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Research Article

Rectangular Microstrip Patch Antenna Design using IE3D Simulator

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Abstract

In this paper, a rectangular microstrip patch antenna is studied and the results are simulated using IE3D simulator at an operating frequency of 3 GHz. Microstrip Patch Antenna are low profile antennas, conformable to planar and non-planar surfaces, simple and easy to manufacture using modern printed circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MIMC design and when the particular patch shape and size are selected; they are very versatile in terms of resonant frequency, polarization, pattern and impedance .IE3D is a Moment of Method Simulator which solves the Maxwell's Equations in an integral form through the use of Green's functions. The results are analyzed and discussed in terms of return loss, bandwidth, 3D radiation pattern, Efficiency vs. frequency plot, Total Field Directivity vs. Frequency Plot The return loss comes out to be -26 dB and bandwidth is 2.34% for the designed antenna. The length of the antenna is nearly half wavelength in the dielectric; it is a very critical parameter, which governs the resonant frequency of the antenna.

Keywords: *Coaxial Probe Feed, Directivity, Radiation Efficiency, Antenna Efficiency, Green's function, IE3D Simulator, Method of Moment, Radiation Pattern, Return Loss.*

1. Introduction

By definition, an antenna is a device used to transform an RF signal, travelling on a conductor, into an electromagnetic wave in free space. The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1983) defines the antenna or aerial as a means for radiating or receiving radio waves. In other words it is a transitional structure between free space and a guiding device that is made to efficiently radiate and receive radiated electromagnetic waves. Modern printed circuit fabrication techniques have made it possible to build low profile antennas that are extremely useful. Such antennas are referred to as microstrip or printed circuit antennas. Microstrip antennas are planar resonant cavities that leak from their edges and radiate. Printed circuit techniques can be used to etch the antennas on soft substrates to produce low-cost and repeatable antennas in a low profile. 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. These antennas are used in high performance aircraft, spacecraft, satellite and missiles; where size, weight, cost, performance, ease of installation and aerodynamic profiles are important (Balanis, 2005). Simplicity, low manufacturing cost and the flexibility to configure to specialized geometries are some of the other advantages of patch antennas (Stutzman, W.L.; Thiele, *G.A*, 1998). Other advantages include easy fabrication into linear or planar arrays, and easy integration with microwave integrated circuits, mechanically robust when mounted on rigid surfaces, compatible with MIMC design and when the particular patch shape and size are selected; they are very versatile in terms of resonant frequency, polarization, pattern and impedance. In addition by adding loads between the elements and the ground plane such as varactor diodes adaptive elements with variable resonant frequency, impedance, polarization can be achieved. A microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. This concept was undeveloped until the revolution in electronic circuit miniaturization and large-scale integration in 1970. After that many authors have described the radiation from the ground plane by a dielectric substrate for different configurations. The early work of Munson on micro strip antennas for use as a low profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems. Various mathematical models were developed for this antenna and its applications were extended to many other fields. The number of papers, articles published in the journals for the last ten years, on these antennas shows the importance gained by them. The micro strip antennas are the present day antenna designer's choice. Among the first two models were the Transmission line model and Cavity model. Both approaches are relatively easy to implement into a computer program and require relatively short computation time. However, with these models the antenna characteristics are not very accurate and are

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usually limited to the case of narrow band microstrip antennas (P. Bhartia, 1980). Later more rigorous methods have been proposed such as Full Wave Analysis, FDTD and MPIE. In these methods, the antenna characteristics can be determined by solving the integral equations (method of moment). The integral equation method are not restricted to the case of single microstrip patch antenna but can also be applied to microstrip array and to multilayer configuration. However a major drawback of these methods is long computation time and the relatively large computer memory requirements (Kin-Lu Wong, et al, 1999).In this paper, we have design a rectangular patch antenna at an operating frequency of 3 GHz and results are simulated using IE3D simulator. IE3D is a full-wave electromagnetic simulator based on the method of moments. IE3D solves the Maxwell's Equations in an integral form through the use of Green's functions. It can be used to calculate and plot the *S*11 parameters, VSWR, current distributions as well as the radiation patterns It can model structures with finite ground planes and differential feed structures, can model true 3D metallic structures in multiple dielectric layers in open, closed or periodic boundary,

2. Structure of Microstrip Patch Antenna

A microstrip antenna is made up of two parallel conductors that are separated by a dielectric substrate. The lower conductor usually acts as a ground plane and the upper conductor is a patch, therefore such antennas are also called patch antennas. The rectangular patch excited in its fundamental mode has a maximum directivity in the direction perpendicular to the patch (broadside). The patch can be of various shapes such as rectangular, circular, square, elliptical, dipole and triangular among others but regular shapes are generally used to simplify analysis and performance prediction. Substrate properties such as dielectric constant and thickness are important considerations in the design of microstrip antennas.

