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Design High Directive Rectangular Microstrip Patch Antenna With Superstrate

Darshan1 , Ravi Antil2 , Devraj Gautam3

***Abstract*—**
This paper presents the effects of superstrate & designed to enhance the performance parameters of rectangular microstrip patch antennas. The modified split ring resonator (MSRR) is used in design. At frequency 2.2 GHz, the microstrip patch antenna is designed with the help of superstrate. Metamaterial superstrate is a significant method to obtain high directivity of one or a few antennas. In this paper, the characteristics of directivity enhancement using metamaterial structures as antenna superstrates that is artificial magnetic superstrate. This design helps to enhance gain and efficiency of microstrip patch antenna at resonance frequency. The simulated and observative results through HFSS, 10 db impedance bandwidth of rectangular microstrip patch antenna is at 2.2 GHz, The radiation efficiency, gain and directivity of proposed antenna are presented at 2.2 GHz. The coding has been done by MATLAB and simulation results has been done by HFSS.

***Index Terms*— Artificial Magnetic Superstrate, HFSS, MATLAB, Parabolic.**

I. INTRODUCTION

In Modern wireless communication world, A new designed Microstrip antennas have recently received much attention due to the increasing demand of small antennas for personal communication equipment. **Deschamps is firstly proposed the concept of the Microstrip Patch antenna in 1953**. Microstrip antennas are also known as microstrip patch antennas, or simply patch antennas. The approaching maturity of microstrip antenna technology, coupled with increasing demand and this has many advantage in frequency range of 1 to 6 GHz, applications for such antennas, has led us to design a new modified observative microstrip patch antenna. Microstrip patch antennas are widely used in wireless communication applications because of their low profile, mechanically rugged, light weight, low cost, narrowband, wide-beam antenna, conformability, low cost fabrication and ease of integration with feed networks.

a) Microstrip Patch Antenna

Microstrip antenna consists of very small conducting patch built on a ground plane separated by dielectric substrate. This patch is generally made of conducting material such as copper or other materials, it can take any of possible shapes like rectangle. We are taking artificial magnetic substrate to design microstrip patch antenna. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. The conducting patch, theoretically, can be designed of any shape like square, triangular, circular, rectangular, however rectangular and circular configurations are the most commonly used. In this paper, Rectangular Micro strip Patch antenna is used. Usage of some of the other configurations are very complex to analyze and require large numerical computations. However Microstrip antenna has a drawback of low bandwidth and low gain. We are using artificial magnetic substrate to improve antenna parameters. The bandwidth can be increased by cutting slots and stacking configuration and Gain can be increased by using different patch elements in an array to achieve maximum radiation characteristics. In its most fundamental form, a Micro strip patch antennae consist of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. It is illustrated in figure1(A).

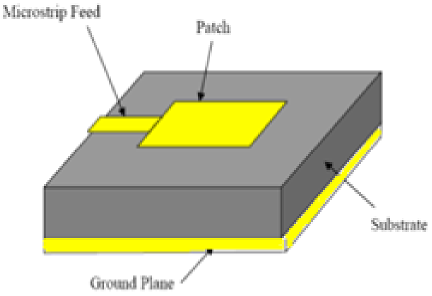

Figure 1 (A) Structure of Microstrip Patch Antenna

b) Merits And De-Merits Of The Microstrip Antenna

- Low bandwidth.
- Lower gain
- Low fabrication cost
- Low weight, low volume and thin profile configurations .
- Large ohmic loss in the feed structure of arrays.
- Poor end fire radiator except tapered slot antennas.
- Extra radiations from feeds and junctions.
- Low power handling capacity

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***1)Darshan**, Department Name- Electronics and Communication Engineering, College Name- Mahaveer Swami Institute of Technology affiliated by Deenbandhu chotu Ram University of Science and Technology, Murthal Haryana City Name-Delhi, Country Name-India, Mobile No-+91-9034613452*
***2) Ravi Antil**, Department Name- Electronics and Communication Engineering, College Name- Mahaveer Swami Institute of Technology affiliated by Deenbandhu chotu Ram University of Science and Technology, Murthal Haryana City Name-Delhi, Country Name-India, Mobile No-+91-8950102089*
***3)Devraj Gautam**,Department Name- Electronics and Communication Engineering, College Name- Ambedkar Institute of Advanced Communication Technologies & Research,affiliated by Guru Gobind Singh Indraprastha University Name-Delhi, Country Name-India, Mobile No-+91-99530353244).*

- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces
- Linear and circular polarizations.

