Antenna Patterns and Their Meaning

Much can be learned about how an antenna performs from its patterns. This paper describes many of the common antenna parameters that can be understood from the patterns.

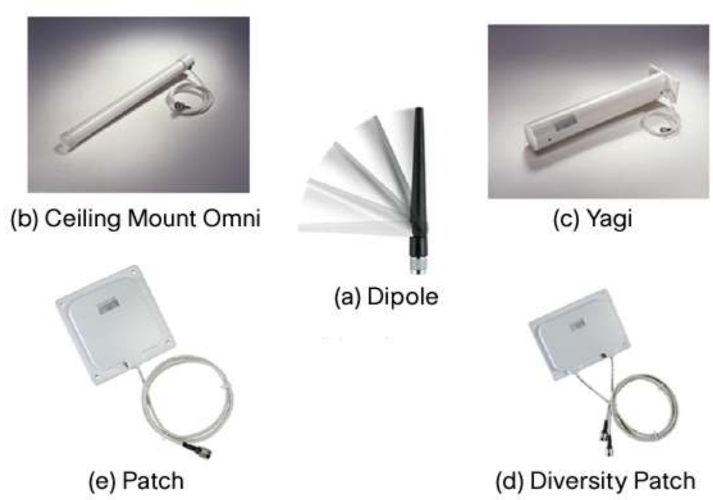
Introduction

A major component of a wireless LAN system is the antenna. There are several different types and they all have their place. However, there can be some confusion surrounding the language used to specify antennas as well as the basic function of each type of antenna. The purpose of this white paper is to dispel the confusion surrounding antennas and their function. This document is not meant to be an electromagnetic primer nor a deployment guide. Rather, it should be used as a dictionary of basic antennas and antenna terminology as well as a tutorial specifically covering antenna patterns and the parameters associated with those patterns. The focus is on many of the various antennas that might be encountered in a wireless LAN system.

We begin with a glossary of basic definitions and then progress through a discussion of some common antenna types and their properties. Along the way, the antenna patterns are shown and explained, including the 3-D radiation pattern from the antennas. Typical performance from each antenna type is described as well. Of course, there are plenty of exceptions to the “typical” antenna, as many antenna types can be designed to enhance one or more parameters. But it is often helpful to see a few examples and have some of these parameters highlighted.

In a WLAN system, commonly used antennas are dipoles, omnidirectional antennas, patches and Yagis. These antennas are shown in Figure 1. Although these antenna packages might vary somewhat from one manufacturer to another, these are typical packages for these types of antennas. The function of each of these antenna types is explained in some detail in this paper.

Figure 1. Various Antennas Commonly Found in WLAN Systems



Historical Note: The antenna type that we commonly refer to as a Yagi was first developed in the late 1920's by two professors, Shintaro Uda and Hidetsugu Yagi at Tohoku University in Japan. While the antenna was mainly developed by Uda, Professor Yagi popularized the antenna design in the US and elsewhere through various conference presentations. Yagi's name has been associated with this antenna type since that time.

Basic Definitions

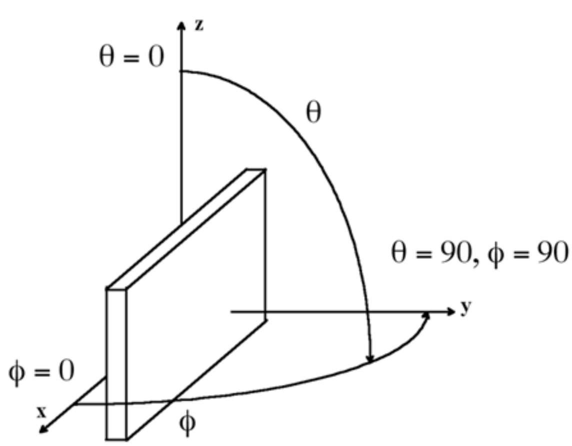
We often define antennas and antenna terminology in terms of a transmitting antenna, but all the definitions apply to receiving antennas as well. In fact, an antenna's properties are the same in either operating mode. So, whether it is stated or not, all the definitions and descriptions describe antennas that are either part of a transmitter or a receiver.

Antenna. An *antenna* is a transducer between a guided wave and a radiated wave, or vice versa. The structure that "guides" the energy to the antenna is most evident as a coaxial cable attached to the antenna. The radiated energy is characterized by the antenna's radiation pattern.

Antenna pattern. The radiation pattern or *antenna pattern* is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy). It is important to state that an antenna radiates energy in all directions, at least to some extent, so the antenna pattern is actually three-dimensional. It is common, however, to describe this 3D pattern with two planar patterns, called the *principal plane patterns*. These principal plane patterns can be obtained by making two slices through the 3D pattern through the maximum value of the pattern or by direct measurement. It is these principal plane patterns that are commonly referred to as the antenna patterns.

Characterizing an antenna's radiation properties with two principal plane patterns works quite well for antennas that have well-behaved patterns – that is, not much information is lost when only two planes are shown. Figure 2 shows a possible coordinate system used for making such antenna measurements.

Figure 2. Antenna Measurement Coordinate System

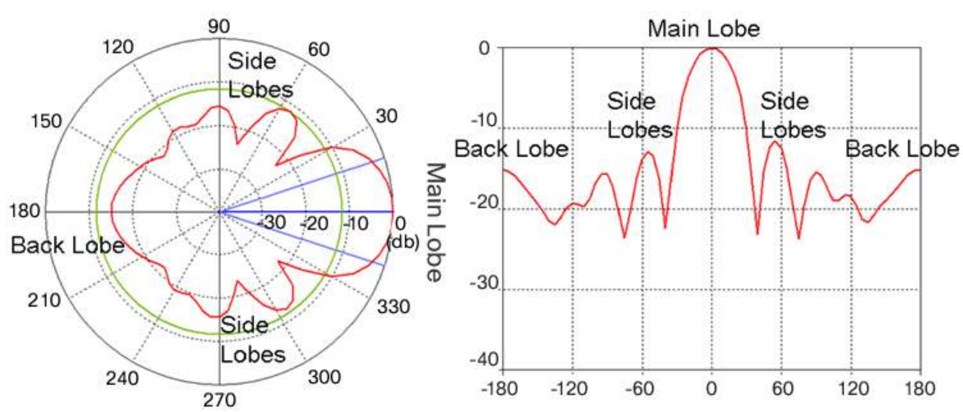


In discussions of principal plane patterns or even antenna patterns, you will frequently encounter the terms *azimuth plane pattern* and *elevation plane pattern*. The term *azimuth* is commonly found in reference to “the horizon” or “the horizontal” whereas the term *elevation* commonly refers to “the vertical”. When used to describe antenna patterns, these terms assume that the antenna is mounted (or measured) in the orientation in which it will be used. In Figure 2, the x-y plane (θ = 90 deg) is the azimuth plane. The azimuth plane pattern is measured when the measurement is made traversing the entire x-y plane around the antenna under test. The elevation plane is then a plane orthogonal to the x-y plane, say the y-z plane (φ = 90 deg). The elevation plane pattern is made traversing the entire y-z plane around the antenna under test.

