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Design and Development of Microstrip Patch Antenna at 2.4 GHz for Wireless Applications

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Abstract

Due to the existence of growth in development of low cost, less weight, highly reliable, minimal profile antennas for wireless devices, it poses a new challenge for the design of antenna in wireless communications. This paper presents design and simulation of a rectangular micro strip patch array antenna at 2.4 GHz for wireless communications that provides a radiation pattern along a wide angle of beam and achieves a gain of 11.6 dBi. The rectangular micro strip patch antenna was analysed using Ansof/Ansys HFSS and also made a comparison among the different substrates which shows different results based on same parameters.

1. Introduction

In recent years there is a need for more compact antennas due to rapid decrease in size of personal communication devices. As communication devices become smaller due to greater integration of electronics, the antenna becomes a significantly larger part of the overall package volume. This results in a demand for similar reductions in antenna size. In addition to this, low profile antenna designs are also important for fixed wireless application. The microstrip antennas used in a wide range of applications from communication systems to satellite and biomedical applications. In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape. The rectangular microstrip patch antenna is the widely used of all the types of microstrip antennas that are present The substrate material, dimension of antenna, feeding technique will determines the performance of microstrip antenna. To enhance the gain, the array of patch elements is used instead of single patch. Hence among different feeding techniques, edge fed technique is used for the design of rectangular microstrip patch antenna at 2.4 GHz. The substrate material mainly used for design technique is Rogers RT duroid 5880(tm) with $\epsilon r = 2.2$. The software tool HFSS is used because it is a high performance full wave Electro-Magnetic (EM) field simulator for arbitrary 3D volumetric passive device modelling. It integrates simulation, visualization, solid modelling, and automation in an easy to learn environment where solutions to your 3D EM problems are quickly and accurate obtained.

2. Background

A microstrip patch antenna is very simple in the construction using a conventional microstrip fabrication technique[1]. The most two models of the rectangular patch antenna are transmission line model and the cavity model.

2.1 Antenna Shape

Microstrip patch antenna has a ground plane on the one side of a dielectric substrate which other side has a radiating patch as shown in Figure 1. A rectangular patch is used as the main radiator. The patch is generally made of conducting material such as copper or gold and can take any possible shape. Dielectric constant of the substrate (ϵr) is typically in the range $2.2< \epsilon r <12$

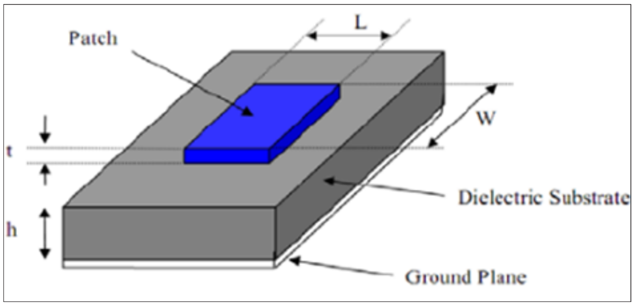

Figure 1. Microstrip antenna.

For good antenna performance, a low dielectric constant with thick dielectric substrate is desirable, as it provides better radiation, better efficiency and larger bandwidth.

3. Analysing Method

Transmission line model depicts the microstrip antenna by two slots of width W and height h separated by transmission line of length L. The microstrip is a non homogeneous of two dielectrics, typically, substrate and the air. Most of the electric field lines reside some part in the air and rest in the substrate. This results that transmission does not support Transverse Electric-Magnetic (TEM) mode of transmission, as phase velocities would be different in substrate and in the air. So, dominant mode of propagation will be the quasi-TEM mode. An effective dielectric constant (ϵreff) must be obtained to account for wave propagation in the line and fringing. The value of ϵreff must be smaller than ϵr, as fringing fields across patch periphery was not totally included in the substrate, it also spread in the air as shown in Figure 2.

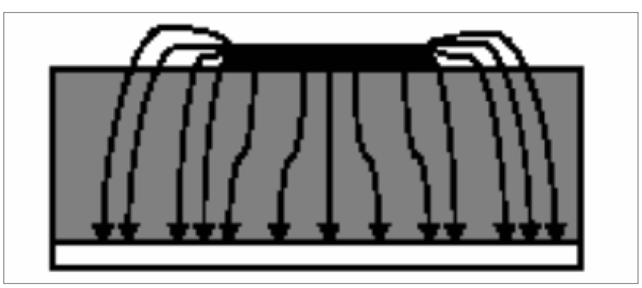

Figure 2. Electric field lines.