II. METAMATERIALS

In modern communication world, a observative research has the use of metamaterials as superstrates for antennas to achieve gain enhancement. Microstrip patch antenna has improved and enhanced directivity by use of metamaterials as Artificial Magnetic superstrate.

2.1 Artificial Magnetic Superstrate

Artificial magnetic materials are a branch of metamaterials which are designed to provide desirable magnetic properties which do not exist in natural materials. These artificial structures are designed to provide either negative or enhanced positive relative permeability. Dielectric material used as an artificial magnetic superstrate layer above a microstrip patch antenna has remarkable effects on its gain and resonant characteristics. We measured the gain of antennas with and without a superstrate and found that the gain of a patch antenna with a superstrate was enhanced. The magnetic metamaterials demonstrate larger than unity permeability (μ) values due to the fact that they are magnetically polarized under the influence of EM field. Another related metamaterial is the magneto-dielectric which can be polarized both electrically and magnetically when exposed to an applied EM field so that it has both relative permeability (μ) and permittivity (ε) greater than unity. Magneto-dielectric materials have been utilized recently as substrates for miniaturization of microstrip antenna and as superstrate for gain enhancement of planar antenna [5].

2.2 Advantages and Disadvantages of Superstrate

The potential application of magneto dielectric materials as a superstrate is to improve the gain of microstrip antennas. Magneto-dielectrics are materials that can be polarized both electrically and magnetically when exposed to an applied electromagnetic field, so they have both relative permeability and permittivity higher than one. To enhance the gain of planar antennas include the use of nonmagnetic dielectric or electromagnetic band gap structure all these trends require fairly thick layers, leading to a significant increase of antenna profile [22].

I. DESIGN CONSIDERATION

Microstrip patch antenna consists of very thin metallic strip (i.e. patch) placed on ground plane where the thickness of the metallic strip is restricted by t<< λ0 and the height is restricted by 0.0003λ0 ≤ h ≤ .05λ0. The Microstrip patch is designed so that its radiation pattern maximum is normal to the patch.

3.1 Design Procedure for Patch Antenna

The Performance of the Micro strip patch antenna depends on its resonant frequency, dimension. Depending on the dimension, the operating frequency, radiation efficiency, directivity, return loss are influenced. For an efficient radiation, the practical width of the patch can be calculated by using the following.

3.2 Design Equations

Equations for dimension of rectangular patch antenna:

- **Width of the patch :**

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (3.1)$$

- **Length of the patch :**

$$L\frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}\sqrt{\varepsilon r_{eff}}} - 2\Delta L \qquad (3.2)$$

- **Effective dielectric constant :**

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{\frac{-1}{2}} \qquad (3.3)$$

- **Normalized extension of length ΔL :**

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \qquad (3.4)$$

- **Effective length of the patch :**

$$L_{eff} = L + 2\Delta L \qquad (3.5)$$

- **Resonant frequency of the patch:**

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_{reff}}}\frac{}{\sqrt{\mu_{\square}\varepsilon_{\square}}} \qquad (3.6)$$

- **Edge impedance of patch antenna:**

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \qquad (3.7)$$

- **Conductance of the single slot:**

$$G_1 = \frac{1}{90}\left(\frac{W}{\lambda\square}\right)^2 \quad where\ W \ll \lambda$$

$$G2 = \square\frac{1}{120}\left(\frac{W}{\lambda\square}\right) \quad where\ W \gg \lambda\square \qquad (3.8)$$

- **Mutual conductance of patch antenna**

$$G12 = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k\square\, W\cos\theta}{2}\right)}{\cos\theta}\right]^2 J\square(k\square\, L\sin\theta)(\sin\theta)^3 d\theta$$
(3.9)

4 DESIGN AND SIMULATION RESULTS

4.1 Design Specification

The three essential parameters for the design of a rectangular Microstrip Patch Antenna are as:

• **Frequency of operation (f_0)** The resonant frequency of the antenna must be selected appropriately. The design resonant frequency selected for UMTS band applications is 2.2 GHz.