The antenna patterns (azimuth and elevation plane patterns) are frequently shown as plots in polar coordinates. This gives the viewer the ability to easily visualize how the antenna radiates in all directions as if the antenna was “aimed” or mounted already. Occasionally, it may be helpful to plot the antenna patterns in Cartesian (rectangular) coordinates, especially when there are several side lobes in the patterns and where the levels of these side lobes are important.

Lobes. Any given antenna pattern has portions of the pattern that are called *lobes*. A “lobe” can be a main lobe, a side lobe or a back lobe and these descriptions refer to that portion of the pattern in which the lobe appears. In general, a *lobe* is any part of the pattern that is surrounded by regions of relatively weaker radiation. So a lobe is any part of the pattern that “sticks out” and the names of the various types of lobes are somewhat self-explanatory. Figure 3 provides a view of a radiation pattern with the lobes labeled in each type of plot.

Figure 3. Radiation Patterns in Polar and Cartesian Coordinates Showing Various Types of Lobes



(a) Pattern in Polar Coordinates (b) Pattern in Cartesian Coordinates

Isotropic radiator. An *isotropic radiator* is a hypothetical lossless antenna that radiates its energy equally in all directions. This imaginary antenna would have a spherical radiation pattern and the principal plane cuts would both be circles (indeed, any plane cut would be a circle).

Gain. The *gain* of an antenna (in any given direction) is defined as the ratio of the power gain in a given direction to the power gain of a reference antenna in the same direction. It is standard practice to use an isotropic radiator as the reference antenna in this definition. Note that an isotropic radiator would be lossless and that it would radiate its energy equally in all directions. That means that the gain of an isotropic radiator is G = 1 (or 0 dB). It is customary to use the unit dBi (decibels relative to an isotropic radiator) for gain with respect to an isotropic radiator. Gain expressed in dBi is computed using the following formula:

GdBi = 10*Log (GNumeric/GIsotropic) = 10*Log (GNumeric)

Occasionally, a theoretical dipole is used as the reference, so the unit dBd (decibels relative to a dipole) will be used to describe the gain with respect to a dipole. This unit tends to be used when referring to the gain of omnidirectional antennas of higher gain. In the case of these higher gain omnidirectional antennas, their gain in dBd would be an expression of their gain above 2.2 dBi. So if an antenna has a gain of 3 dBd it also has a gain of 5.2 dBi.

Note that when a single number is stated for the gain of an antenna, it is assumed that this is the maximum gain (the gain in the direction of the maximum radiation).

It is important to state that an antenna with gain doesn't create radiated power. The antenna simply directs the way the radiated power is distributed relative to radiating the power equally in all directions and the gain is just a characterization of the way the power is radiated.

3-dB beamwidth. The *3-dB beamwidth (or half-power beamwidth)* of an antenna is typically defined for each of the principal planes. The 3-dB beamwidth in each plane is defined as the angle between the points in the main lobe that are down from the maximum gain by 3 dB. This is illustrated in Figure 3. The 3-dB beamwidth in the plot in this figure is shown as the angle between the two blue lines in the polar plot. In this example, the 3-dB beamwidth in this plane is about 37 degrees. Antennas with wide beamwidths typically have low gain and antennas with narrow beamwidths tend to have higher gain. Remember that gain is a measure of how much of the power is radiated in a given direction. So an antenna that directs most of its energy into a narrow beam (at least in one plane) will have a higher gain.

Front-to-back ratio. The *front-to-back ratio (F/B)* is used as a figure of merit that attempts to describe the level of radiation from the back of a directional antenna. Basically, the front-to-back ratio is the ratio of the peak gain in the forward direction to the gain 180-degrees behind the peak. Of course on a dB scale, the front-to-back ratio is just the difference between the peak gain in the forward direction and the gain 180-degrees behind the peak.

Polarization. The *polarization or polarization state* of an antenna is a somewhat difficult and involved concept. An antenna will generate an electromagnetic wave that varies in time as it travels through space. If a wave traveling “outward” varies “up and down” in time with the electric field always in one plane, that wave (or antenna) is said to be *linearly polarized* (vertically polarized since the variation is up and down rather than side to side). If that wave rotates or “spins” in time as it travels through space, the wave (or antenna) is said to be *elliptically polarized*. As a special case, if that wave spins out in a circular path, the wave (or antenna) is *circularly polarized*. This implies that certain antennas are sensitive to particular types of electromagnetic waves. The practical implication of this concept is that antennas with the same polarization provide the best transmission/reception path.

Consider antennas that generate and are sensitive to linearly polarized waves. If a linearly polarized antenna launches a linearly polarized electromagnetic wave traveling “up and down” or vertically, the best possible receiver of that electromagnetic wave will be another antenna that is similarly linearly polarized (vertically polarized). Linear polarization also includes the possibility of the electromagnetic waves traveling “right to left” (horizontally) as well. Often antennas can simply be physically rotated to make them horizontally or vertically polarized, although this may not always be the best choice.

Circularly polarized antennas can radiate electromagnetic waves that spin clockwise or counter-clockwise depending on the structure. So a similarly polarized antenna should be used to receive these signals. This spin direction is typically characterized by left circular polarization (LCP) or right circular polarization (RCP).

Note that the polarization of an antenna doesn't always imply anything about the size or shape of the antenna. A dipole is usually called vertically polarized because of the way a dipole is typically used, that is, because it is mounted vertically, but the antenna is linearly polarized. Likewise, antennas that are circular in their construction do not have to be circularly polarized. Many circular patches are linearly polarized and many rectangular patches are circularly polarized. These examples are simple demonstrations of the fact that the polarization state of an antenna is not related to its shape.

VSWR. The *voltage standing wave ratio (VSWR)* is defined as the ratio of the maximum voltage to the minimum voltage in a standing wave pattern. A standing wave is developed when power is reflected from a load. So the VSWR is a measure of how much power is delivered to a device as opposed to the amount of power that is reflected from the device. If the source and load impedance are the same, the VSWR is 1:1; there is no reflected power. So the VSWR is also a measure of how closely the source and load impedance are matched. For most antennas in WLAN, it is a measure of how close the antenna is to a perfect 50 Ohms.

VSWR bandwidth. The *VSWR bandwidth* is defined as the frequency range over which an antenna has a specified VSWR. Often, the 2:1 VSWR bandwidth is specified, but 1.5:1 is also common.

Directional antenna. A *directional antenna* is one that radiates its energy more effectively in one (or some) direction than others. Typically, these antennas have one main lobe and several minor lobes. Examples of directional antennas are patches and dishes.

Omnidirectional antenna. An *omnidirectional antenna* is an antenna that has a non-directional pattern (circular pattern) in a given plane with a directional pattern in any orthogonal plane. Examples of omnidirectional antennas are dipoles and collinear antennas.

