

Performance Characteristics of Rectangular Patch Antenna

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Abstract: Micro strip antennas are among the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well (Below approximately 1 GHz, the size of a micro strip antenna is usually too large to be practical, and other types of antennas such as wire antennas dominate). Also called patch antennas, micro strip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness h , with relative permittivity and permeability ϵ_r and μ_r . Here we have generated simulations using HFSS software to know the performance characteristics of rectangular patch antenna. The design parameters are also discussed along with simulations. We observed performances of return loss, directivity, radiation boundaries, excitations and gain over its operating frequency.

Keywords: Return loss, Directivity, Gain, Radiation boundaries, Substrate, Co-axial feed.

1. Introduction

A micro strip or patch antenna is a low profile antenna that has a number of advantages over other antennas it is lightweight, inexpensive, and easy to integrate with accompanying electronics. While the antenna can be 3D in structure (wrapped around an object, for example), the elements are usually flat; hence their other name, planar antennas. Note that a planar antenna is not always a patch antenna^[1].

The following drawing shows a patch antenna in its basic form: a flat plate over a ground plane (usually a PC board). The center conductor of a coax serves as the feed probe to couple electromagnetic energy in and/or out of the patch^[1]. The electric field distribution of a rectangular patch excited in its fundamental mode is also indicated.

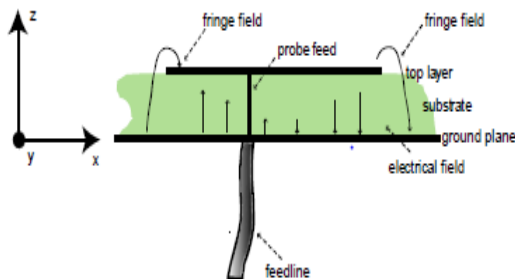


Figure 1. Basic form of Patch Antenna

The electric field is zero at the center of the patch, maximum (positive) at one side, and minimum (negative) on the opposite side. It should be mentioned that the minimum and maximum continuously change side according to the instantaneous phase of the applied signal^[2]. The electric field does not stop abruptly at the patch's periphery as in a cavity; rather, the fields extend the outer periphery to some

degree. These field extensions are known as fringing fields and cause the patch to radiate^[1]. Some popular analytic modeling techniques for patch antennas are based on this leaky cavity concept. Therefore, the fundamental mode of a rectangular patch is often denoted using cavity theory as the TM₁₀ mode.

Since this notation frequently causes confusion, we will briefly explain it. TM stands for transversal magnetic field distribution. This means that only three field components are considered instead of six. The field components of interest are: the electric field in the z direction and the magnetic field components in x and y direction using a Cartesian coordinate system^[2], where the x and y axes are parallel with the ground plane and the z -axis is perpendicular.

In general, the modes are designated as TM _{n m z} . The z value is mostly omitted since the electric field variation is considered negligible in the z -axis. Hence TM _{n m} remains with n and m the field variations in x and y direction. The field variation in the y direction (impedance width direction) is negligible; Thus m is 0. And the field has one minimum to maximum variation in the x direction (resonance length direction); Thus n is 1 in the case of the fundamental. Hence the notation TM₁₀^[2].

2. Dimensions

The resonant length determines the resonant frequency and is about $1/2$ for a rectangular patch excited in its fundamental mode. The patch is, in fact, electrically a bit larger than its physical dimensions due to the fringing fields^[3]. The deviation between electrical and physical size is mainly dependent on the PC board thickness and dielectric constant.

A better approximation for the resonant length is:

$$L = 0.49 \lambda_d = 0.49 * \lambda_0 / \epsilon_r \quad (1)$$

This formula includes a first order correction for the edge extension due to the fringing fields,

With:

L = resonant length

λ_d = wavelength in PC board

λ_0 = wavelength in free space

ϵ_r = dielectric constant of the PC board material [4]

Other parameters that will influence the resonant frequency:

- Ground plane size
- Metal (copper) thickness
- Patch (impedance) width

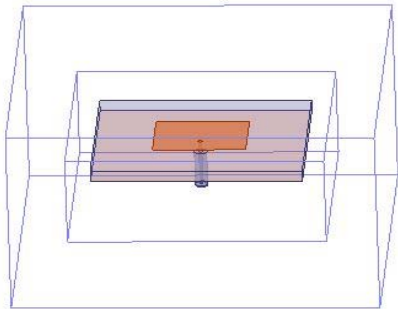


Figure 2. Module of Rectangular Patch Antenna

3. Construction

The module has been designed over operating frequency of 10 GHz. Patch dimensions are 1.19*0.90cm. Substrate thickness is 62mil. Substrate dimensions are 3*3cm. Feed locations are 0 and 0.30cm along X and Y axes [5]. Coaxial inner radius is 0.025 and outer radius is 0.085cm. Coaxial probe feed length is 0.25cm.

