Design & Simulation of Rectangular Shaped Patch Antenna Used for ISM band using HFSS

Minhaz G. Vayada, Mohammed G. Vayada, Arti Patel

Abstract— **Microstrip patch antenna is widely used because of its advantages but main drawback is its narrow bandwidth, to overcome this drawback software like HFSS, CAD-FEKO can be used for optimum patch design that includes design patch and ground plane dimensions, an antenna used in ISM band which works on 2.4 GHz can also be designed using these tools. Performance of antenna also depends on substrate material and patch sizes, analysis of performance of antenna can be carried out for different substrate material and better bandwidth can be achieved. In this work HFSS tool is used for designing and simulating patch antenna for getting better bandwidth, VSRR and S_{11} by selecting appropriate dimensions of Superstrate.**

Index Terms— **Bandwidth, FEM, HFSS, Patch, S11**

I. INTRODUCTION

Microstrip patch antenna is used due to its many advantages like small in size, easily installable and light in weight but main disadvantage of microstrip antenna is its bandwidth. To overcome the bandwidth problems, different bandwidth enhancement techniques have been adopted. In this work the modeling of microstrip patch antenna for ISM band is designed which is widely use for cordless phone, Bluetooth devices, NFC devices and wireless computer networks, this design is simulated in HFSS 11.

II. MICROSTRIP PATCH ANTENNA

Microstrip antennas are one of the most widely used type of antenna. A microstrip antenna consists of a radiating metallic patch or an array of patches situated on one side of a thin, non-conducting, substrate panel with a metallic ground plane situated on the other side of the panel. The metallic patch is normally made of thin copper foil or copper-foil-plated with a corrosion resistive metal, such as gold, tin, or nickel. Each patch can be designed with a variety of shapes, with the most popular shapes being rectangular or circular. The dielectric substrate is used primarily to provide proper spacing and mechanical support between the patch and its ground plane. It is also often used with high dielectric-constant material to load the patch and reduce its size. The substrate material should be low in insertion loss with a loss tangent of less than 0.005, in particular for large array application. Generally, substrate materials can be separated into three categories in accordance with their dielectric constant.

1) Having a relative dielectric constant ε_r in the range of 1.0 to 2.0. This type of material can be air, polystyrene foam, or dielectric honeycomb.
2) Having ε_r in the range of 2.0 to 4.0 with material consisting mostly of fiberglass reinforced Teflon.
3) With ε_r between 4 and 10. The material can consist of ceramic, quartz, or alumina. [8]

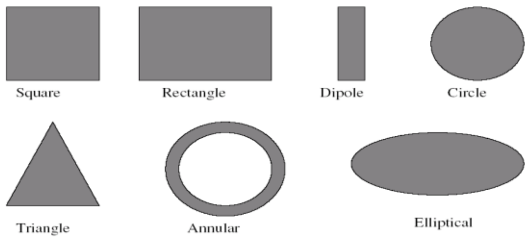

Fig. 1 Geometry of Commonly Known Microstrip Patch

A. *Basic Principal of Operation*

The primary source of this radiation is the electric fringing fields between the edges of the conductor element and the ground-plane behind it. By analyzing this we discovered that the Q (quality factor) of the dielectric cavity formed by two short circuit walls and four open circuit walls depended on several parameters. The parameters are dielectric constant (εr), height (h) of the Substrate, patch dimensions and the frequency. Results showed that at high frequency, radiation loss is the main source of energy dissipation as shown in Fig. 2.

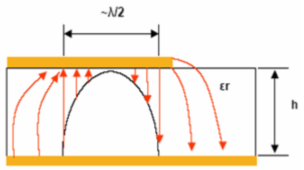

Fig.2 Operation of Microstrip Patch Antenna

The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as an open-circuit boundary condition. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect "magnetic conductor" on the sides. This point of view is very useful in analyzing the patch antenna, as well as in understanding its behavior. Inside the patch cavity the electric field is essentially z directed and independent of the z-coordinate. Hence, the patch cavity modes are described by a double index (m, n). For the (m, n) cavity mode of the rectangular patch, the electric field has the form [8][9]