Common Antennas and Their Patterns

In this section, some common antennas are described along with details about typical patterns that can be expected from these common antennas. Described here are a dipole, a collinear array, a single patch antenna, a patch array, a Yagi and even a sector antenna. The patterns from each antenna are shown and explained in detail, including a 3D radiation pattern. The emphasis is on describing the patterns and the parameters that are derived from these patterns.

It is important to mention that it doesn't really matter in which direction the patterns are shown. The orientation of a particular pattern is often a matter of personal preference. For example, some people like directional antenna patterns to always point up while others like them to point to the right or left because that's the way the antenna will often be deployed. The important thing is to have some basic knowledge of what these antennas are meant to do, so that you can understand the pattern parameters. Then the pattern's direction is of little importance.

The patterns shown here represent output from simulated antennas. The omnidirectional patterns have been rotated so that the elevation plane patterns appear to radiate out toward the horizon, as is typical of an omnidirectional antenna deployment. The patches and the Yagi patterns remain as simulated, that is, they appear in the same coordinate system in which they were simulated, not deployed.

Omnidirectional Antennas

Omnidirectional antennas are commonly referred to as “omnis.” In addition, an omni often refers to an omnidirectional antenna but specifically not a dipole. Often, an omni refers to an omnidirectional antenna that has more gain than a dipole. However, a dipole is an omnidirectional antenna as we will see in the next section. The dipole is just a special case.

Dipole Antennas

A dipole antenna most commonly refers to a half-wavelength (λ/2) dipole. The physical antenna (not the package that it is in) is constructed of conductive elements whose combined length is about half of a wavelength at its intended frequency of operation. This is a simple antenna that radiates its energy out toward the horizon (perpendicular to the antenna). The patterns shown in Figure 4 are those resulting from a perfect dipole formed with two thin wires oriented vertically along the z-axis.

The resulting 3D pattern looks kind of like a donut or a bagel with the antenna sitting in the hole and radiating energy outward. The strongest energy is radiated outward, perpendicular to the antenna in the x-y plane.

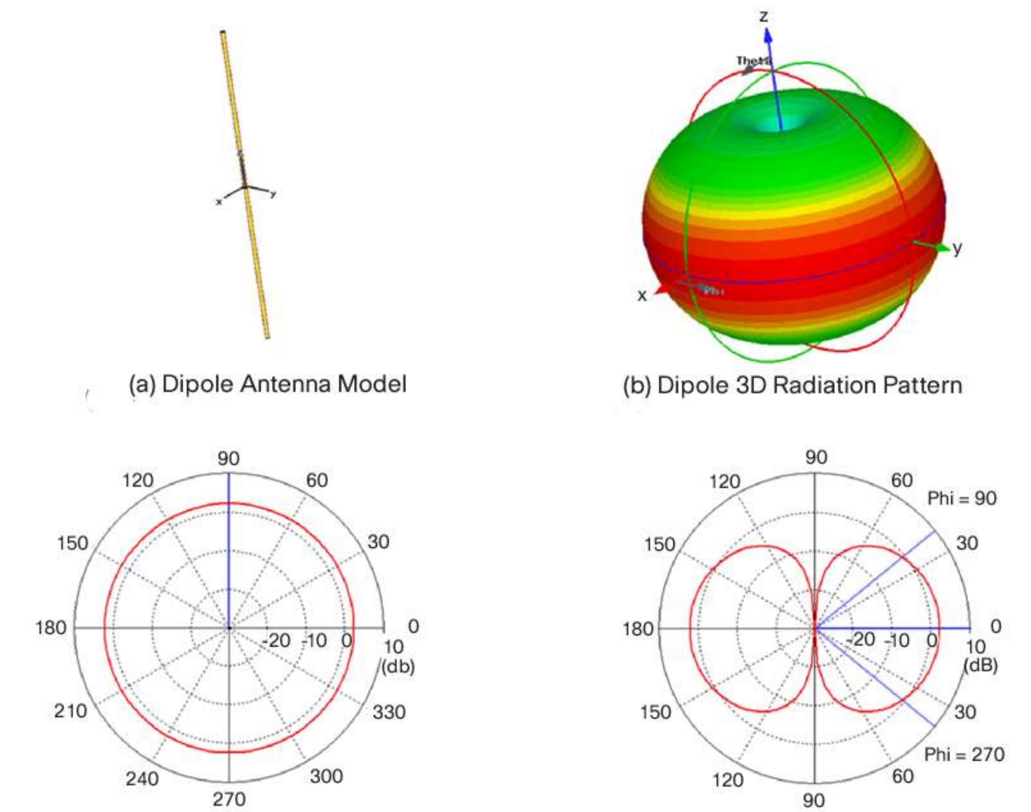
The azimuth plane pattern is formed by slicing through the 3D pattern in the horizontal plane, the x-y plane in this case, just as you would slice through a bagel. Notice that the azimuth plane pattern is non-directional, that is, the antenna radiates its energy equally in all directions in the azimuth plane. So the azimuth plane pattern is a circle, passing through the peak gain at all angles, shown in Figure 4c.

Notice that the patterns in any orthogonal plane (any plane, actually) are directional in nature and so this antenna meets the definition of an omnidirectional antenna. The elevation plane pattern is formed by slicing the 3D pattern through an orthogonal plane (either the x-z plane or the y-z plane). From the elevation plane pattern we see that the dipole antenna has an elevation plane beamwidth of 78-degrees as indicated on the pattern in Figure 4d by the two blue lines. These lines are drawn where the gain is down from the peak by 3-dB. The elevation plane beamwidth is the total angular width between the two 3-dB points on the curve.

The gain of the half-wave dipole is approximately 2.2 dBi. The value of 2.2 dBi is achieved at the horizon in the elevation plane and everywhere in the azimuth plane. Note that the azimuth plane pattern is a circle passing through the gain value of 2.2 dBi at all angles. These values are the 3-dB beamwidth and gain of a theoretical half-wave dipole. Dipole antennas are often quoted this way although many of the dipoles on the market don’t quite achieve these theoretical numbers.

Given these antenna patterns, you can see that a dipole antenna should be mounted so that it is vertically oriented with respect to the floor or ground. This results in the maximum amount of energy radiating out into the intended coverage area. The null in the middle of the pattern will point up and down. Indoors, this typically isn’t a concern because of the close proximity of the ceiling and all the multipath present in the indoor environment.

Figure 4. Dipole Antenna with 3D Radiation Pattern, Azimuth Plane Pattern and Elevation Plane Pattern



(a) Dipole Antenna Model

(b) Dipole 3D Radiation Pattern

(c) Dipole Azimuth Plane Pattern

(d) Dipole Elevation Plane Pattern

Collinear Omni Antennas

In order to create an omnidirectional antenna with higher gain, multiple omnidirectional structures (either wires or elements on a circuit board) can be arranged in a vertical, linear fashion to retain the same omnidirectional pattern in the azimuth plane but a more focused elevation plane beam which then has higher gain. This is frequently referred to as a *collinear array*. Note that the higher gain doesn't imply that the antenna creates more power. It means that the same amount of power is radiated in a more focused way.