In the following figure we observe all the mentioned dimensions, they are substrate dimension along X and Y, substrate thickness, patch dimension along X and Y, Feed along X and Y and finally coaxial inner and outer radius.

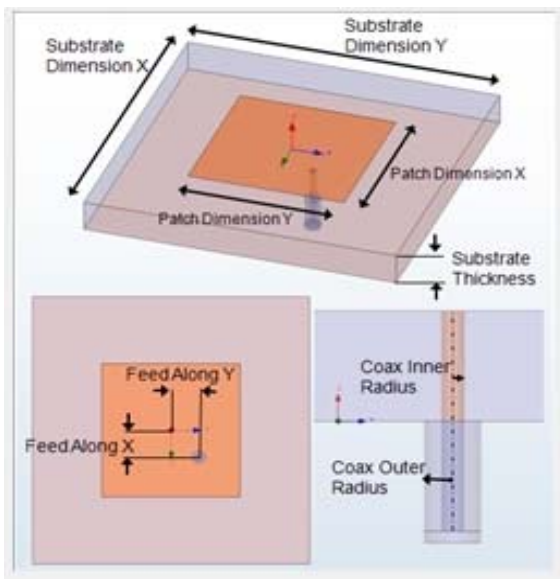


Figure 3. Representations of the Rectangular Patch Antenna

4. Boundaries

Boundary conditions enable you to control the characteristics of planes, face, or interfaces between objects. Boundary conditions are important to understand and are fundamental to solution of Maxwell's equations.

The wave equation that is solved by Ansoft HFSS is derived from the differential form of Maxwell's Equations. For these expressions to be valid, it is assumed that the field vectors are single-valued, bounded, and have continuous distribution along with their derivatives [5]. Along boundaries or sources, the fields are discontinuous and the derivatives have no meaning. Therefore boundary conditions define the field behavior across discontinuous boundaries.

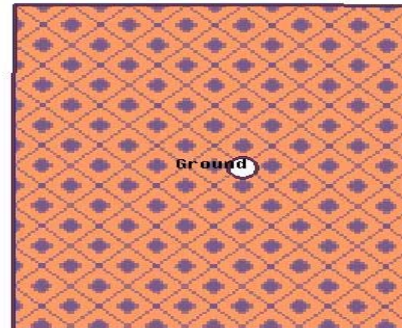


Figure (4a)



Figure 4(b)

Figure 4(a) and Figure 4(b) are Boundary conditions of Ground and Patch

4.1 Radiation Boundary

Radiation boundaries, also referred to as absorbing boundaries, enable you to model a surface as electrically open: waves can then radiate out of the structure and toward the radiation boundary [5]. The system absorbs the wave at the radiation boundary, essentially ballooning the boundary infinitely far away from the structure and into space. Radiation boundaries may also be placed relatively close to a structure and can be arbitrarily shaped. This condition eliminates the need for a spherical boundary. For structures that include radiation boundaries, calculated S-parameters include the effects of radiation loss. When a radiation boundary is included in a structure, far-field calculations are performed as part of the simulation.

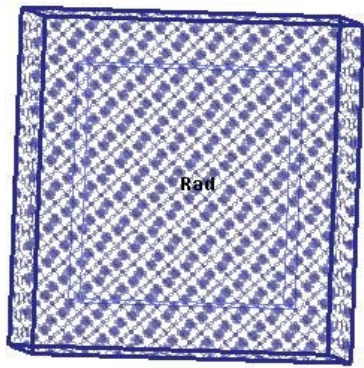


Figure 5. Radiation Boundary of Air Box



Figure 6. Boundary Condition of Coaxial Outer

4.2 Port Field Display

Ports are a unique type of boundary condition that allows energy to flow into and out of a structure. You can assign a port to any 2D object or 3D object face. Before the full three-dimensional electromagnetic field inside a structure can be calculated, it is necessary to determine the excitation field pattern at each port [6]. Ansoft HFSS uses an arbitrary port solver to calculate the natural field patterns or modes that can exist inside a transmission structure with the same cross section as the port. The resulting 2D field patterns serve as boundary conditions for the full three-dimensional problem.