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B. Material Consideration

The purpose of the substrate material of a microstrip antenna is primarily to provide mechanical support for the radiating patch elements and to maintain the required precision spacing between the patch and its ground plane. With higher dielectric constant of the substrate material, the patch size can also be reduced due to loading effect. Certainly, with reduced antenna volume, higher dielectric constant also reduces bandwidth. There is a variety of types of substrate materials. The relative dielectric constant of these materials can be anywhere from 1 to 10.Materials with dielectric constants higher than 10 should be used with care. They can significantly reduce the radiation efficiency by having small antenna volumes. The most popular type of material is Teflon-based with a relative dielectric constant between 2 and 3. This Teflon-based material, also named PTFE (poly tetra fluoro ethylene), has a structure form very similar to the fiberglass material used for digital circuit boards, but it has a much lower loss tangent or insertion loss.

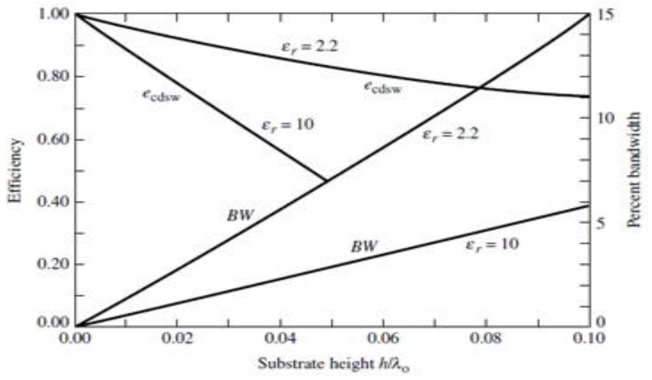

Fig.3 Analysis of Efficiency, Bandwidth and Substrate Height

The selection of the appropriate material for a microstrip antenna should be based on the desired patch size, bandwidth, insertion loss, thermal stability, cost, etc. For commercial application, cost is one of the most important criteria in determining the substrate type. For example, a single patch or an array of a few elements may be fabricated on a low-cost fiberglass material at the L-band frequency, while a 20-element array at 30 GHz may have to use higher-cost, but lower loss, Teflon-based material. For a large number of array elements at lower microwave frequencies (below 15 GHz), a dielectric honeycomb or foam panel may be used as substrate to minimize insertion loss, antenna mass, and material cost with increased bandwidth performance.[8]

C. Feeding Techniques

There are many configurations that can be used to feed microstrip antennas. The four most popular techniques are the microstrip line, coaxial probe, aperture coupling, and proximity coupling.

D. Method of Analysis

The preferred model for the analysis of Microstrip Patch antenna is the transmission line model, cavity model, full wave length model (Which include primarily integral equations/ Moment Methods). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

III. DESIGN PROCEDURE

The design procedure used throughout thesis is applicable for antennas that work in the frequency range of ISM band. The frequency band is used in Cordless phones, Bluetooth devices, NFC devices, and wireless computer networks etc. The design techniques are also applicable to any frequency ranges, which can be selected according to the designer’s wish.

STEP 1: Width Calculation (W): the width of a micro strip patch is given by equation

$$W = \frac{c}{2 f_a \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

STEP 2: Calculation Of Effective Dielectric Constant (εreff): The effective dielectric constant is given by equation

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

STEP 3: Calculation of the Effective Length (Leff) - The effective length

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}} \tag{3}$$

STEP 4: Calculation of the Length Extension (ΔL):

$$\Delta L = \frac{0.412h(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{4}$$

STEP 5: Calculation Of Actual Length Of Patch (L): The actual length is obtained by rewriting equation as:

$$L = L_{eff} - 2\Delta L \tag{5}$$

Substituting L_{eff}= 3.0068cm and (ΔL = 0.073852cm we get L= 2.8591 cm The width to length ratio of the patch is 1, Sometimes known as aspect ratio of the patch Typically the width of patch is taken to be W≤ 2L for wideband design.