To design the patch antenna, following things has to be determined.

- ϵreff = Effective dielectric constant
- ϵr = Dielectric constant of substrate
- h = Height of dielectric substrate
- W = Width of the patch
- L = Length of the patch

Assume Figure 3 a rectangular microstrip antenna of width *W*, length *L* resting on the height of a substrate *h*. The coordinate axis was selected as the height along *z* direction, length along *x* direction and width along *y* direction.

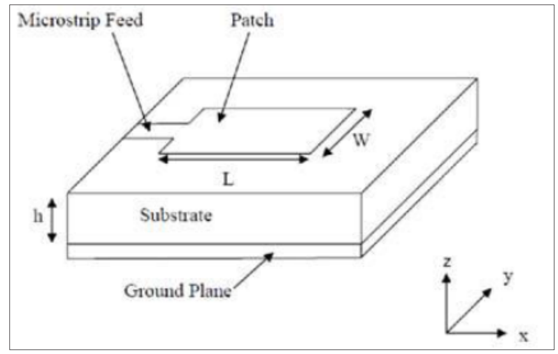

Figure 3. Microstrip patch antenna.

In order to operate in the fundamental mode, length of the patch should be slightly less than $\lambda/2$, where λ is the wavelength equal to $\lambda 0/\surd$. The TM10 implies that field varies a cycle of $\lambda/2$ along the length, and width of the patch has no variation.

The microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends as shown in Figure 4.

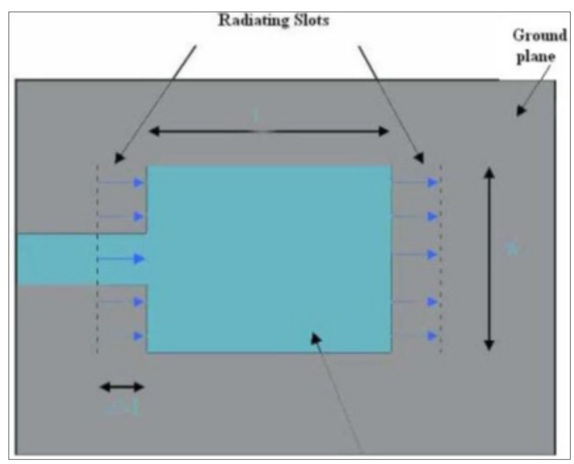

Figure 4. Rectangular microstrip antenna.

The voltage is maximum along the width of the patch and due to the open ends, the current is minimum. With respect to the ground plane the fields at the edges can be resolved into tangential and normal components.

The normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase as seen in Figure 5. The patch is λ/2 long and hence they cancel each other in the broadside direction. The tangential components which are in phase means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are λ/2 apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance Δ*L*.

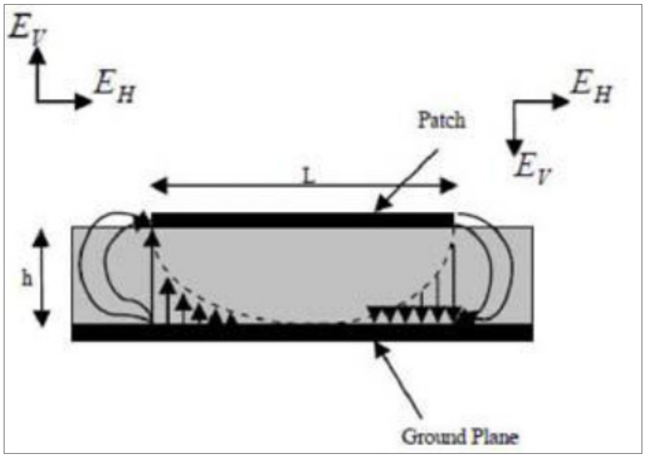

Figure 5. Side view of antenna.