• **Dielectric constant of the substrate (ε_r)**

The dielectric material selected for design is FR4_EPOXY which has a dielectric constant of 4.4.

• **Height of dielectric substrate (h)**

Because of using FR4_EPOXY, so height of dielectric substrate is 1.6 mm. So, the essential parameters for the design are given in table 4.1.

Table 4.1 Design specification of Patch Antenna

Substrate material used	FR4_EPOXY
Operating frequency (f_0)	2.2 GHz
Relative permittivity of substrate (ε_r)	4.4
Height of substrate (h)	1.6 mm

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. 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. Dimensions of substrate are given in table 4.2.

4.2 Design of Simple Microstrip Patch Antenna

The analysis of the simple patch antenna has been designed with the following specification:

- **Input Impedance**

The typical impedance at the edge of a rectangular patch can be approximated as by equation (3.7) and this equation solved using MATLAB software, we get = 310 Ω which does not match well with a 50 Ω standard microstrip. The characteristic impedance of the transition section should be 124 Ω.

- **Simulation Setup**

The software used to design and simulate the Microstrip Patch Antenna is HFSS 13.0.

With the help of MATLAB program, we obtained the dimensions as shown in table 4.2. Here, MATLAB program is based upon equations discussed above and [22-23].

Table 4.2 Dimensions of Microstrip patch Antenna

Substrate material used	FR_4 EPOXY
Dielectric constant of substrate	4.4
Resonating Frequency	2.2 GHz
Length of patch antenna	32.2 mm
Width of patch antenna	41.5 mm
Length of Substrate	125 mm
Width of substrate	125 mm
Height of Substrate	1.6 mm
Width of feed line	2.92 mm

4.3 Simple Patch Antenna and Simulation Results

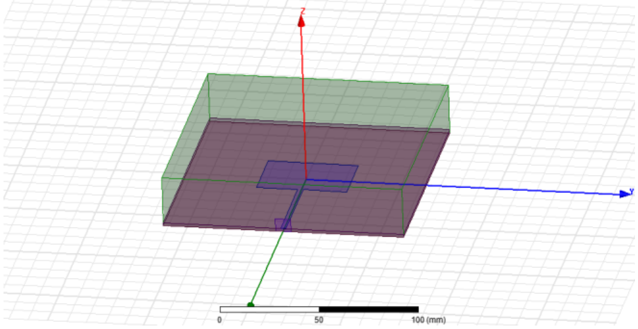


Figure 4.3(a): Simple patch antenna

Figure 4.3(a) shows the HFSS design of simple patch antenna with microstrip feeding as per dimension given in table 4.2. Operating frequency of Simple patch antenna is 2.2GHz.

4.3.1 Returns Loss of Simple Patch Antenna

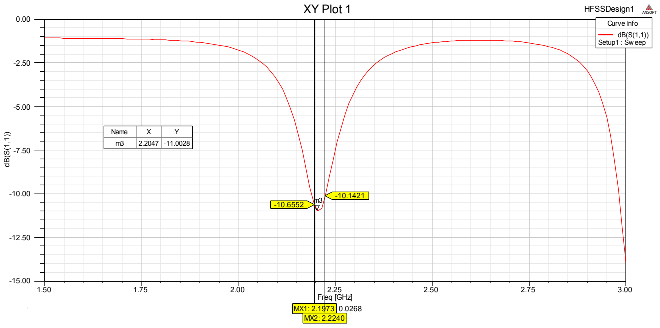


Figure 4.3(b): Returns loss of simple patch antenna

Figure 4.3(b) shows the return loss at resonating frequency 2.2 GHz is -11 dB and impedance band width is 1.22%.