STEP 6: Determination of Feed Point Location

A coaxial probe type feed is to be used in this design. The feed point must be located at that point on the patch, where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point. For

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different locations of the feed point, the return loss (RL) is compared and that feed point is selected where the RL is most negative [6]

IV. SIMULATING IN HFSS

In order to calculate the full three-dimensional electromagnetic field inside a structure and the corresponding S-parameters, HFSS employs the finite element method (FEM). FEM is a very powerful tool for solving complex engineering problems, the mathematical formulation of which is not only challenging but also tedious. The basic approach of this method is to divide a complex structure into smaller sections of finite dimensions known as elements. These elements are connected to each other via joints called nodes. Each unique element is then solved independently of the others thereby drastically reducing the solution complexity. The final solution is then computed by reconnecting all the elements and combining their solutions. These processes are named assembly and solution respectively in the FEM. FEM finds applications not only in electromagnetic but also in other branches of engineering such as plane stress problems in mechanical engineering, vehicle aerodynamics and heat transfer. FEM is the basis of simulation in HFSS

A. Steps for antenna analysis using HFSS

1. Create a parametric solid model for geometry.
2. Specify material property.
3. Specify boundary condition and excitations
4. Specify analysis and frequency sweep setup information
5. Perform the analysis
6. Examine the results.
7. Examine the fields.