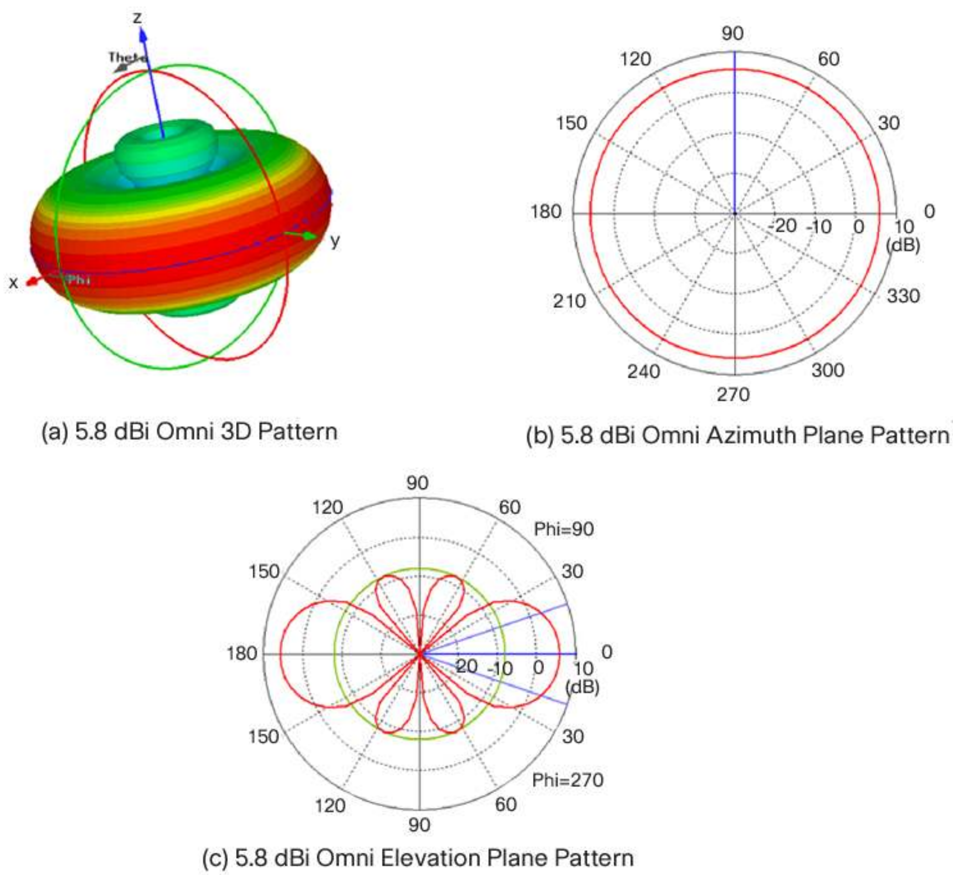
A typical omni pattern is shown in Figure 5. The antenna shown in the figure was formed from an array of three dipoles, oriented along the z-axis. Notice now that the 3D pattern shown in Figure 5a looks like a flatter "bagel" with a little "bowl" stuck to the top and bottom. The bagel forms the omnidirectional azimuth plane shown in Figure 5b and the main lobes in the elevation plane, just like the dipole. The little "bowls" on the top and bottom form the sidelobes present in the elevation plane in Figure 5c.

Again, the azimuth plane pattern is formed by slicing the 3D pattern through the horizontal plane (the x-y plane). As expected, the pattern is circular and it passes through the peak gain at all angles. Note that the pattern in the orthogonal planes is directional, so this antenna meets the basic definition of an omnidirectional antenna.

The resulting gain is about 5.8 dBi with an elevation plane beamwidth of about 38 degrees, as indicated again by the blue lines in the elevation plane shown in the Figure 5c. This beamwidth is significantly narrower than the dipole. It is easy to see how the energy radiated from this antenna is more focused, resulting in higher gain (with respect to the dipole).

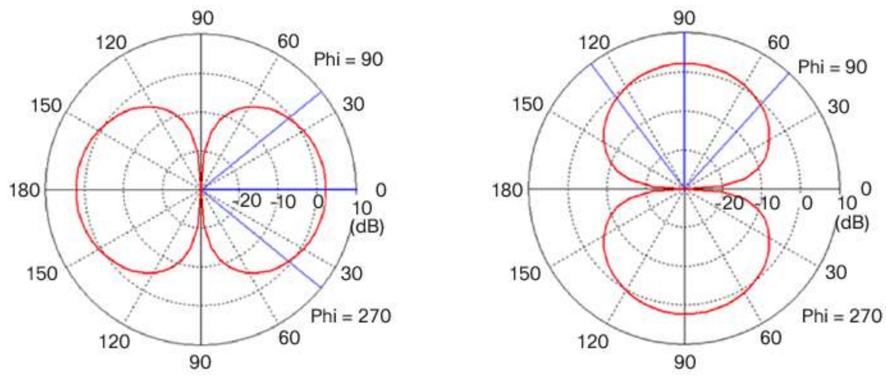
As is typical of higher gain omnidirectional antennas, the elevation plane shows obvious side lobes. The side lobes in the principal plane patterns are formed by slicing through the “bowls” that sit above and below the main lobes in the 3D pattern. These lobes are about 14 dB down from the peak of the main lobes. Note that the azimuth plane pattern is still the same well-behaved, circular pattern as in the dipole, but the elevation plane pattern is much narrower, indicating that the power is radiated in a more directed way, thus producing a higher gain.

Figure 5. 3D Radiation Pattern from 5.8 dBi Omnidirectional Antenna, Azimuth Plane Pattern and Elevation Plane Pattern



As shown in Figures 4 and 5, the goal of a dipole or any omni is to radiate energy equally in all directions in a plane. For dipoles and collinear arrays, the omnidirectional plane is intended to be the azimuth plane (the plane of the floor or the ground). For this reason, it doesn’t matter how the patterns are presented. It is understood that the elevation plane pattern is always orthogonal to the azimuth plane pattern. The orientation of the actual plot is largely dependent on the orientation of the antenna in the measurement system and that’s all there is to it. So, whether the elevation plane looks like Figure 6a or Figure 6b, you can be certain that when your dipole or omni is oriented vertically, the antenna will radiate out toward the horizon in an omnidirectional fashion.

Figure 6. Elevation Plane Demonstration



Directional Antennas

Directional antennas are used for coverage as well as point-to-point links. They can be patch antennas, dishes, horns or a whole host of other varieties. They all accomplish the same goal: radiating their energy out in a particular direction.