4.3.2 Gain Pattern of Simple Patch Antenna

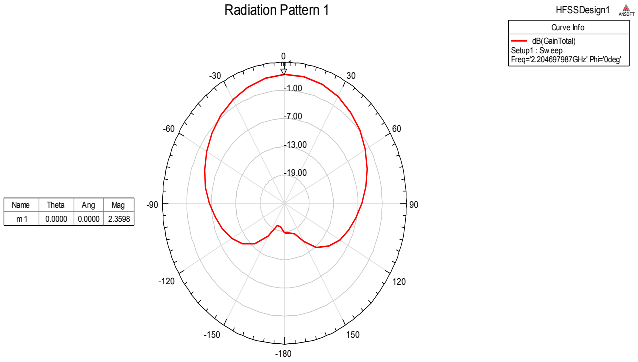


Figure 4.3(c): Gain Pattern of Simple Patch Antenna

Figure 4.3(c) shows the gain of simple patch antenna at resonating frequency 2.2 GHz is 2.36 dB.

4.3.3 Directivity of Simple Patch Antenna

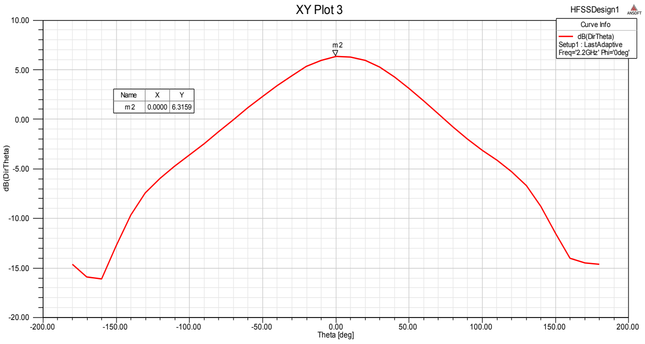


Figure 4.3(d): Directivity of Simple Patch Antenna

Figure 4.3(d) shows the directivity of simple patch antenna at resonating frequency 2.2 GHz is 6.31dB.

4.3.4 Efficiency of Simple Patch Antenna

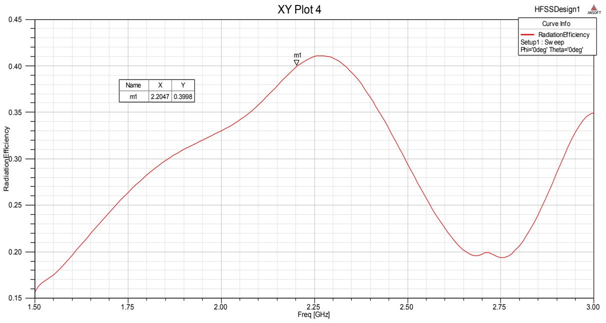


Figure 4.3(e): Efficiency of simple patch antenna

Figure 4.3(e) shows the efficiency of simple patch antenna at resonating frequency 2.2 GHz is 40 %.

4.8 Microstrip Patch Antenna with Parabolic Taper Feed Line Loaded with Artificial Magnetic Superstrate.

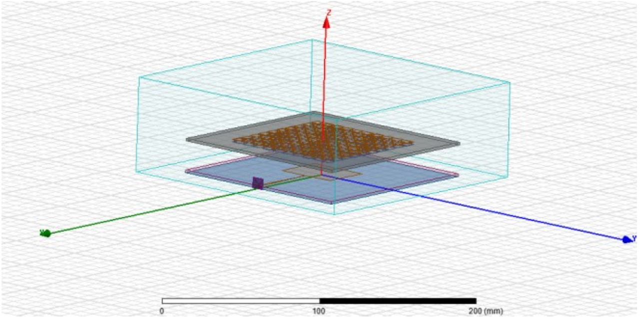


Figure 4.8(a): Parabolic tapered patch antenna with superstrate

Figure 4.8(a) shows the parabolic tapered patch antenna with superstrate layer. Width profile for parabolic taper is shown and equation are discussed in chapter 2. First parabolic tapered patch antenna is designed as per table 4.4. Superstrate has been designed with the help of modified split ring resonator (MSRR). Unit cell dimensions of MSRR are given in table 4.5. On the basis of data given in table 4.5 we have designed planar 10×10 array of MSRRs printed on the host dielectric layer to provide the engineered magnetic material whose effective relative permeability and permittivity is shown in table 4.5.