4. Design Consideration

We have designed an array of rectangular patch antenna of the center frequency 2.4 GHz sweeping between 1.2 to 3.6 GHz. Gains required as 11.5 dBi. We have employed a hybrid structure where we are using rogers RT duroid 5880 as a substrate. The three essential parameters for the design of microstrip patch antenna are: 1. Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately, 2. Dielectric constant of the substrate (ϵ r), and 3. Height of dielectric substrate (H): For the microstrip patch antenna the height of the dielectric substrate is critical since the antenna should not be bulky. The transmission line model will be used to design the antenna. The probe type feed is used in this design.

4.1 Antenna Design Calculations

A) Frings factor:

$$\Delta L = 0.412h\ \frac{(€_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(€_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

B) Calculation factor:

$$L = L_{eff} - 2\Delta L$$

$$\text{Where } L_{eff} = \frac{C}{2Lf_0\sqrt{€_{reff}}}$$

C) For a rectangular Micro strip patch antenna.
Frequency for any TM10 mode is given as:

$$f_0 = \frac{C}{2\sqrt{€_{reff}}}\left[\left(\frac{m}{l}\right)^2+\left(\frac{n}{w}\right)^2\right]^{\frac{-1}{2}}$$

Where m and n are modes along L and W respectively

D) Calculation of width
For efficient radiation, the width W is given as:

$$W = \frac{C}{2f_0\sqrt{\frac{€_r+1}{2}}}$$

E) Calculation of the ground plane dimensions (Lg and Wg)

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by[9] that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

L(g) = 6h + L = 6(12) + 46.23 mm = 118.23 mm

W(g) = 6h + W = 6(12) + 62.04 mm = 134.04 mm

Hence after calculating all the parameters using the above formulae, the rectangular microstrip patch antenna was designed.

A) Determination of feed point location
The feed co-ordinates were calculated Yf =W/2 and Xf = X0 -ΔL.
where,

$$X0 = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{50}{Z0}}$$

and

$$Z0 = \sqrt{50 * Zin}$$

B) Dielectric Substrate

It was found suitable to select a thin dielectric substrate with low dielectric constant by considering the trade-off between the antenna dimensions and its performance. Thin substrate permits to reduce the size and also spurious radiation as surface wave, and low dielectric constant–for higher bandwidth, better efficiency and low power loss. The simulated results were found satisfactory (Table 1).

Table 1. Dimensions of patch antenna

1.	Solution frequency	2.4 GHz
2.	Length	76 mm
3.	Width	58 mm
4.	Length of the patch	38 mm
5.	Width of the patch	29 mm
6.	Probe feed length	3.14 mm
7.	Probe feed width	1.09 mm

4.2 Software Tool

The software used to model and simulate the microstrip patch antenna is HFSS. HFSS is a high-performance full-wave EM field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S-Parameters, Resonant Frequency, and Fields[4].

A) Structure of Patch Antenna Design in HFSS

The rectangular patch array antenna design is shown in Figure 6 in 3D model. It consists of patch elements on one side of a dielectric sub-state and a planar ground on the other side. It was assigned with a air box boundary and virtual radiation to create far field radiation pattern and assigned with a excitation in lumped port.

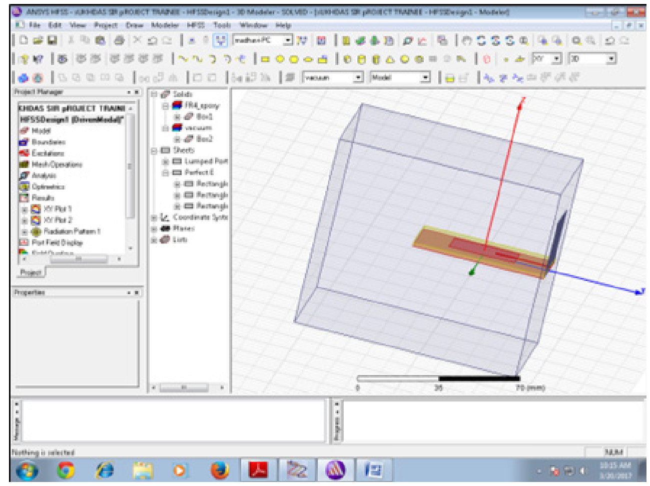

Figure 6. Design of single patch antenna in HFSS.