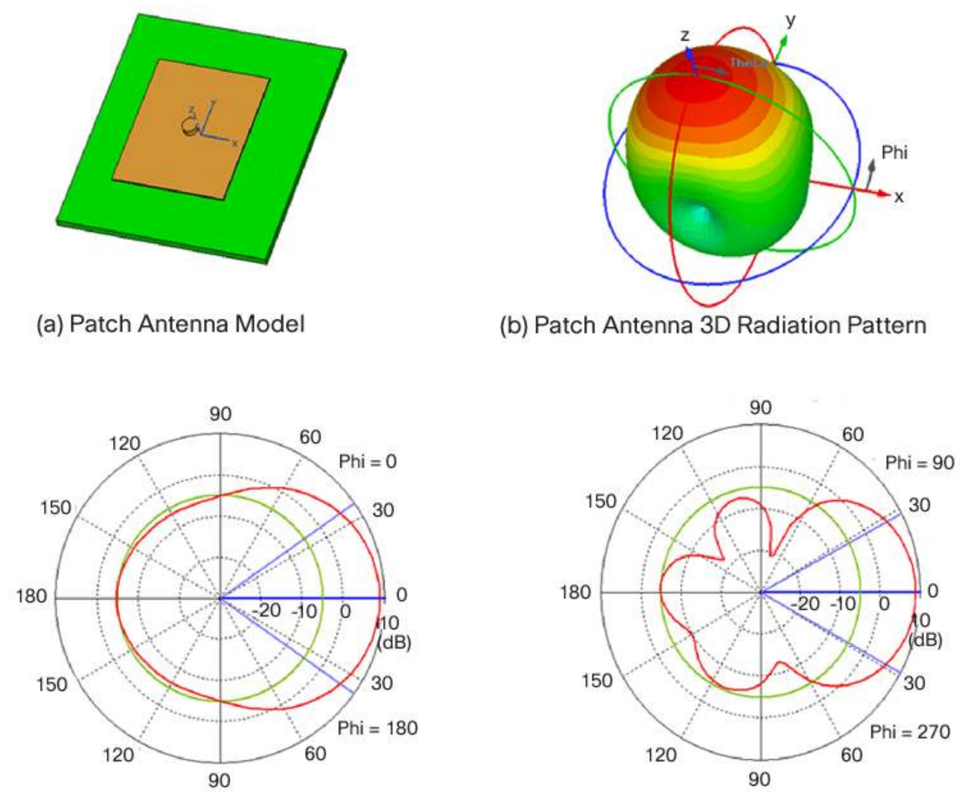
Patch Antennas

A patch antenna, in its simplest form, is just a single rectangular (or circular) conductive plate that is spaced above a ground plane. Patch antennas are attractive due to their low profile and ease of fabrication.

The radiation pattern of a single patch is characterized by a single main lobe of moderate beamwidth. Frequently, the beamwidths in the azimuth and elevation planes are similar, resulting in a fairly circular beam, although this is by no means universal. The beamwidths can be manipulated to produce an antenna with higher or lower gain, depending on the requirements. An antenna built with a single patch will have a maximum gain of about 9 dBi or a bit less.

The patch antenna in Figure 7 shows how simple these antennas can be. This is a simple rectangular patch built over a rectangular ground plane. The radiation patterns exhibit typical patch antenna characteristics. There is a single main lobe with a fairly wide beamwidth with shallow nulls pointing up and down from the antenna. Other than that, there aren't many features to the pattern. The one shown in Figure 7 is designed to have higher gain rather than symmetrical plane patterns. The gain is about 8.8 dBi with an azimuth plane beamwidth of 70 degrees and an elevation plane beamwidth of 57 degrees. These are not uncommon beamwidths for single patch antennas.

Figure 7. Single Patch Antenna with 3D Radiation Pattern, Azimuth Plane Pattern and Elevation Plane Pattern



(a) Patch Antenna Model (b) Patch Antenna 3D Radiation Pattern

(c) Patch Antenna Azimuth Plane Pattern (d) Patch Antenna Elevation Plane Pattern

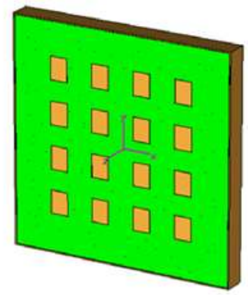
The azimuth and elevation plane patterns are derived by simply slicing through the 3D radiation pattern. In this case, the azimuth plane pattern is obtained by slicing through the x-z plane, and the elevation plane pattern is formed by slicing through the y-z plane. Note that there is one main lobe that is radiated out from the front of the antenna. There are three back lobes in the elevation plane (in this case), the strongest of which happens to be 180 degrees behind the peak of the main lobe, establishing the front-to-back ratio at about 14 dB. That is, the gain of the antenna 180 degrees behind the peak is 14 dB lower than the peak gain.

Again, it doesn't matter if these patterns are shown pointing up, down, to the left or to the right. That is usually an artifact of the measurement system. A patch antenna radiates its energy out from the front of the antenna. That will establish the true direction of the patterns.

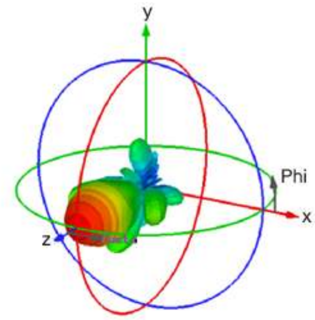
Patch Array Antennas

A patch array antenna is, in general, some arrangement of multiple patch antennas that are all driven by the same source. Frequently, this arrangement consists of patches arranged in orderly rows and columns (a rectangular array) as shown in Figure 8. The reason for these types of arrangements is higher gain. Higher gain commonly implies a narrower beamwidth and that is, indeed, the case with patch arrays. The array shown here has a gain of about 18 dBi with an azimuth and elevation plane beamwidth of about 20 degrees. Notice that the back lobes are very small and that the front-to-back ratio is about 30 dB. The first sidelobes are down from the peak about 14 dB.

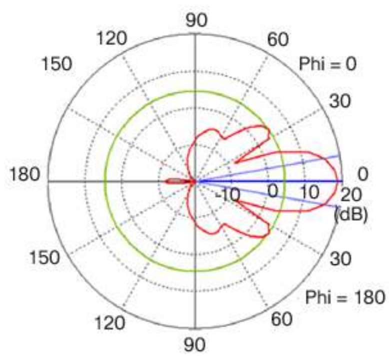
Figure 8. A 4x4 Patch Array Antenna with 3D Radiation Pattern, Azimuth Plane Pattern and Elevation Plane Pattern



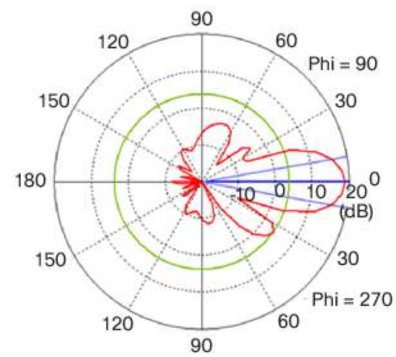
(a) 4x4 Patch Array Antenna



(b) 4x4 Patch Array 3D Radiation Pattern



(c) 4x4 Patch Array Azimuth Plane Pattern



(d) 4x4 Patch Array Elevation Plane Pattern

Antenna patterns are frequently shown normalized to the peak gain. The peak gain (in dBi) is simply subtracted from the gain at all the points on the curve and the pattern is plotted with the new values. These patterns are expressed in dB with 0 dB corresponding to the peak gain. A normalized pattern is especially useful when the sidelobe levels and the depth of the nulls are of interest since it's easier to read their respective levels. The patterns of the patch array shown here have enough lobes and features that a look at their normalized patterns in rectangular coordinates might be interesting. Figure 9 shows the azimuth plane in both polar and Cartesian (rectangular) coordinates. Figure 10 shows the elevation plane in both coordinate systems.