B. MPA with Substrate

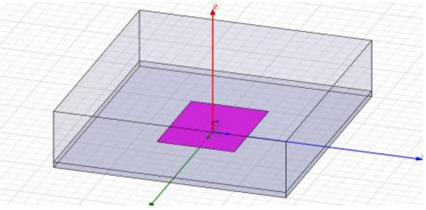


Fig. 3 Top View of MPA

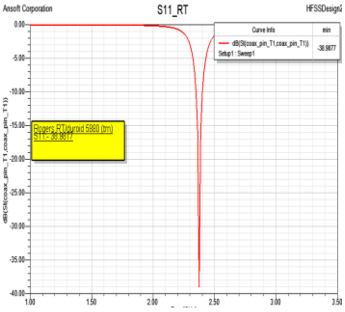


Fig. 4 S11 Plot for rectangular Plane

Using different material to form a new design in Microstrip Patch Antenna

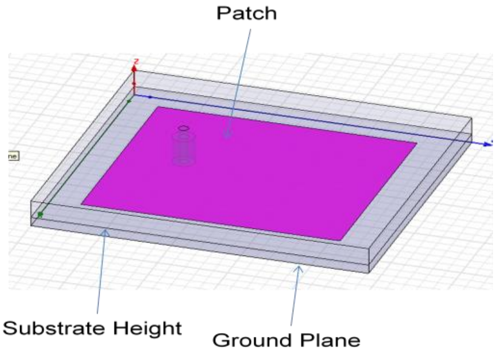


Fig. 5 MPA with FR-4 M

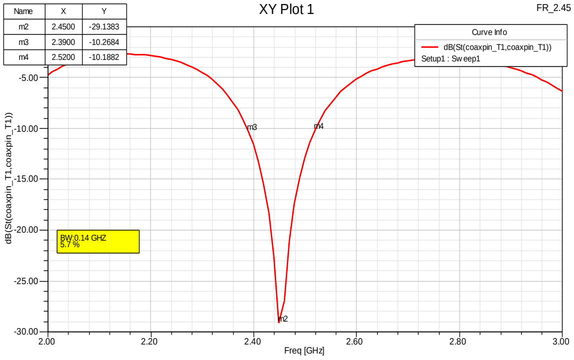


Fig. 6 S11 for FR-4 Material

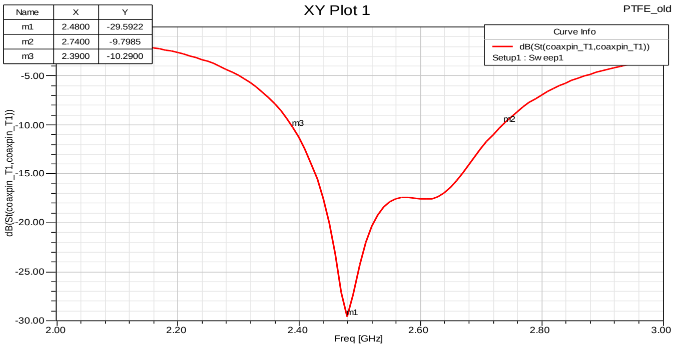


Fig. 7 Result of S11 with PTFE Material

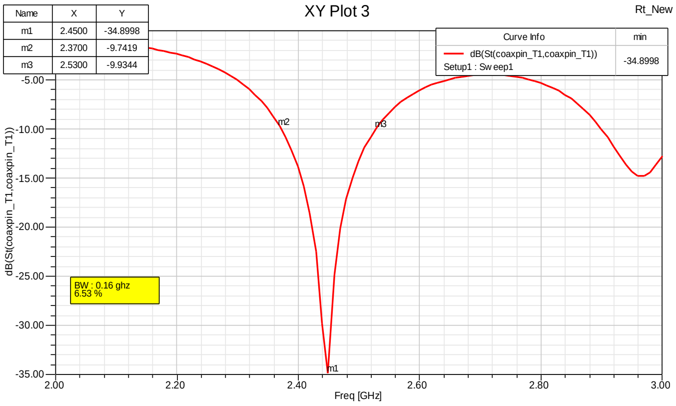


Fig. 8 Result of S11 with RT/Duroid Material

MPA with Superstrate

We are getting better S11 by applying Superstrate. In this Concept we are adding one layer at some height of Patch. Height of layer we are set by trial and error method.

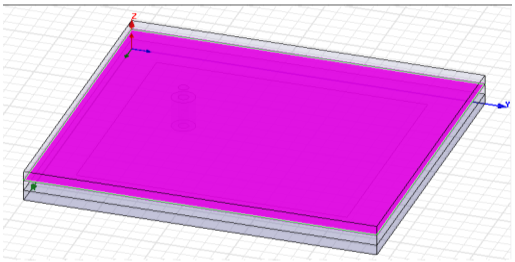


Fig. 9 Top view of Microstrip antenna with Superstrate.

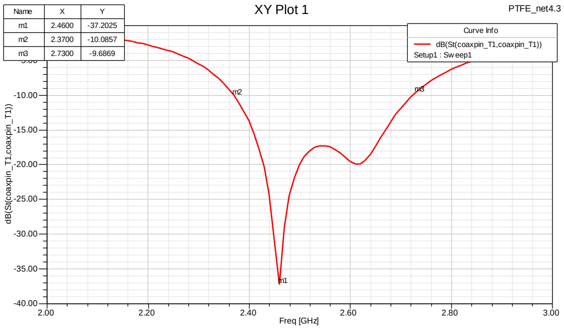


Fig. 10 S11 for Superstrate

Here we have shown results of PTFE material with Superstrate. Height of Superstrate layer for this design we have kept is 4.3 mm.from result we can see improving S11 = -37.20 at 2.46 GHZ with VSWR =1.03.Also we get Reflected Power = 0.02 and Reflection Coefficient=0.01 from VSWR – Return loss Equation.

Fig. 11 Result of VSWR with Superstrate layer

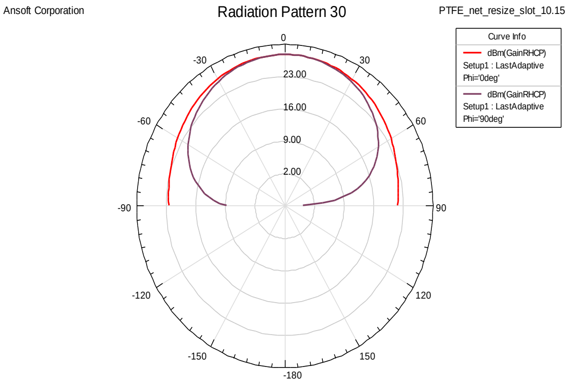


Fig. 12 Realized RHCP Gain (dbm)

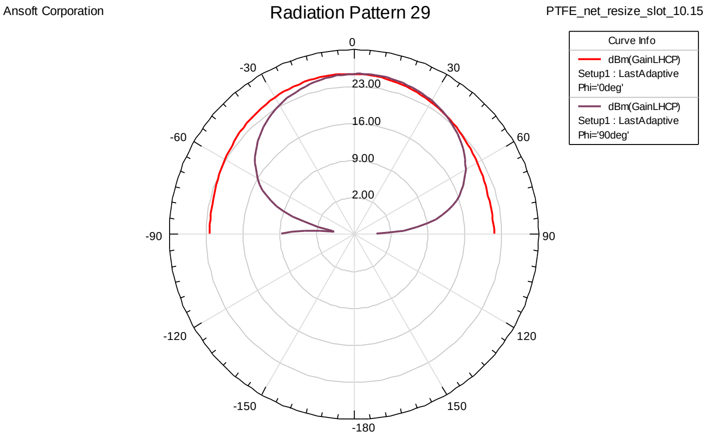


Fig. 13 Realized LHCP Gain (dbm)