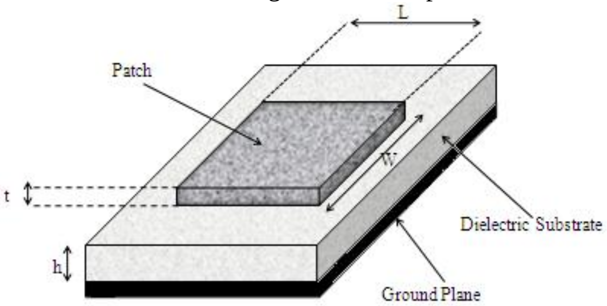

Fig.1. Basic Structure of a Microstrip Patch Antenna

Various substrates are available with values of dielectric constant between 2.2 and 12. Thick substrates with lower dielectric constant result in better efficiency, larger bandwidth and a larger antenna size i.e. good antenna performance. On the other hand, thin substrates with higher dielectric constant cause reduced efficiency, smaller bandwidths and smaller element sizes, .excitation of surface waves that deteriorate the radiation pattern. To increase the narrow bandwidth and radiation efficiency of patch antenna, stacked or slotted patch antennas can be used. Of equal importance is the method which is used to feed the antenna. Microstrip line, coaxial probe, aperture coupling and proximity coupling are the four commonly used methods

3. Design Parameters

The microstrip patch has been designed for the S-band frequency ranges (3GHz in this case). The design flow for the single patch dimensions, using the cavity model approach is as follows:

Step 1: Calculation of the Width (*W*):

The width of the Microstrip patch antenna is given as:

$$W=\frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}}$$

Substituting c = 3.00e+008 m/s, ε_r = 2.32 and f_0 =3 GHz, we get:
***W* = 0.038 m = 38 mm**

Step 2: Calculation of Effective dielectric constant (ε_{reff}):

The effective dielectric constant is:

$$\varepsilon_{reff}=\frac{(\varepsilon_r+1)}{2}+\frac{(\varepsilon_r-1)}{2}\left[1+\frac{12h}{W}\right]^{-1/2}$$

Substituting ε_r = 2.32, W = 38 mm and h = 1.59 mm we get:
ε_{reff} **= 2.1985**

Step 3: Calculation of the Effective length (L_{eff}):

The effective length is:

$$L_{eff}=\frac{c}{2f_0\sqrt{\varepsilon_{reff}}}$$

`Substituting ε*reff* = 2.1985, c = 3.00e+008 m/s and f_0 = 3 GHz we get:
L_{eff} **= 0.033721 m = 33.721 mm**

Step 4: Calculation of the length extension (Δ*L*):
The length extension is:

$$\Delta L=0.412h(\varepsilon_{reff}+0.3)(W/h+0.264)/(\varepsilon_{reff}-0.258)(W/h+0.8)$$

Substituting ε*reff* = 2.1985, W = 38 mm and h = 1.59 mm we get:
Δ*L* **= 0.843 mm**

The dominant mode is thus TM_{01}. The results have been obtained using IE3D Simulator.

3.1. Feeding Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories: contacting and non-contacting.
1) In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line.
2) In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch.

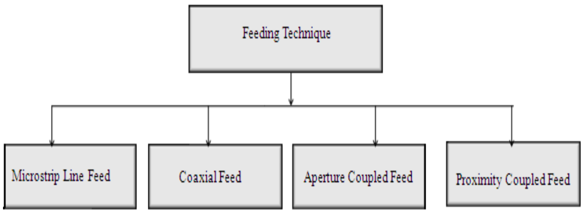

Fig.2. Feeding Techniques

Table 1: Comparison of different Feed Methods

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture coupled Feed	Proximity coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

4. Advantages and Disadvantages of the Microstrip Antenna

Microstrip antennas have several advantages similar to conventional microwave antennas, as these cover a broad range of frequency from 100 MHz to 100 GHz. Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often in the form of Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication.