The side lobe levels are easily readable from the rectangular plots. In the azimuth plane, the side lobes are down about 14 dB from the peak. The first side lobe levels are more than 14 dB down in the elevation plane. Note that the back lobe is 30 dB down from the peak. That means the front-to-back ratio is 30 dB. Of course, if the patterns are given in normalized form, the peak gain must be given to determine absolute levels of any of the pattern parameters. The side lobes are labeled in all the plots. Notice that the lower side lobes are to the left of the main beam in the Cartesian plots. These plots show the main beam at 0 degrees, so below the main beam would imply negative angle and above the main beam would imply positive angle.

Figure 9. Azimuth Plane Patterns of the 4 x 4 Patch Array in Polar and Rectangular Coordinates

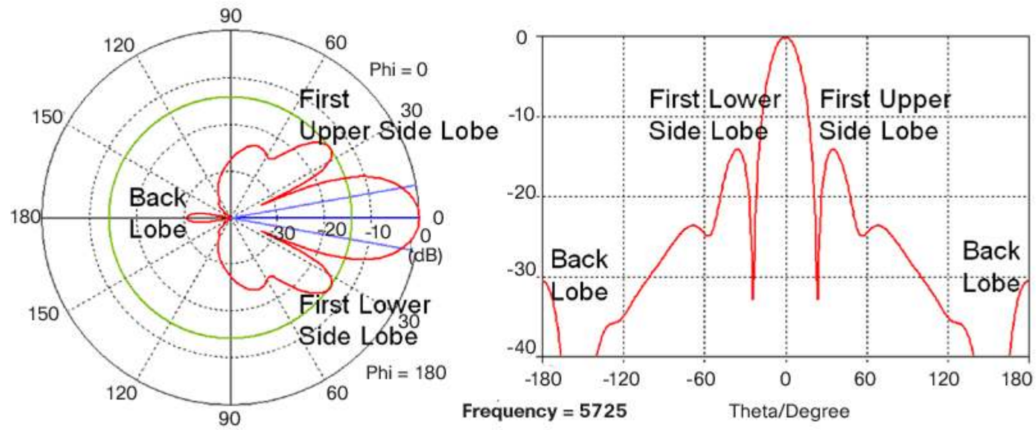
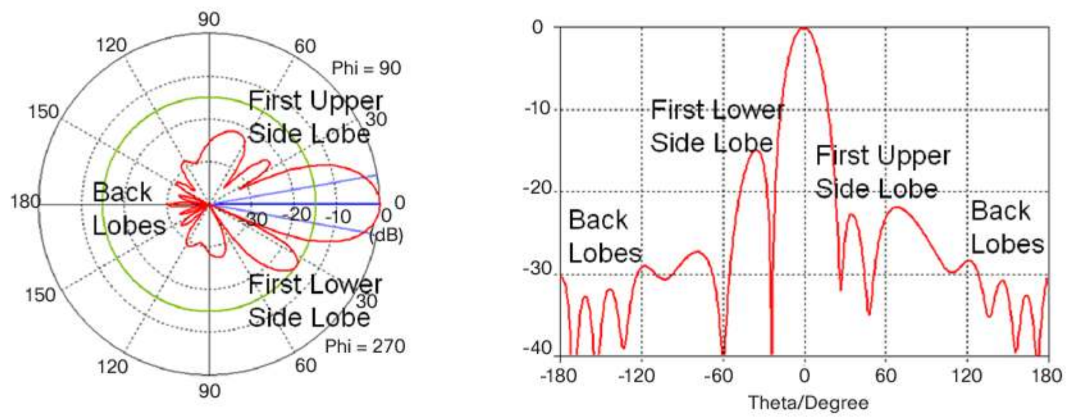


Figure 10. Elevation Plane Patterns of the 4 x 4 Patch Array in Polar and Rectangular Coordinates

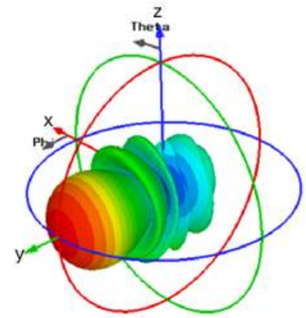


Yagi Antennas

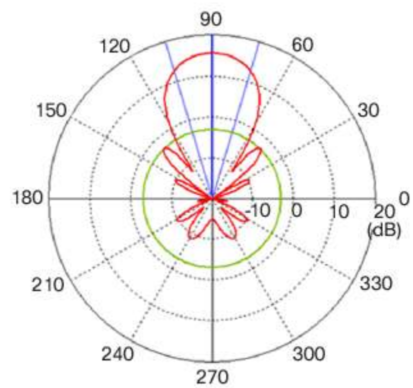
A Yagi antenna is formed by driving a simple antenna, typically a dipole or dipole-like antenna, and shaping the beam using a well-chosen series of non-driven elements whose length and spacing are tightly controlled. The Yagi shown here in Figure 11 is built with one reflector (the bar behind the driven antenna) and 14 directors (the bars in front of the driven antenna). This configuration yields a gain of about 15 dBi with azimuth and elevation plane beamwidths that are basically the same, around 36 degrees. That is a common feature of Yagi antennas. Many times these antennas are designed so that they can be rotated for either horizontal or vertical polarization, so having the same 3-dB beamwidth in each plane is a nice feature in those instances.

Figure 11. Yagi Antenna Model with 3D Radiation Pattern, Azimuth Plane Patten, and Elevation Plane Pattern

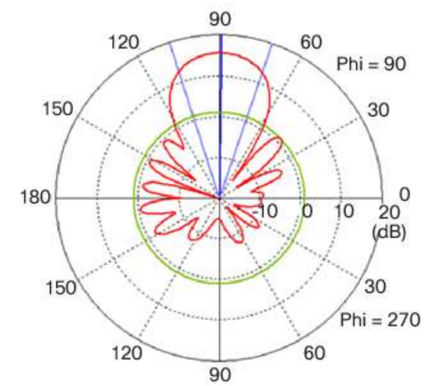
(a) Yagi Antenna Model



(b) Yagi Antenna 3D Radiation Pattern



(c) Yagi Antenna Azimuth Plane Pattern



(d) Yagi Antenna Elevation Plane Pattern

Again, the Yagi antenna is a directional antenna that radiates its energy out in one main direction. Very often, these antennas are enclosed in a tube, with the result that the user may not see all the antenna elements. Their directional nature seems to be somewhat intuitive due to their common, tubular form factor. It is easy to visualize aiming these antennas much like a rifle.