Table 4.3: Dimensions of unit cell MSRR

Substrate material used	FR_4 EPOXY
Dielectric constant (ε_r)	4.4
Thickness of substrate (h)	1.6 mm
Length of unit cell substrate (Δx)	8.5 mm
Width of unit cell substrate (Δy)	8.5 mm
Height of unit cell substrate (Δz)	1.6 mm
Length of MSRR (lx)	6.5 mm
Width of MSRR (ly)	6.5 mm
Width of metallic strip (s)	0.5 mm
Space between metallic strip	0.5 mm
loss tangent (tan δ)	0.02
Effective relative Permeability	7.8774
Effective relative Permittivity	6.8795.
Height of Superstrate from patch	20 mm

4.8.1 Return Loss of Microstrip Patch Antenna with Parabolic Taper Feed Line Loaded with Superstrate

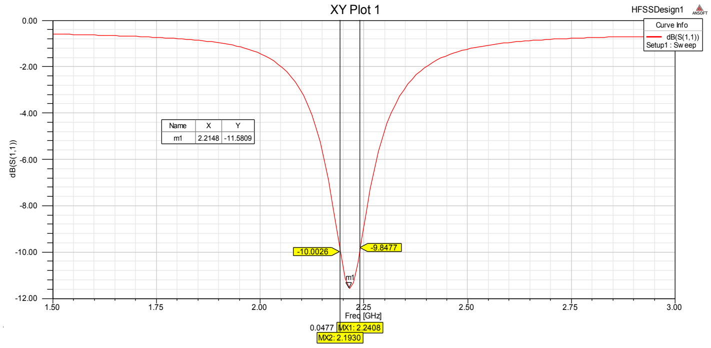


Figure 4.8(b): Return loss of Parabolic tapered patch antenna with superstrate

Figure 4.8(b) shows the return loss -11.58 dB at resonating frequency 2.2 GHz and impedance band width is 2.168%.

4.8.2 Gain Pattern of parabolic Taper Patch Antenna with Superstrate

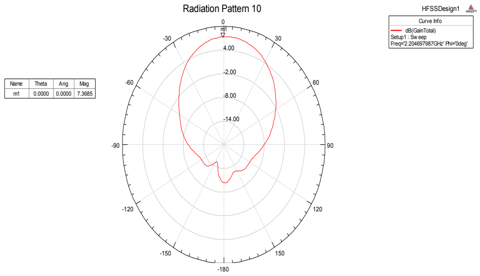


Figure 4.8(c): Gain pattern of parabolic Taper patch antenna with superstrate

Figure 4.8(c) shows the gain is 7.3685 dB at resonant frequency 2.2 GHz.

4.8.3 Directivity of Microstrip Patch Antenna with parabolic Taper Feed Line with superstrate

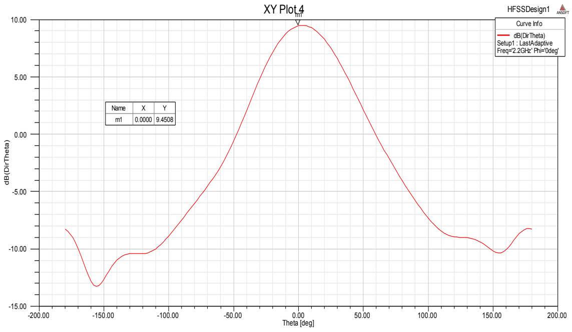
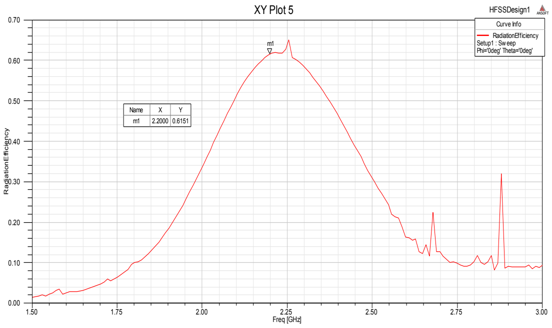


Figure 4.8(d) Directivity of parabolic taper patch antenna with superstrate

Figure 4.8(d) shows the directivity of parabolic tapered feed line at operating frequency 2.2 GHz is 9.45 dB.