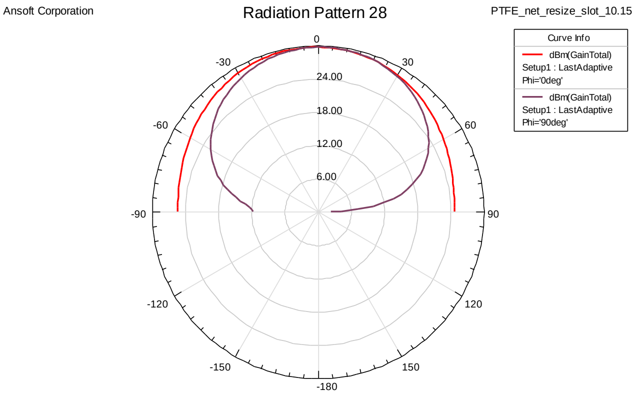


Fig. 14 Realized gain (db)

V. RESULT ANALYSIS

Following table include design parameters for microstrip patch antenna for different substrate which also shows the comparison of return loss and bandwidth.

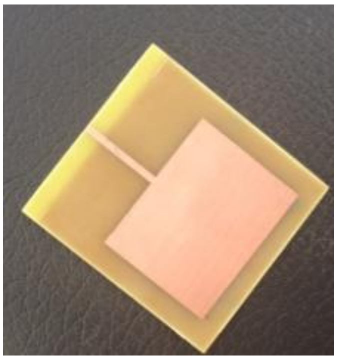
Table 1 S11 and Bandwidth Comparison for different materials

€	**H**	**W**	**L**	**Yf**	**Xf**	**Wg**	**Lg**	**S11**	**BW (%)**
4.4	1.6	37.26	28.83	18.63	7.14	46.86	38.43	15.59	2.85
3	1.6	43.29	34.81	21.65	10.34	52.89	44.41	12.84	2.04
10	1.6	26.11	19.14	13.05	3.21	35.71	28.74	11.02	1.7
6	1.6	32.73	24.72	16.36	5.28	42.33	34.32	15.65	2.46
5.7	1.6	33.45	25.36	16.73	5.55	43.05	34.96	15.36	2.46
3.2	1.6	42.25	33.72	21.12	9.72	51.85	43.32	14.03	2.03
4.4	1.7	37.1	27.45	8.6	8.6	47.46	39	29.13	5.03
2.2	1.7	39.15	31.4	13.26	13.26	49.72	43.02	34.89	5.7
2.5	1.7	37	33	10.15	10.15	48.2	44.2	29.59	14.11

Table 2 Result Analysis for Microstrip antenna

RESULT ANALYSIS With & Without Superstrate Layer					
Material	**Dielectric Constant**	**Superstrate Layer Height**	**Parameter**	**Without Superstrate layer**	**With Superstrate Layer**
Fr4	4.4	2.95	**S11**	-29.13	-30.1
			VSWR	1.07	1.06
			Reflected power	0.12	0.1
			Reflection Coefficient	0.03	0.03
PTFE	2.5	4.3	**S11**	29.59	-37.2
			VSWR	1.07	1.04
			Reflected power	0.12	0.02
			Reflection Coefficient	0.02	0.01
RT/ Duroid	2.2	3.5	**S11**	-34.89	-38.13
			VSWR	1.04	1.03
			Reflected power	0.03	0.02
			Reflection Coefficient	0.02	0.01

VI. FINAL HARDWARE DESIGN



The patch antenna is designed using FR 4 Material.

Fig. 15 Hardware design

VII. CONCLUSION

For different type of material we are getting different qualities of antenna and have to trade of another quantity as per Table we can see that the S11 of RT/Duroid is -34.89 and for FR4 its -29.13. This antenna can also be moulded as reconfiguration antenna as a future scope and different material can be apply to get optimum bandwidth and S11.

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