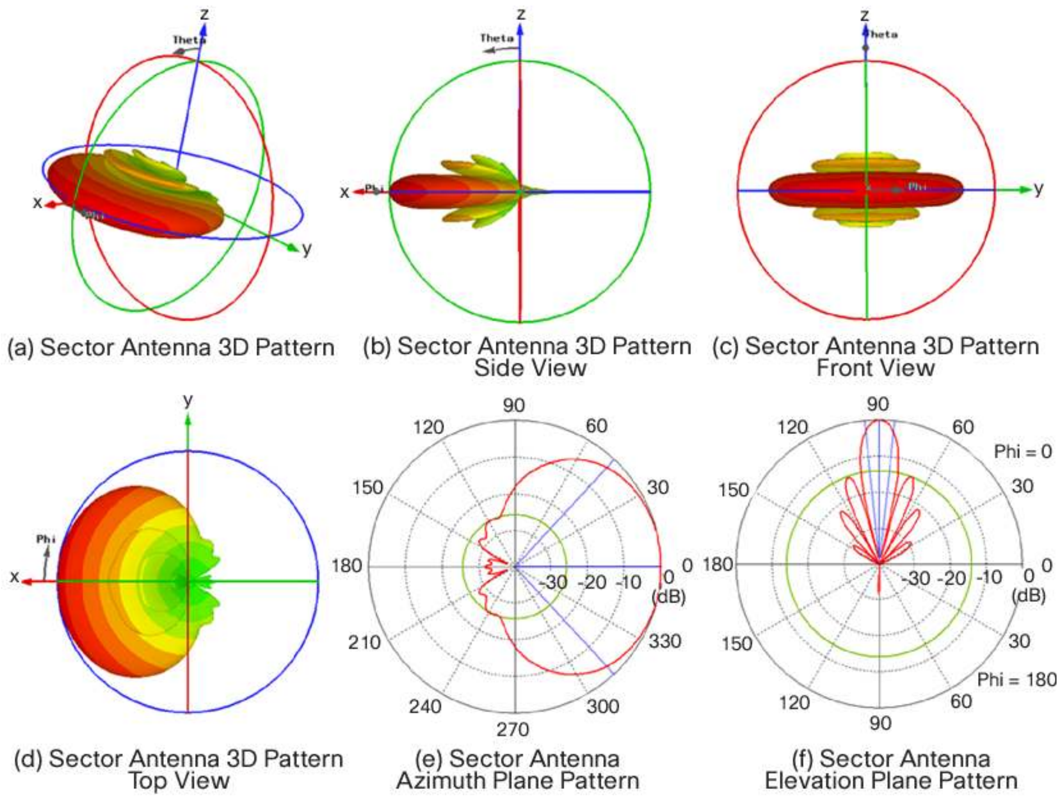
Sector Antennas

A sector antenna or "sector panel" is a somewhat specialized antenna frequently encountered in outdoor systems where wide coverage areas are desired. Very often they are built from an array of dipoles placed in front of a shaped reflector. The size and shape of the reflector determines the performance of these antennas to a large extent. Many of these antennas have reflector shapes that are somewhat flat with some ridges or other features along the edges. A sector antenna is almost always categorized by its azimuth plane 3-dB beamwidth. Commonly available are 60-, 90-, and 120-degree sectors. Sectors are frequently deployed higher up in the air and may have side lobe and front-to-back ratio requirements associated with them. The presence of other antennas and the height of the deployment can weigh heavily on the actual antenna selection.

Figure 12 shows the patterns from a sector antenna, including a few images of the 3D pattern. Notice that the pattern is wide in the azimuth plane, but very narrow in the elevation plane. This is typical of sectors and that is how they achieve their high gains, by compressing the elevation plane. This sector was formed with a vertical array of ten dipoles strategically placed in front of a shaped reflector.

This is an 18 dBi, 90-degree sector. It is a 90-degree sector because the azimuth plane 3-dB beam is 90-degrees as shown in Figure 9e. In this case the elevation plane beamwidth is about 12 degrees and the first side lobes (elevation plane, Figure 9f) are down about 14 dB. Note that the principal plane patterns aren't oriented in any particular manner. Remember that they don't really have to be oriented in any particular way when you know what the antenna is supposed to do. It is assumed that the azimuth plane is parallel to the ground and the elevation plane is perpendicular to the ground.

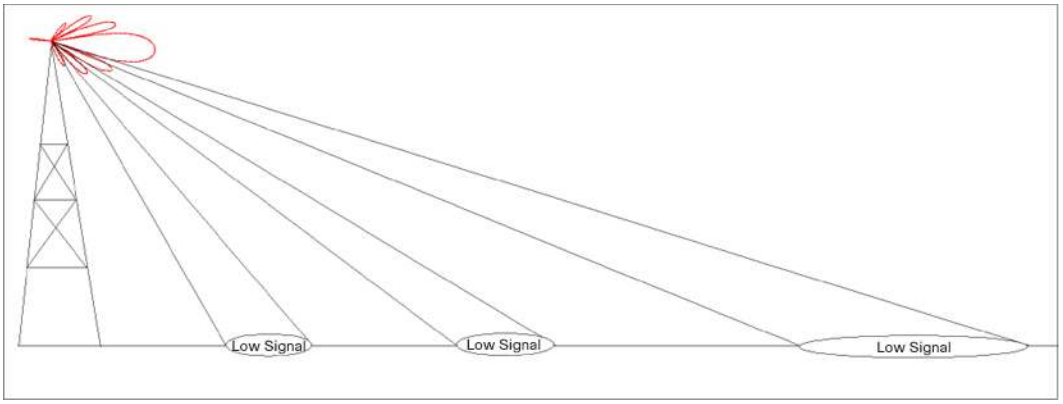
Figure 12. Various 3D Radiation Patterns from a 90 degree Sector Antenna, Azimuth Plane Pattern and Elevation Plane Pattern



One of the problems encountered when deploying sectors, or omnidirectional antennas for that matter, is that there can be several nulls in the elevation plane. When the gain is higher, the number of nulls (and side lobes) generally goes up as well. When the antennas are used in offices or in low hanging outdoor deployments, this is seldom a problem. Signal strengths are generally high enough everywhere to guarantee service to all users with careful planning. But when the antennas are mounted high in the air on towers, these nulls can affect the performance of the system.

Figure 13 illustrates the problem. Assume that the sector antenna is mechanically tilted down by 5 degrees. This effectively tilts the elevation plane pattern down 5 degrees as shown. This puts certain regions under the antenna in areas below the nulls in the pattern resulting in areas of low signal strength.