4.8.4 Radiation Efficiency of Microstrip Patch Antenna with Parabolic Taper Feed line



Loaded with superstrate

Figure 4.8(e) Efficiency of parabolic taper patch antenna with superstrate

Figure 4.8(e) shows the radiation efficiency of parabolic tapered feed line with superstrate at resonating frequency 2.2 GHz is 61.51 %.

4.9 Comparison of Simulation Results

Table 4.4: Comparison table of Patch Antenna with different tapering

Types of Taper	Return loss(dB)	Impedance B.W. (%)	Gain (dB)	Directivity (dB)	Efficiency (%)
No Taper	-11	1.22	2.36	6.3	40
Parabolic taper	- 49.12	2.61	3.02	6.91	40.2
Parabolic taper using Superstrate	- 11.58	2.17	7.37	9.45	61.5

Table 4.6 shows the comparison of simulation results observed that:

- Return loss of parabolic taper is improved comparatively rather than all others.
- Gain, directivity and efficiency of parabolic taper are better with superstrate.

4.10 Return loss Comparison of different patch antenna with different profiles.

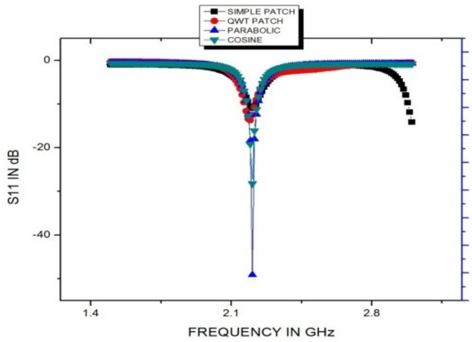


Figure 4.10: Return loss of patch antenna with different profile

Figure 4.10 shows the comparison of the return loss of patch antenna with different profile and all the return loss values are taken from table 4.6.Different colours are used to define the position of return loss of different profile.

5EXPERIMENTAL RESULTS

5.1 Prototype of Proposed Parabolic Tapered Patch Antenna

A prototype is an early sample, model of a product fabricate to test a concept or procedure as a thing to be replicated or learned from. A prototype is designed to test and trial a new design to enhance accuracy by system analysts and users. Prototyping serves to provide specifications for a real, working system rather than a theoretical one.

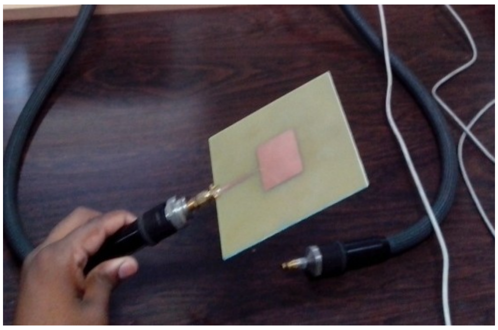


Figure 5.1: Real time picture of fabricated parabolic tapered microstrip patch antenna

Figure 5.1 shows the fabricated parabolic tapered patch antenna. Design specification of this structure is given in the table 4.4 & Experimental result for return loss is verified through VNA

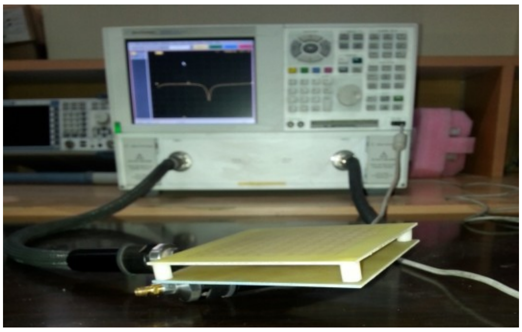


Figure 5.2: Experimental feedback of fabricated parabolic tapered microstrip patch antenna with superstrate