4.1 Advantages

• Because of its size, light weight, ease of installation and thin profile configurations it can be made conformal to the host surface.
•Low fabrication cost, readily available to mass production using printed circuit technology.
• Required no cavity backing.
• Linear and circular polarizations are possible.
• Easily integrated with microwave integrated circuits.
• Capable of dual and triple frequency operations.
•Feed lines and matching network can be fabricated simultaneously.

4.2 Disadvantages

• High Q resulting in narrow bandwidth, generally a few percent.
• Undesired radiation from the feed.
• Low gain and efficiency, in addition to high levels of cross polarization.
• Can handle low power of the order of tens of watts.
• It is difficult to achieve polarization purity.
• Thicker substrate results in excitation of surface waves.
• Most microstrip antennas radiate into half space.
• Extraneous radiation from feeds and junctions.
• Large ohmic loss in large feed network.

5. Results and Discussions

5.1Radiation Pattern Plot

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial co-ordinates which are specified by the elevation angle (θ) and the azimuth angle (φ). More specifically it is a plot of the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity. It can be plotted as a 3D graph or as a 2D polar or Cartesian slice of this 3D graph. It is an extreme parameter as it shows the antenna's directivity as well as gain at various points in space. It allows us to display the True 3D Radiation Pattern and Mapped 3D Radiation Pattern of a pattern file in the list at a selected frequency.

5.1.1.3D Radiation Pattern of a Rectangular Patch

On the 3D pattern display, there are 3 axes. Those are the axis for the three main angles: (Theta, Phi) = (0, 0), (90, 0) and (90, 90).

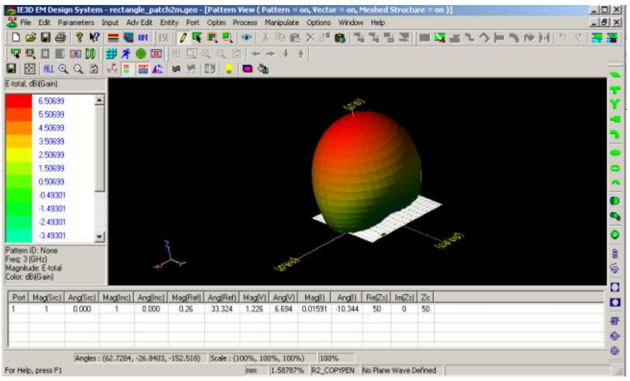

Fig.3. 3D Radiation Pattern at 3GHz.

5.1.2 Mapped 3D Radiation Pattern of a Rectangular Patch

Mapped 3D Radiation Pattern - It is the pattern with the theta angle mapped to the radius of a cylindrical coordinate system. The radius in the cylindrical system represents value of the theta angle. The mapped 3D radiation pattern obtained after simulation is shown in figure

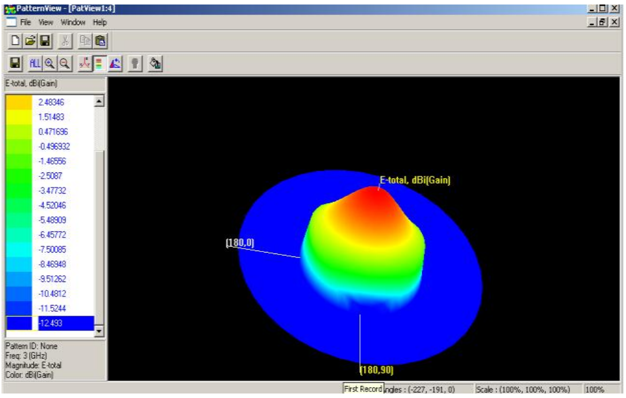

Fig-4: Mapped 3D Radiation Pattern at 3GHz.