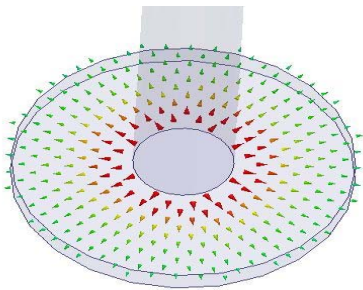


Figure 7. Port field display of coaxial feed

5. Results and Simulations

5.1 Return Loss

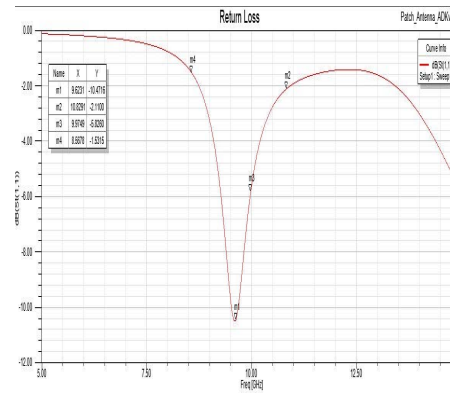


Figure 8. Return Loss Over its operating frequency

5.2 Input Impedance

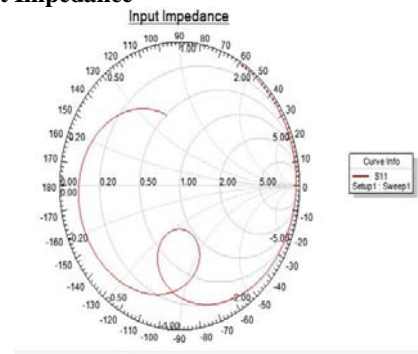


Figure 9. Input Impedance of Patch Antenna

5.3 Directivity

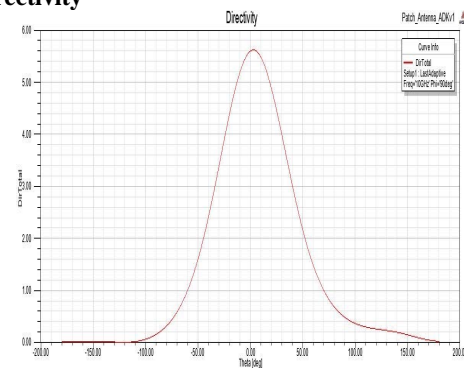


Figure 10. Directivity of Patch Antenna over Last Adaptive setup of Phi = 90°

5.4 Gain

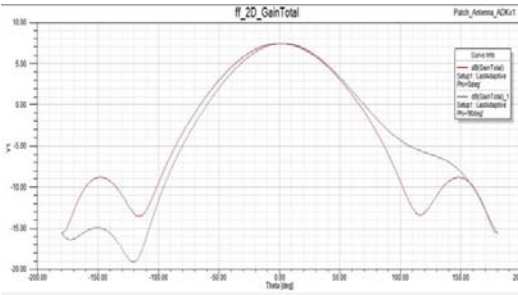


Figure 10: Total Gain over Last Adaptive setup at Phi = 0° and 90° in 2D configuration

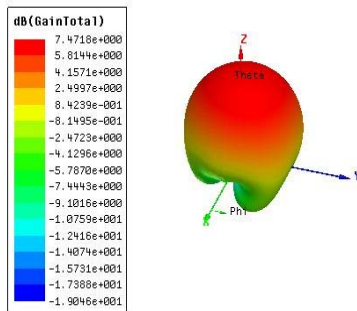


Figure 11: Total Gain over Last Adaptive setup at Phi = 0° and 90° in 3D configuration

The rectangular patch excited in its fundamental mode has a maximum directivity in the direction perpendicular to the patch (broadside). The directivity decreases when moving away from broadside towards lower elevations. The 3 dB beam width (or angular width) is twice the angle with respect to the angle of the maximum directivity, where this directivity has rolled off 3dB with respect to the maximum directivity. So far, the directivity has been defined with respect to an isotropic source and hence has the unit dBi. An isotropic source radiates an equal amount of power in every direction. Quite often, the antenna directivity is specified with respect to the directivity of a dipole. The directivity of a dipole is 2.15 dBi with respect to an isotropic source. The directivity expressed with respect to the directivity of a dipole has dBd as its unit.

Antenna gain is defined as antenna directivity times a factor representing the radiation efficiency. This efficiency is defined as the ratio of the radiated power (Pr) to the input power (Pi). The input power is transformed into radiated power and surface wave power while a small portion is dissipated due to conductor and dielectric losses of the materials used. Surface waves are guided waves captured within the substrate and partially radiated and reflected back at the substrate edges. Surface waves are more easily excited when materials with higher dielectric constants and/or thicker materials are used. Surface waves are not excited when air dielectric is used [7]. Several techniques to prevent or eliminate surface waves exist, but this is beyond the scope of this article. Antenna gain can also be specified using the total efficiency instead of the radiation efficiency only. This total efficiency is a combination of the radiation

efficiency and efficiency linked to the impedance matching of the antenna [8].

6. Conclusions

In this paper, the basic properties of linear polarized patch antennas have been covered. We defined a basic set of specifications that allow the user to understand and write a set of requirements for a specific application. Besides the ones covered here, many more design options and different implementations of patch antennas are available. Coverage of these alternatives is beyond the scope of this article, but they should be considered during the specification and development phases of the antenna.

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