Figure 5.2 shows the experimental feedback of fabricated parabolic patch antenna with superstrate through VNA. The parameter of this figure is discussed in table 4.1, table 4.2

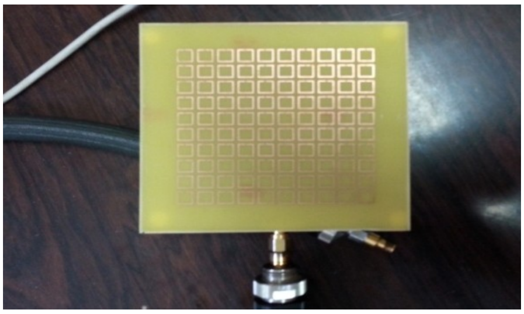


Figure 5.3: Top view of fabricated parabolic tapered microstrip patch antenna with superstrate

Figure 5.3 shows the top view of superstrate designed by modified split ring resonator. Design specification of MSRR is discussed in table 4.1.

5.2 Comparison of Parabolic tapered Patch Antenna with and without Superstrate.

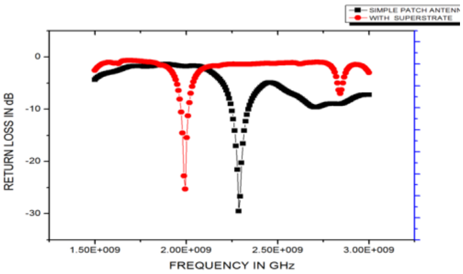


Figure 5.4: Comparison results of parabolic tapered patch antenna with and without superstrate in return loss form.

Table 5.1: Experimental Result

Parabolic Tapered Patch Antenna	Return loss	Resonating frequency
Without superstrate	-29 dB	2.3 GHz
With superstrate	-25 dB	2 GHz

Table 5.1 shows the return loss of parabolic tapered patch antenna before and after using artificial magnetic superstrate. This experimental result is verified through VNA. The return loss without superstrate is -29 dB at 2.3 GHz and with superstrate is -25 dB at 2 GHz as given in table 5.1.

6 CONCLUSION AND FUTURE PROSPECTS

6.1 Conclusion

Various structures of rectangular microstrip patch antenna have been designed and simulated on Ansoft's HFSS. First the simple patch antenna has been designed, and then QWT patch antenna has been designed. After these analyses, simple patch antenna with taper techniques like exponential, cosine and parabolic has been designed. Parameters such as return loss, gain pattern, directivity and radiation efficiency of all these structure have been compared. The return loss of parabolic tapered shows better results as compare to other tapering techniques. Further, to improve the performance of patch antenna, artificial magnetic superstrate structure is used. After superstrate gain is improved by 4.35 dB, directivity is improved by 2.55 dB, and efficiency is improved by 21.3%. The total height of the proposed structure antenna with superstrate is $\lambda_0/7$ mm.

6.2 Future Prospects

Several areas of future work can be expanded to improve offshoots discussed in this dissertation. Some of the future works based on the ideas given in this dissertation are as follows:

- Shapes and size of MSRR in the superstrate can be improved.
- Design of microstrip antenna with more number of superstrate layers.

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***1)Darshan**, Department Name- Electronics and Communication Engineering, College Name- Mahaveer Swami Institute of Technology affiliated by Deenbandhu chotu Ram University of Science and Technology, Murthal Haryana City Name-Delhi, Country Name-India, Mobile No-+91-9034613452*

***2) Ravi Antil**, Department Name- Electronics and Communication Engineering, College Name- Mahaveer Swami Institute of Technology affiliated by Deenbandhu chotu Ram University of Science and Technology, Murthal Haryana City Name-Delhi, Country Name-India, Mobile No-+91-8950102089*

***3)Devraj Gautam**,Department Name- Electronics and Communication Engineering, College Name- Ambedkar Institute of Advanced Communication Technologies & Research,affiliated by Guru Gobind Singh Indraprastha University City Name-Delhi, Country Name-India, Mobile No-+91-99530353244*