5. Simulation Results

The rectangular patch array antenna is simulated using Ansoft HFSS. The parameters evaluated were gain, beam width and return loss.

A) Figure 7 of 3D polar plot for patch array antenna

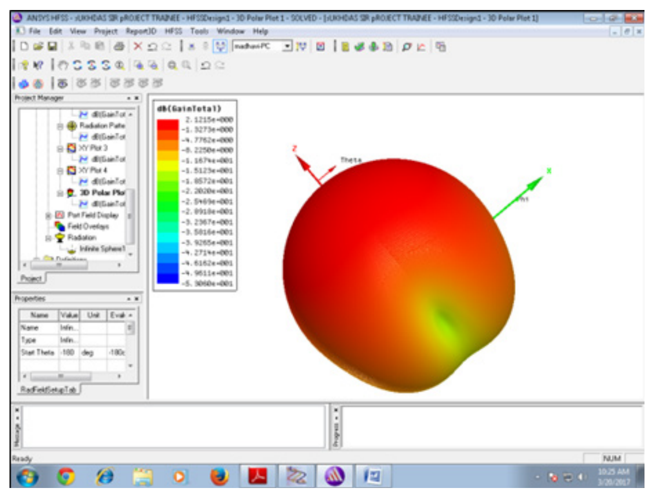

Figure 7. 3D polar plot for patch array antenna.

B) 3D Radiation pattern for patch array antenna

Figure 8 shown the beam width for patch array antenna obtained was 40 degrees in E-plane and 26 degrees in H-plane.

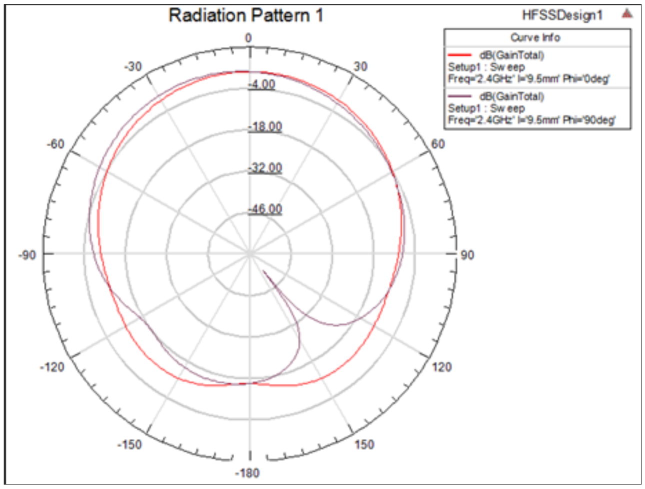

Figure 8. 3D radiation pattern for patch antenna.

The return loss for patch array antenna is shown in Figure 9. The return loss is found to be varying between 2.24 GHz to 2.5 GHz. Its value at 2.24 GHz is -18.75 dB and 12.2 dB at 2.4 GHz.

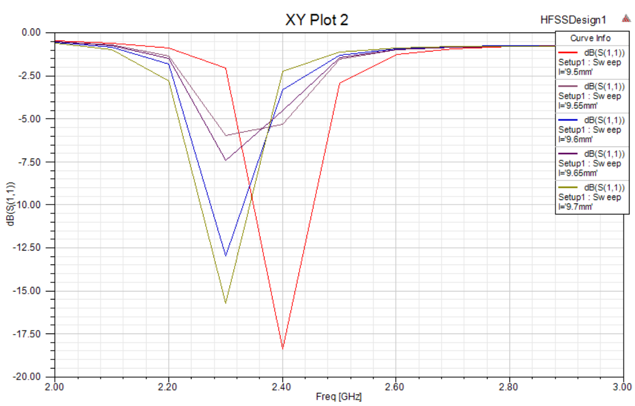

Figure 9. Return loss of patch array antenna.

6. Conclusion

Thus the design and simulation of microstrip patch array antenna was successfully designed and analysed using Ansoft/Ansys HFSS. The performance parameters were achieved with gain 12 dB and beam width 40 degrees in E-plane and 26 degrees in H-plane for patch array antenna. The fabrication of this patch array antenna will be our targeted work

7. Acknowledgement

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