5.1.3 True 3D Radiation Pattern of a Rectangular Patch

It is the pattern in the actual 3D space. The size of the pattern from the origin represents how strong the field at a specific (theta, phi) angle. The True 3D radiation pattern obtained after simulation is shown in figure

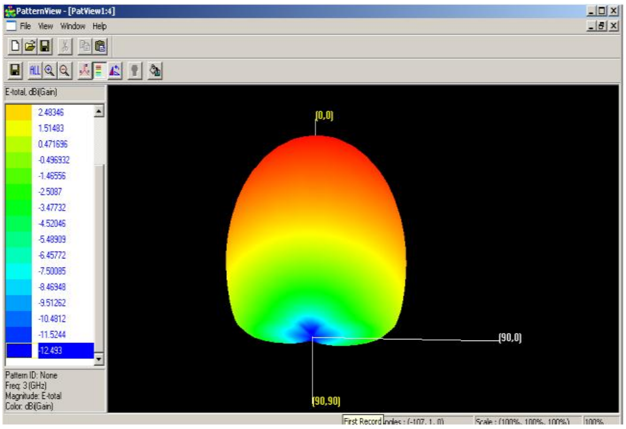

Fig-5: True 3D Radiation Pattern at 3GHz.

5.2 Return Loss

Microstrip and coaxially fed patch antennas are commonly used in various types of smart antenna systems. In order for any given antenna to operate efficiently, the maximum transfer of power must take place between the feeding system and the antenna. Return Loss is a parameter similar to the *VSWR* which indicates the amount of power that is lost to the load and does not return as a reflection.

Fig.6. shows the best value of return loss after optimization which is about -26 dB. The value of return loss should be minimum in order to minimize the reflection wave and able to maximize the transmitting power thus operating the antenna with the better performance. This graph also represents the bandwidth of the antenna which is about 2.34% in this case.

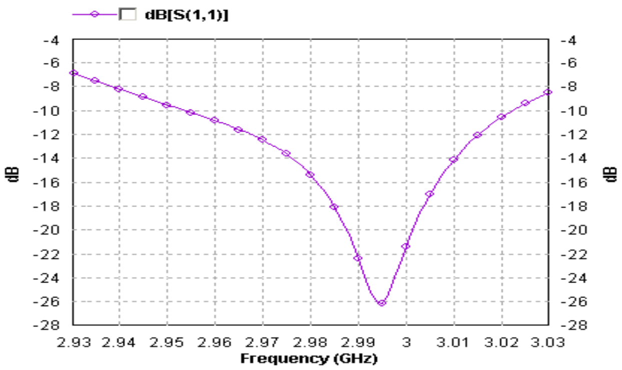

Fig-6: Return loss characteristics of a rectangular patch antenna,L=32mm,W= 38mm, e_r= 2.32, h= 1.59mm.

5.3.1 2D Azimuth Radiation Pattern(Castesian Plot) of a Rectangular Patch

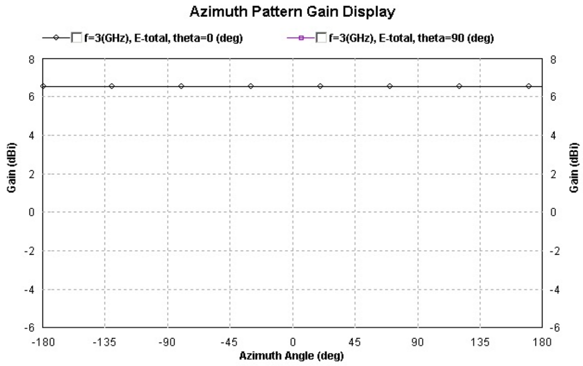

Fig.7: 2D Azimuth Radiation Pattern(Castesian Plot) for at 3GHz.

5.3.2 2D Azimuth Radiation Pattern(Polar Plot) of a Rectangular Patch

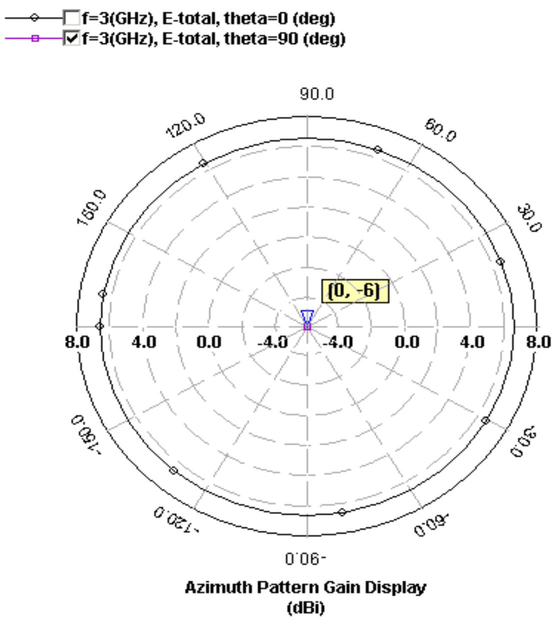

Fig.8: 2D Azimuth Radiation Pattern(Polar Plot) at 3GHz.

