

The Fundamentals of Patch Antenna Design and Performance

By Gary Breed
Editorial Director

Here is a basic tutorial on microstrip patch antennas, intended to familiarize engineers with the structure, feed and radiation properties of this common type of antenna

Microstrip patch antennas (also just called *patch antennas*) are among the most common antenna types in use today, particularly in the popular frequency range of 1 to 6 GHz. This type of antenna

had its first intense development in the 1970s, as communication systems became common at frequencies where its size and performance were very useful. At the same time, its flat profile and reduced weight, compared to parabolic reflectors and other antenna options, made it attractive for airborne and spacecraft applications. More recently, those same properties, with additional size reduction using high dielectric constant materials, have made patch antennas common in handsets, GPS receivers and other mass-produced wireless products.

This tutorial article is intended to provide basic information on patch antenna design and operation, directed to engineers who are mainly designers of RF/microwave circuits. We hope that this information will assist them as they design circuitry connected to these antennas, or as they are called on to evaluate and specify a vendor's antenna product for their current project.

Basic Patch Antenna Design

Although there are many variations on patch antenna design, the basic configuration is shown in Figure 1, where l is then length (relative to the feedpoint) and w is the width. In the simplest configuration, $l = w = \lambda_{\text{eff}}/2$, or an electrical one-half wavelength, including

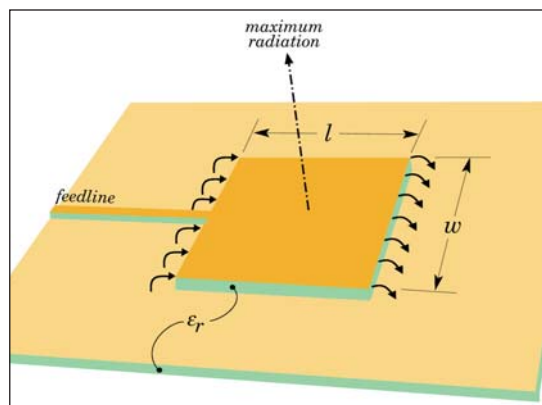


Figure 1 . Basic configuration of the microstrip patch antenna.

the shortening effect of the dielectric constant (ϵ_r) of the material between the patch and the conducting surface (or *substrate*) below.

The two edges of the patch that are connected to, and opposite from, the feed connection provide the radiation, acting as slot antennas, where each slot is the gap between the edge of the patch and the ground plane beneath the intervening dielectric layer. The arrows at the left and right edges of the patch represent the currents between the patch conductor and ground plane. At the edges, where they are not contained, these currents result in the desired radiation of electromagnetic waves from the two edge slots.

We can easily see that the microstrip feedline excites the center of the slot formed by the edge of patch that to which it is connected. Between the underside of the patch and the substrate ground plane, a low impedance transmission line is formed that subsequently feeds the slot at the opposite side. Since the

PATCH ANTENNAS

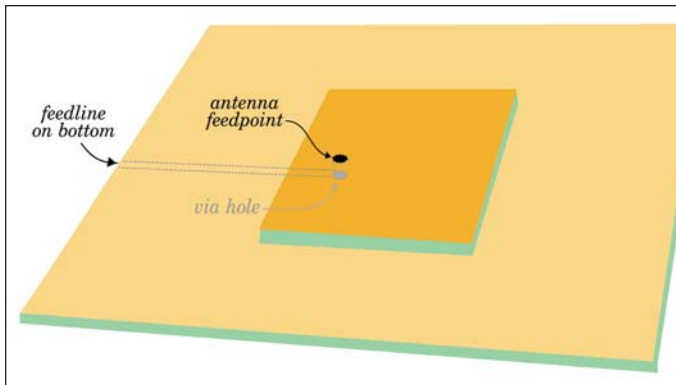


Figure 2 · Feeding the patch antenna with the feedline on the underside of the substrate laminate. The location of the feed is selected for the proper impedance, and to create a current distribution that results in the desired polarization of the radiated wave.

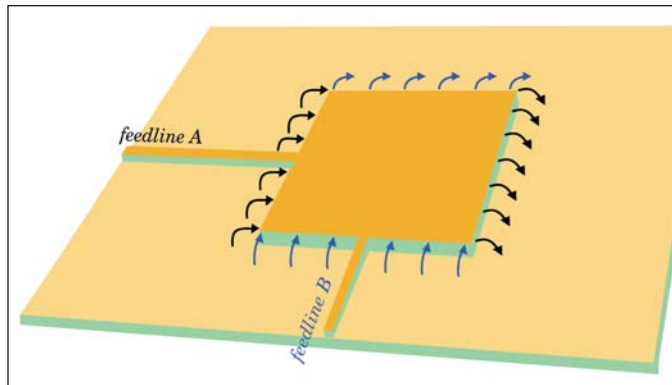


Figure 3 · A patch may be fed at two points along adjacent edges. This creates two independent radiated waves that are orthogonally polarized. When the phase shift between the two modes is set to 90° circularly polarized radiation is achieved.

electrical length of this line is $\lambda/2$, the impedance at the fed edge is repeated at the other, which effectively feeds the two slots in-phase with nearly equal antenna currents. Thus, the patch operates as an array of two slots with a free-space separation somewhat less than $\lambda/2$. Maximum radiation is normal to the plane of the patch. Polarization is at right angles to the length of the slots, parallel to the feedline orientation shown in Fig. 1.