Figure 13. Coverage Gaps from Elevation Plane Nulls

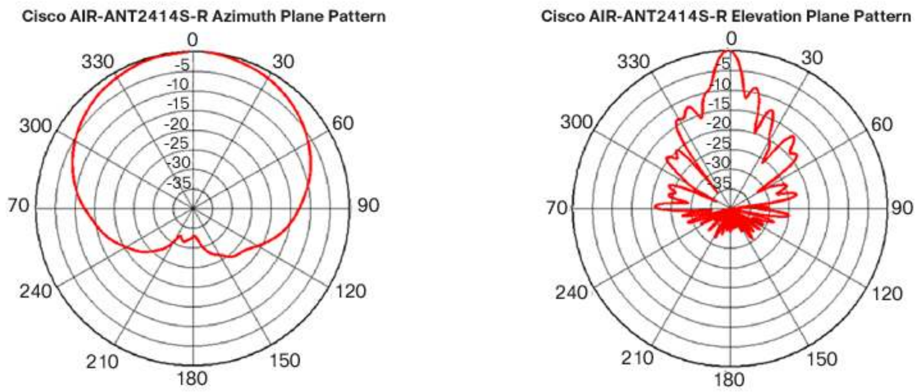


System users “in the nulls” might have a problem depending on how much signal actually gets transmitted to the ground. The further out from the antenna, the worse the problem gets not only because the signal strength gets lower as the distance from the antenna increases, but also because the size of the low-signal area gets bigger. Notice too that many users are getting their coverage from the side lobes rather than from the main beam. This can be an important consideration.

Some sectors are specifically designed to combat this problem with “null fill.” When the nulls are filled in, the distribution of energy to the various antenna elements in the array is changed so that more energy is radiated “below” the antenna. As a result, the peak gain of the main lobe is generally reduced. In order to preserve the peak gain, more elements must be added and the antenna gets physically larger. An example of a sector with “null fill” is shown below in Figure 14. This is actually the Cisco® AIR-ANT2414S-R. The AIR-ANT2414S-R is a 14 dBi, 90-degree sector antenna. Many of the 90-degree sector antennas on the market for 2.4 GHz are shorter, but do not have the “null fill” property. This antenna was designed to keep the gain relatively high while filling in the nulls “under the antenna,” particularly the deep first null and second null that affect the coverage far away from the antenna.

Figure 14. A Cisco 90-degree Sector Antenna with Azimuth and Elevation Plane Patterns

(a) Cisco AIR-ANT2414S-R, 14 dBi Sector Antenna

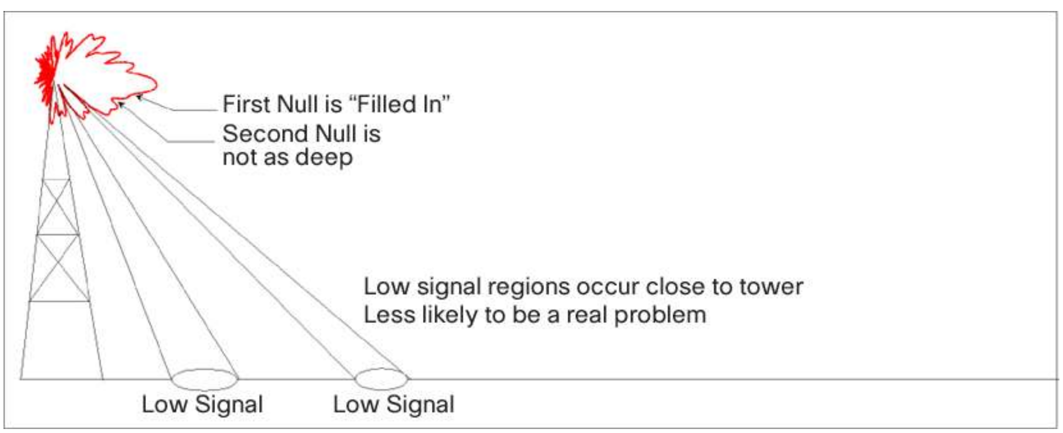


(b) Cisco AIR-ANT2414S-R Azimuth Plane Pattern

(c) Cisco AIR-ANT2414S-R Elevation Plane Pattern

Notice that the first two nulls in the elevation plane “under the antenna” are not as deep or seem to be gone altogether. This allows for increased signal levels to users who might otherwise be without coverage as illustrated in Figure 15. The figure shows that if the antenna is tilted down 5 degrees as in the previously illustrated case, there is no null pointed far away from the antenna. The nulls that still exist point to areas close to the tower, where total lack of coverage is less likely due to the shorter ranges involved.

Figure 15. Illustration of Reduced Coverage Gaps from a Sector Antenna with “Null Fill”



Summary

This paper covered basic antenna definitions and explained terms frequently encountered in examining antenna patterns. Gain and beamwidth definitions were made and pattern parameters such as front-to-back ratio and side lobe levels were discussed. Along the way, the basic function of several common antennas was covered. Omnidirectional antennas like dipoles and collinear arrays were shown to radiate their power out in all directions in a plane, away from the vertical axis of the antenna. Increasing the gain reduces the elevation plane beamwidth and typically increases the number of side lobes. In general, directional antennas, like patches and Yagis, radiate their power out from the front of the antenna. In these cases, both the azimuth plane and elevation plane patterns become important. Increasing the gain will tend to reduce both the azimuth and elevation plane beamwidths unless specific design measures are taken. This is apparent in the design of sector antennas where the azimuth plane beamwidth is typically large compared to the elevation plane beamwidth.

Knowing how these antennas behave prevents confusion when examining the antenna patterns and helps eliminate concerns about “which way the antenna points” when looking at the patterns. The function of the antenna establishes the orientation of the azimuth and elevation plane patterns. The user can then orient or “aim” the pattern in any direction and still understand how the antenna will perform.

Finally, an illustration of some of the effects of nulls and side lobes was shown in the discussion of sector antennas. Two sector antennas were shown mounted high on a tower. One of the sectors made no attempt to control the elevation plane nulls and the other was designed to fill in the worst of the nulls. The regions of low signal level resulting from elevation plane nulls were shown and discussed. It is apparent from this simple discussion that antennas have to be carefully deployed to get the best performance from the system. Knowing the basic definitions and functionality of these common antenna types will provide the basis for good deployment decisions.

References

The following books are excellent references for definitions and basic theory. They also contain a wealth of antenna theory that may be somewhat challenging.

John D. Kraus and Ronald J. Marhefka, *Antennas for all Applications*, McGraw-Hill, 2002

Constantine Balanis, *Antenna Theory*, John Wiley & Sons, 1997

Americas Headquarters
Cisco Systems, Inc.
170 West Tasman Drive
San Jose, CA 95134-1706
USA
www.cisco.com
Tel: 408 526-4000
800 553-NETS (6387)
Fax: 408 527-0883

Asia Pacific Headquarters
Cisco Systems, Inc.
168 Robinson Road
#28-01 Capital Tower
Singapore 068912
www.cisco.com
Tel: +65 6317 7777
Fax: +65 6317 7799

Europe Headquarters
Cisco Systems International BV
Haarlerbergpark
Haarlerbergweg 13-19
1101 CH Amsterdam
The Netherlands
www-europe.cisco.com
Tel: +31 0 800 020 0791
Fax: +31 0 20 357 1100

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