5.4. Average Current Density Distribution of a Rectangular Patch

Fig.9. is the Average current density distribution plot of a Rectangular Patch at 3 GHz. It shows the average strength of the time-harmonic current density distribution at a specific frequency. The colour represents the average strength of the current density at a specific point. For the default continuous tone display, the red colour means strong current density. The blue colour means weak current density.

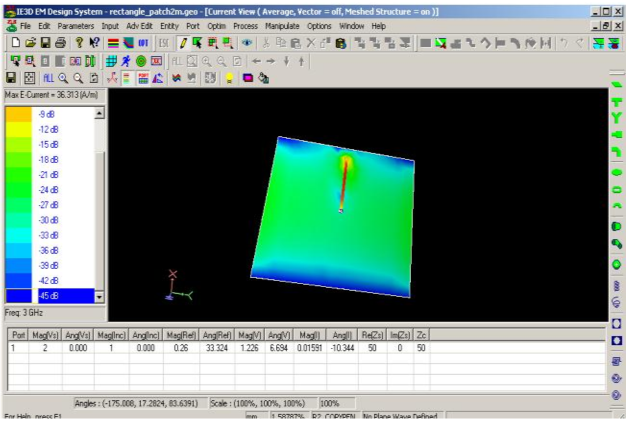

Fig.9: The Average Current Distribution Display at 3GHz.

5.5. Efficiency vs. Frequeny Plot of a Rectangular Patch

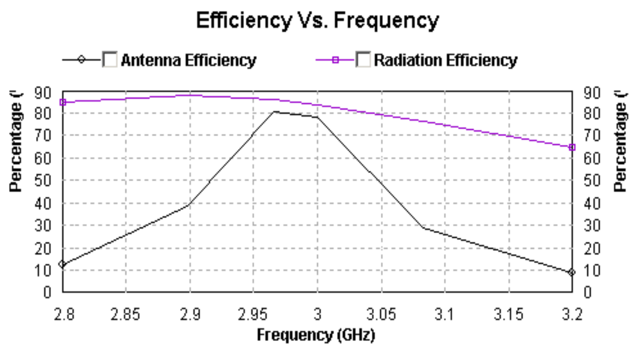

Fig.10: Efficiency vs. Frequency Plot

Fig.10. shows the graph of Efficiency vs. Frequency. Here we have measured Antenna Efficiency and Radiation Efficiency of a Rectangular Patch Antenna. Radiation Efficiency is 83.65% at 3 GHz whereas the Antenna Efficiency comes out to be 77.995%.

5.6.Total Field Directivity vs. Frequeny Plot of a Rectangular Patch

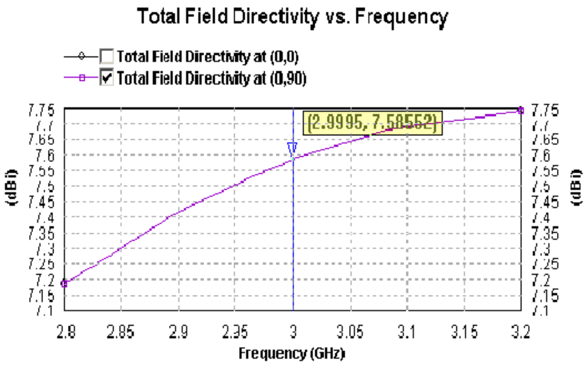

Fig.11: Total Field Directivity vs. Frequency Plot

6. Conclusion

In this paper, a microstrip patch antenna is studied and the results are simulated using IE3D simulator with an operating frequency of 3 GHz The designed microstrip rectangular patch antenna efficiently resonates at 3GHz and gives good return loss of -26 dB with an impedance matching at 50 GHz, directivity as 7.585 and with a gain of 6dB. Antenna Radiation Efficiency comes out to be 83.65% at 3 GHz whereas the Antenna Efficiency comes out to be 77.995% finding application in weather radar, surface ship radar, and some communications satellites.

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