Radiation toward the back of the substrate is greatly reduced by the shielding effects of the ground plane layer. The amount of reduction depends on the extent to which the ground plane extends beyond the patch area. To make a smaller product, many commercial antennas have ground planes that are only slightly larger than the patch. While they have less reduction of rearward radiation than a larger design, they still have useful gain and directivity. One familiar application of this type of patch antenna is the rectangular antenna (usually in a plastic housing) used widely in 2.4 GHz or 5 GHz WLAN systems.

Alternate Feed Methods

A common variation in patch antenna design is the location and

routing of the feed, to obtain a desired feedpoint impedance, to control the polarization, or for convenient layout (or all of these characteristics simultaneously). Figure 2 shows the most common of these alternate feed methods, which routes the feedline under the ground plane, isolating it from the radiating side of the structure. The connection to the patch is made through a hole in the substrate using a via or connecting wire.

Removing the feedline from the radiating side of the structure eliminates possible interaction between the feed system and antenna. It has the additional advantage of allowing the designer to include more microstrip circuitry on the backside. These circuits may be impedance matching networks, filters, phase shift networks and power dividers, for an individual patch or for arrays comprising multiple patch elements.

In a more complex system, active elements may be included as well, such as a low noise amplifier, transmit-receive switching diodes, and active variable phase shifters. In wide bandwidth or multiband systems, the supporting circuitry may also switch or tune impedance matching components.

The configuration of Fig. 1 can be expanded to support two simultane-

ous feeds, delivering two radiated waves that are orthogonal in polarization. Figure 3 shows how these two feeds are connected, and how the radiating currents appear at the edge slots. The feed system can be designed to provide a phase shift between the two polarizations, with 90 degrees delivering circularly-polarized radiation. Of course, a -90 degree phase shift will result in circular polarization of the opposite sense.

The methods of Figs. 2 and 3 can be combined in various ways. For

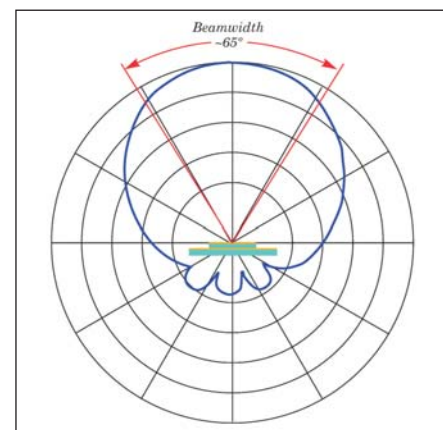


Figure 4 · Measured pattern of a patch antenna, with a typical beamwidth of 65° and fairly well suppressed rearward radiation. Pattern asymmetry is common due to both construction and measurement variations.

example, it is possible to choose a single through-hole feed location that results in circular polarization. The necessary phase shift is the result of different current flow paths in the region between the patch and ground plane.

Radiation Pattern and Gain

The simple patch of Fig. 1 has a radiation pattern like that shown in Figure 4. As noted earlier, the two radiating slots create a two-element array, which results in a narrower beam width than a simple slot (which is like a dipole). In addition, the backing surface reduces rearward radiation, which increases gain in the forward direction. The array gain, dipole-like directivity and uni-directional characteristic are combined for approximately 8 to 9 dBi gain (approx. 6-7 dB relative to a dipole, or dBd).

The beamwidth is similar in both the x and y planes, creating roughly a “cone” of radiation outward from the patch. For typical patch construction, the -3 dB beamwidth is about 65 degrees, or ± 32.5 degrees from boresight.

The radiation pattern is relatively narrow for a simple antenna, which makes patch antennas desirable for assembly into arrays. Modern computer-aided design even allows the arrays to follow curves contours of aircraft or vehicle bodies. Adaptive technologies that can vary both phase shift and power to each element allow those arrays to be electronically steerable. An example of this type of array is airborne satellite communications antennas used on most commercial passenger aircraft. With this capability, the former shortwave radio communication used on trans-oceanic flights can be replaced with higher capacity and more reliable satellite links.

Advantages of Patch Antennas

The unique property of the microstrip patch antenna is its two-dimensional structure. As a flat antenna, arrays can have a large aperture, with corresponding high gain, but having low volume and weight. As noted above, curved implementations can be made to conform to aircraft hulls.

The dielectric layer can be manipulated to fit different applications. Air dielectric has very low loss, making patch arrays useful for wireless communications systems, where its low weight and high gain are also valuable. When used with a high dielectric constant material such as ceramics, the effective wavelength is much smaller and the antenna can be greatly reduced in size. Many GPS antennas take advantage of this property to reduce the relatively large size of an L-band patch, resulting in compact antennas, often with LNAs integrated into the assembly.

Disadvantages

The most significant disadvantage is that the relatively large x - y dimensions of a patch create higher-order modes that allow radiation, or reception of interference, at other frequencies. The bandpass filtering effect found in other antenna types must be replaced with additional circuitry to eliminate any problems. However, it should be noted these additional modes also allow the intentional design of multi-band patch antennas.

Notes on Design Variations

We conclude this short tutorial by noting that microstrip patch antennas have as many variations as any component in RF/microwave technology! There are an astounding number of different shapes, feed systems, and array configurations. These design options make this type of antenna a fascinating area of study, since many problems can be addressed regarding frequency of operation, pattern shape, gain and multi-frequency coverage. A search of the literature on this topic will clearly show the wide range of performance that can be obtained.