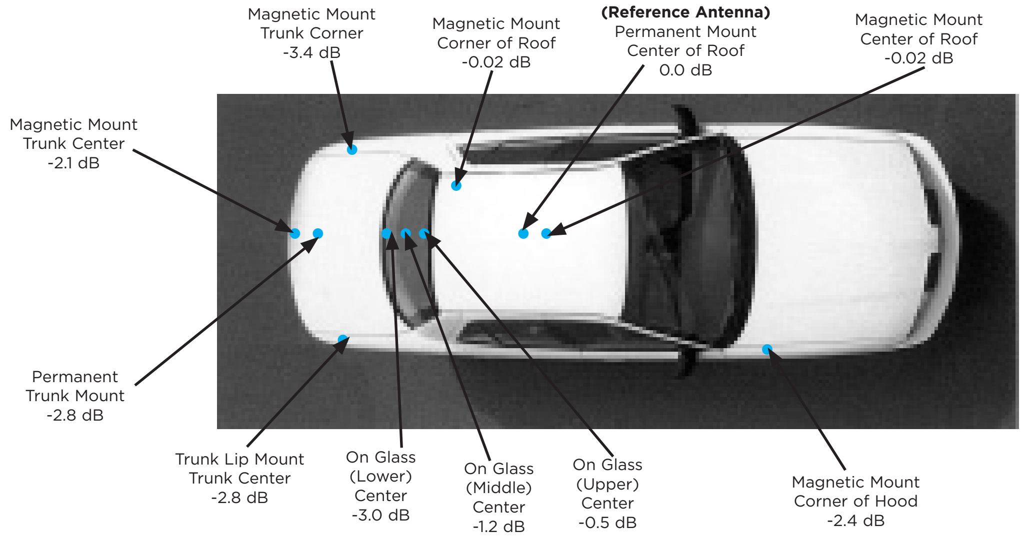
An antenna consisting of a parabolic reflector and a radiating or receiving element at or near its focus. Solid Parabolics utilize a dish-like reflector to focus radio energy of a specific range of frequencies on a tuned element. Grid Parabolics employ an open-frame grid as a reflector, rather than a solid one. The grid spacing is sufficiently small to ensure waves of the desired frequency cannot pass through, and are hence reflected back toward the driven element.

PULSE-LARSEN ANTENNA TYPES

Mobile:	Collinear, Whip, Low Profile, Active GPS, Combi GPS/Cellular
Portable:	Whip, Helical, End Fed Half Wave, Sleeve, Half Wave Dipole, Embedded Omni, Printed Dipole
Base Station:	Whip, Collinear, Yagi, Panel, In-building Sectoral, Omni-ceiling Mount

MOBILE ANTENNA PLACEMENT

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



Pulse Electronics / LARSEN ANTENNAS

Antenna Basic Concepts